BLACK PEPPER

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BLACK PEPPER

Piper nigrum

Edited by

P.N.Ravindran

Indian Institute of Spices Research
Kozhikode, Kerala, India

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dedicated
to
my wife
Shylaja
and daughters
Neelima
&
Namitha
for their understanding, help, affection and love
that has made my life rich and happy

CONTENTS

FOREWORD

Black pepper, christened the 'King of Spices' and 'black gold', is the most important and most widely used spice in the world, occupying a position that is supreme and unique. In the past, black pepper ranked with gold and was used as barter money. It was so precious that only kings and others in the highest class were allowed to possess it. It was the lure of Indian pepper that brought the western world to the Indian sub-continent.

Black pepper originated in the tropical evergreen forests of the Western Ghats; and the Malabar coast of India was the centre of the pepper trade from time immemorial. From here, pepper was carried to Indonesia and Malaysia by traders and travelers, and these countries became major producers during the first half of the present century. India has approximately 48 per cent of its area under pepper, but its share in production is only about 27.3 per cent. The productivity is highest in Thailand followed by Malaysia, China, Indonesia, Vietnam and Brazil. In the next 50 years, the producing countries should gear up to double their pepper production to meet the global demand without any substantial increase in the area, as the availability of land for agricultural purposes will decrease in the coming decades. Pepper productivity has to go up substantially and this increase in productivity can be achieved only through a strong R and D back up.

I am very happy that Harwood Academic Publishers has taken the lead in publishing the first ever monograph on black pepper. However, it is more heartening that this monograph has been edited by Dr P.N.Ravindran of the Indian Institute of Spices Research whose expertise in the field is well known.

I congratulate the publishers and Dr Ravindran for this timely initiative.

R.S.Paroda
Secretary (DARE) & (ICAR)
Ministry of Agriculture
Government of India

PREFACE TO THE SERIES

There is increasing interest in industry, academia and the health sciences in medicinal and aromatic plants. In passing from plant production to the eventual product used by the public, many sciences are involved. This series brings together information which is currently scattered through an ever increasing number of journals. Each volume gives an in-depth look at one plant genus, about which an area specialist has assembled information ranging from the production of the plant to market trends and quality control.

Many industries are involved, such as forestry, agriculture, chemical, food, flavour, beverage, pharmaceutical, cosmetic and fragrance. The plant raw materials are roots, rhizomes, bulbs, leaves, stems, barks, wood, flowers, fruits and seeds. These yield gums, resins, essential (volatile) oils, fixed oils, waxes, juices, extracts and spices for medicinal and aromatic purposes. All these commodities are traded world-wide. A dealer's market report for an item may say "drought in the country of origin has forced up prices".

Natural products do not mean safe products and account of this has to be taken by the above industries, which are subject to regulation. For example, a number of plants which are approved for use in medicine must not be used in cosmetic products.

The assessment of safe to use starts with the harvested plant material which has to comply with an official monograph. This may require absence of, or prescribed limits of, radioactive material, heavy metals, aflatoxin, pesticide residue, as well as the required level of active principle. This analytical control is costly and tends to exclude small batches of plant material. Large scale contracted mechanised cultivation with designated seed or plantlets is now preferable.

Today, plant selection is not only for the yield of active principle, but for the plant's ability to overcome disease, climatic stress and the hazards caused by mankind. Such methods as *in vitro* fertilisation, meristem cultures, and somatic embryogenesis are used. The transfer of sections of DNA is giving rise to controversy in the case of some end-uses of the plant material.

Some suppliers of plant raw material are now able to certify that they are supplying organically-farmed medicinal plants, herbs and spices. The Economic Union directive (CVO/EU No 2092/91) details the specifications for the **obligatory** quality controls to be carried out at all stages of production and processing of organic products.

Fascinating plant folklore and ethnopharmacology leads to medicinal potential. Examples are the muscle relaxants based on the arrow poison, curare, from species of *Chondrodendron,* and the antimalarials derived from species of *Cinchona* and *Artemisia*. The methods of detection of pharmacological activity have become increasingly reliable and specific, frequently involving enzymes in bioassays and avoiding the use of laboratory animals. By using bioassay linked fractionation of crude plant juices or extracts, compounds can be specifically targeted which, for example, inhibit blood platelet aggregation, or have antitumour, or antiviral, or any other required activity. With the assistance of robotic devices, all the members of a genus may be readily screened. However, the plant material must be fully authenticated by a specialist.

The medicinal traditions of ancient civilisations such as those of China and India have a large armamentarium of plants in their pharmacopoeias which are used throughout South East Asia. A similar situation exists in Africa and South America. Thus, a very high percentage of the World's population relies on medicinal and aromatic plants for their medicine. Western medicine is also responding. Already in Germany all medical practitioners have to pass an examination in phytotherapy before being allowed to practise. It is noticeable that throughout Europe and the USA, medical, pharmacy and health related schools are increasingly offering training in phytotherapy.

Multinational pharmaceutical companies have become less enamoured of the single compound magic bullet cure. The high costs of such ventures and the endless competition from me too compounds from rival companies often discourages the attempt. Independent phytomedicine companies have been very strong in Germany. However, by the end of 1995, eleven (almost all) had been acquired by the multinational pharmaceutical firms, acknowledging the lay public's growing demand for phytomedicines in the Western World.

The business of dietary supplements in the Western World has expanded from the Health Store to the pharmacy. Alternative medicine includes plant based products. Appropriate measures to ensure the quality, safety and efficacy of these either already exist or are being answered by greater legislative control by such bodies as the Food and Drug Administration of the USA and the recently created European Agency for the Evaluation of Medicinal Products, based in London.

In the USA, the Dietary Supplement and Health Education Act of 1994 recognised the class of phytotherapeutic agents derived from medicinal and aromatic plants. Furthermore, under public pressure, the US Congress set up an Office of Alternative Medicine and this office in 1994 assisted the filing of several Investigational New Drug (IND) applications, required for clinical trials of some Chinese herbal preparations. The significance of these applications was that each Chinese preparation involved several plants and yet was handled as a single IND. A demonstration of the contribution to efficacy, of each ingredient of each plant, was not required. This was a major step forward towards more sensible regulations in regard to phytomedicines.

My thanks are due to the staff of Harwood Academic Publishers who have made this series possible and especially to the volume editors and their chapter contributors for the authoritative information.

Roland Hardman

PREFACE

“In a brightly illuminated and well organized grocetaria of a local departmental store we noticed a woman shopper gazing at rows of neatly arranged, colourful, sifter type containers. The little tins were filled with cinnamon, cloves, ginger, nutmeg, mace, pepper, paprika, sage, marjoram and all the other delightfully aromatic and pungent spices which help milady to please her family and friends with the choicest of delectable dishes”. Thus starts the prologue in John W.Parry’s book on spices. Spices played a significant and colourful role in the history of humankind from pre-biblical times to the modern and may continue that enchanting role *ad infinitum*. Among the spices it was black pepper that captured global attention, and over the years it has come to be known as the ‘King of Spices’ and ‘black gold’. It is black pepper that takes the place of pride in Western cuisine, where its role is unparalleled. It is pepper that imparted spiceness, taste and flavour to the otherwise bland food of the Westerners and can, indeed be termed as the ‘Spice of Life’.

It is difficult for us now, to appreciate the extent of influence that pepper and other spices had on nations and people during the chequered history of human civilization. Wars were fought, kingdoms were built and demolished, cities grew, flourished and declined—the destiny of humankind was influenced so much—all for the sake of spices. Indeed, it is said that one of the most noteworthy creations of modern history—the British Raj—was launched over five miserable shillings that represented the increase in price of a pound of pepper by the Dutch traders which prompted the British to start the British East India Company, which subsequently grew up into the formidable British Raj.

Black pepper has its origins in the Western Ghats of Kerala (the ancient Malabar Coast), and the pepper trade was initially restricted to this region, which was trading pepper with the Arab traders. In the course of time pepper plants were taken to far eastern countries and plantations were established in Malaysia and the Indonesian islands (East Indies). They eventually eclipsed the Malabar Coast in pepper production and export.

In earlier times, pepper in India was valued not so much for its qualities as spice, but for its medicinal properties. Black pepper and its related long pepper are highly valued as ingredients in a variety of indigenous medicinal preparations in the Indian systems of medicine—*Ayurveda, Sidha* and *Unani*.

Kerala, my own state and one of the smallest states in the Indian Union, has a long and uninterrupted history in pepper production and export from pre-biblical times to the present. Kerala is the place of origin and diversity of pepper and the ecologically much degraded forests of Western Ghats still have large populations of wild pepper. There is hardly any household in Kerala without a few pepper plants trailed on jack, mango and in fact on any tree available in the homestead. Some of my childhood memories are associated with the planting of pepper vines with the onset of the monsoon in June, and with its harvesting in December. The exodus of people from the plains to hilly tracts in search of land and work and the subsequent saga of the taming of the wild Western Ghats are part of the socio-cultural history of Kerala. In that process many perished, many became rich owners of plantations. Many who took up pepper cultivation in the virgin forest land suddenly became rich and in due course pepper became the economic mainstay of a large section of the people of Kerala. As the wheel of time turned, problems began to surface; diseases such as foot rot (called quickwilt and black death of pepper) raced through many plantations and many people suddenly found themselves bankrupt. Research and development support for pepper cultivation only began in the seventies. The scientists at the Indian Institute of Spices Research, the Spices Board and a few State Agricultural Universities have been involved for the last two decades in the conservation and study of black pepper and the problems facing its production and management. We are now better informed and better equipped than in the past to effectively tackle the many problems that confront the pepper farmers.

The various chapters in this monograph give the present state of knowledge on black pepper. Each chapter has been written by experts who made their mark in the respective area and are the best choices available. I have put in my best efforts to collect and collate as much information as I possibly could, from many sources. But I still feel inadequate in my attempts.

I earnestly hope that this volume will serve as a reference book to all pepper workers in the world over and to the students of agriculture, horticulture, crop botany and allied subjects. It is my ardent wish that this compilation should trigger an insatiable quest, in the heart of the reader, to delve deeper into the pepper story. Pepper will continue to dominate human lives, from many angles, for decades or perhaps centuries to come. I hope that pepper with its colourful past and promising future will attract more talent into research to tackle the problems which continue to beset this marvellous spice.

P.N.Ravindran

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In the preparation of this volume, especially the chapter on Botany and Crop Improvement, I have used published information from many sources and from many authors. I acknowledge with gratitude all these workers, many do not survive now, but their contributions, I am sure, will survive through this volume in the years to come. I am also thankful to the Malaysian Pepper Marketing Board for supplying some of the photographs included in the text.

I would like to express my sincere thanks to Dr R.S.Paroda, Director General, Indian Council of Agricultural Research (ICAR), New Delhi, for writing a forward and to ICAR for according permission to edit this monograph. I am thankful to Dr K.V.Peter, Director, IISR for his encouragement. I have sincere appreciation to Harwood Academic Publishers for giving me the opportunity to edit this first monograph on black pepper. Finally let me thank all the well wishers who helped me in the preparation of this volume.

1. INTRODUCTION

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Black Pepper, known as the King of Spices, is the most important and most widely used spice in the world. The black pepper of commerce is the dried, mature fruits (commonly called berries) of the tropical, perennial climbing plant *Piper nigrum* L., which belongs to the family Piperaceae. Black pepper (hereafter the name pepper is used to mean black pepper) is a woody climber, grown in the South Western region of India, comprising of the states of Kerala, parts of Karnataka, Tamil Nadu and Goa, the entire region once known as Malabar, a name now used restrictively to mean only the northern part of Kerala. The humid tropical evergreen forests bordering the Malabar Coast (the Western Ghats, one of the hot spot areas of plant bio-diversity on earth) is the centre of origin and diversity for both the King of Spices (Pepper) and Queen of Spices (Cardamom—*Elettaria cardamomum* Maton). The Malabar coast was involved in the cultivation and trade of pepper from very early times. From here pepper was taken to Indonesia, Malaysia and subsequently to other pepper growing countries. Currently pepper is grown in twenty six countries* (Table 1).

Black pepper is rightly called the King of Spices, and its position is supreme among spices. This spice with its characteristic pungency and flavour is an ingredient in many food preparations, and at the dining table it is the only spice invariably served. It was used for different purposes by different people in the past, and continue to be so currently and will remain so in future as well. For the civilized western people it is a spice, an essential additive to their food; for the ancient Egyptians it was an ingredient in the embalming mixture; for the ancient Aryans it was a valuable drug, and now for the common Indians pepper is a spice as well as a medicine, a sure cure for cold and fever and a component of many traditional *Ayurvedic* drugs. Stories richly coloured with imagination were carried by ancient sailors to distant places and its fame reached both Western and Eastern lands.

The white pepper of commerce is also a product from the same pepper plant, produced by removing the pericarp (fruit wall) from ripe pepper fruits, which give the buff coloured seeds—the white pepper. White pepper is preferred in certain countries and also by the elite users because it gives a uniformly dull white powder; while black pepper powder has the black component resulting from the powdered black pericarp. White pepper is traditionally prepared by steeping ripe fruits in water for a few days, rubbing to remove the pericarp; washing and drying. Indonesia is the major producer

* For the identity of various peppers and for terminology for pepper in important countries see Annexure I and II

of white pepper, though small quantities are also produced by other pepper producing countries.

Black pepper was essentially a forest produce in the past, people collected it from forests, where it abounded. The collected pepper was brought to local markets for retail trade with Arab merchants. Domestication of pepper appears to be a much later event. There is, only speculative evidence as to when pepper was introduced to other countries as a domesticated crop. Colonists from India are believed to have introduced pepper cultivation to Indonesia about 100 B.C. (Rosengarten 1973). Many such introductions surely might have taken place subsequently also. The landmarks in the colourful history of pepper are given below.

Landmarks in the History of Pepper (early dates very tentative)

1550 B.C.	Pepper referred to in Eber's papyrus
1500–600 B.C.	Panini recorded the use of pepper in spicing wine. Charaka, the famous physician and Susruta, the ancient surgeon, mentioned the use of pepper in medicine, including in the treatment of eye and ear diseases
4th century B.C.	Theophrastus described the two kinds of pepper—long pepper and black pepper
1st century A.D.	Pliny reported that black pepper came from South India (Malabar) and that the long pepper came from North India. A Chinese envoy visited the Malabar coast in search of pepper.
40 A.D.	Rome captured Egypt and the ancient pepper trade came under the control of Romans.
40 A.D.	Mariner Hippalus discovered the velocity of wind systems (monsoons) of Indian ocean that made ocean journey to the Indian coast easier.
64 A.D.	Pepper described as growing in abundance in south west Asia (?).
40–90 A.D.	The Greek Physician, Dioscorides, mentioned the medicinal uses of pepper and long pepper.
176 A.D.	Customs duty imposed on black pepper imported into Alexandria
408 A.D.	Alaric the Gothic conquered Rome; demanded a ransom of 3000 pounds of pepper. Fall of Rome and Roman influence on spice trade. The Arabs again assumed control over the trade.
540 A.D.	The identity of pepper as the fruit of a vine growing in the Malabar coast of India was established.
200 B.C.–700 A.D.	Jeanine Auboyar, author of Daily Life in Ancient India—from 200 B.C. to 700 A.D., narrates the collection and marketing of pepper and long pepper in the Malabar and export to Alexandria. The trade was under the control of Arabs.

851 A.D.	Chinese traveller Sulaiman visited Kerala coast—recorded the black pepper cultivation and trade with China.
10–11th century	Raja Raja Chola and his son Rajendra, the powerful South Indian Kings, extended their empire to Malay archipelago and to Java-Bali Islands of present day Indonesia. This was probably a route through which pepper plants reached Indonesia and Malaysia.
1154–1189	Reign of Henry II in England and the formation of pepperers guild.
1200	China's hegemony on pepper trade-large quantities were imported from Malabar coast and Java.
1280	Marcopolo described in detail the pepper growing in Java.
1403–1433	The voyages of Zheng He from China to the Malabar coast, touching many ports in between. Strong trade relationships between the Malabar coast and China. This was probably another route through which pepper plants might have reached the near and south east Asian countries.
1430–1440	Nicolo Contai described the pepper trade in Quilon (Kollam) and Calicut (Kozhikode) of Malabar coast and pepper cultivation in Sumatra.
1498	Vasco de Gama discovered the sea route to India and landed near Calicut on the Malabar coast on May 20, 1498.
1500	Pedro Alvares Cabral landed in Calicut accompanied by many ships and men. He established the supremacy of Portugal over spices trade in the Malabar coast.
1502	Vasco de Gama's second voyage to India. He strengthened the Portuguese settlements.
1508	Alfonso de Albuquerque was appointed the viceroy of Malabar coast by the Portuguese king.
1511	Albuquerque sailed to Malacca and captured the land and the spice trade from there. Portuguese was in full control of black pepper trade.
1563	Garcia da Orta described black pepper production in Java.
1550–1600	Decline of Portuguese power in the Malabar coast—supremacy of Dutch for a short period.
1600	Establishment of the British East India Company for trading in spices. British landed in India (Aug 24, 1600 at Surat).
1602	The East India Company's ships reached Sumatra and started trading in pepper. The establishment of the United East India company by Dutch merchants. They reached Johore (Malaysia), Siam, Amboyna (Spice Island) establishing supremacy over Portuguese, but defeated in Moluccas.
1621	Dutch attacked Benda Islands and subjugated the natives.
1636	British started export of pepper from the Malabar coast.

1641	Dutch conquered Malacca and the entire pepper trade from Far East came under their control.
1664	The Portuguese were driven out from their main settlements in Cochin and Cannanore by the Dutch. This was the end of Portuguese chapter in the pepper trade. The Dutch East India company became the master of pepper trade. Jean Baptiste Colbert organized the French India company.
1700–1800	Dutch had to suffer defeat from the hands of the king of Travancore, and their supremacy gradually vanished. The rise of British presence in Malabar. They entered into contract with local rulers for monopoly procurement of pepper and other spices. The French who came to India for spices trade could establish a small pocket-Mahe-on the Malabar coast, otherwise their influence soon waned off. By 1800 the British became the supreme power in pepper trade. The rest is history.
1795–1800	America entered the pepper trade. Their ship, Rajah, travelled to Sumatra for fetching pepper. Subsequently America became a major power in pepper trading.
1933	Pepper introduced into Brazil.
1938	Pepper introduced into Malagasy Republic
1954	Pepper introduced into Tropical African regions
1952–53	First research station for pepper established in India (at Panniyur)
1955	Pepper research began in Sarawak (Malaysia)
1966	First hybrid pepper (Panniyur 1) released.
1971	Beginning of the All India coordinated Research Project on spices with mandate of research on pepper.
1972	Establishment of International Pepper Community with headquarters at Jakarta.
1986	Establishment of National Research Centre for Spices (NRCS) with a major mandate on pepper research.
1996	Upgradation of NRCS into Indian Institute of Spices Research (IISR)

Early History

The history of spices is as old as the recorded history of human civilization itself. The religious texts of antiquity, the *Vedas,* the Bible, the *Quran*—are all replete with references on the use of spices. Spices were in use in ancient Egypt as far back as the age of the pyramids (2600–2100 B.C.). During 3000–2000 B.C., the Assyrians and Babylonians were in close contact with the Malabar Coast of India and were trading in pepper, cardamom and cinnamon. The ancient Babylonia had a flourishing sea trade with Malabar coast and China, touching possibly many ports on the way. This Babylonian-China connection via Malabar Coast could be the earliest possible route through which black pepper plants reached the far east and south east Asian countries. In Eber's Papyrus, dated around 1550 B.C., there were references about pepper and cardamom (In 1874 A.D. George Ebers, a German Egyptologist reported the discovery of a Papyrus roll, now called Eber's Papyrus). Around 1000 B.C. Hatshepsut, the Egyptian Queen, despatched a fleet of five ships to the Malabar Coast of India (?) to collect spices. According to the Bible, the Queen of Sheba made a royal visit to King Solomon (1015–66 B.C.) and she took with her a long convoy of camels laden with spices. The Greek physician, Dioscordis (40–90 A.D.) has described in detail in his *Materia Medica* the medicinal values of spices such as black pepper, cardamom, ginger and turmeric. In Sanskrit pepper had been described as *"Yavanapriya"* (beloved to the Greeks), a clear pointer to the fact that pepper was so dear to the Greeks (Ummer 1989). An ancient Tamil poet has written thus: "the thriving town of Muchiri (Muziri—today's Kodungallur near Cochin), where the beautiful great ships of the Yavanas (Greeks) bringing gold, come splashing the white foam on the waters of the Periyar and return laden with pepper" (Ummer 1989).

The post-epic period of ancient Indian history is often referred to as the rationalistic period. Famous physicians and surgeons of ancient India, like Charaka and Susrutha lived during this period. Charaka wrote his classical treatise *Charaka Samhitha,* wherein he mentioned various spices of Indian origin for use in medicine, such as pepper, *Ocimum,* asafoetida, cinnamon and myrrah and many formulations containing pepper and ginger were given by him as well as by Susrutha. Panini, the great Grammarian also lived in this period, recorded the use of pepper for spicing wine.

King Solomon of Israel and the Phoenician King, Hiram of Tyre, procured their supplies of spices from the Malabar Coast (Rosengarten 1973). By this time the Jews and the Arabs became the major traders in spices. In fact the Arabs held the monopoly of this lucrative trade, a position which continued till the rise of the Roman empire. The Arabs, as middle men, safely guarded the secret of the country of origin of pepper and other spices. The route to India was also kept as a closely guarded secret from the Egyptians and the Greeks. During the 1st century A.D. Rome captured Egypt, and the Romans became a threat to the Arabian traders of spices. Around 40 A.D., during the reign of Emperor Claudius of Rome, the Greek merchant Mariner Hippalus discovered the full power and velocity of wind systems of the Indian Ocean, a secret hitherto known only to the Arabs (Rosengarten 1973). Hippalus soon went into action and demonstrated that a round trip from Egypt—India—Egypt could be completed in less than a year. This event had two side effects: first it drastically reduced the dependence on the overland trade routes, second, several wealthy cities and nations suddenly went bankrupt (Ummer 1989). Hippalus and like him many others came to the Malabar Coast and returned with large booty of Indian spices. The Roman dominance that followed led to the total decline of Arab domination. The Romans were most interested in pepper, ginger and cinnamon. In his *Natural Hisotry* Pliny the Elder (23–79 A.D.) writes:

> It is surprising that the use of pepper has come so much into fashion. Commodities as a rule attract us by their appearance or utility but the only quality of pepper is its pungency and yet it is for this very undesirable element

> that we import it in very huge quantities from the first emporium of India, Muziris.

When in 408 A.D. Alaric the Gothic conquered Rome, he demanded a ransom of 3000 pounds of pepper. This conquest of Rome led to the fall of the Roman empire and the Arabs got yet another chance to become the monopoly traders of spices. This continued almost unhindered till the entry of Portugal and other West European countries in the scene.

The birth of Islam was a great morale booster for the Arabs and their trade in Indian spices grew beyond all proportions. Malabar was simultaneously doing trade with the Arabs and the Chinese, the former based their operations in Kodungallur and Calicut (Kozhikode), while the latter in Quilon. Scholars have identified three developments that were responsible for India's flourishing maritime trade in those days: (i) ship building made rapid strides in the importing countries, huge and sturdy merchant ships with large storage space began to be built; (ii) around 40 A.D. Hippalus came upon the valuable information on the monsoon winds, particularly their force and frequency and this knowledge led to faster and safer voyages, (iii) the mystery of Malabar mud banks was unraveled which made it possible to anchor ships safely (Ummer 1989).

The Chinese entered the arena at this time. History tells us that as early as the first century A.D., a royal messenger of the King of China appeared in Kodungallur asking for spices. The excellent trade relationships between China and the Malabar Coast was recorded by travellers such as Sulaiman who visited the Malabar Coast in 851 A.D. (Ummer 1989). The Chinese played, perhaps, a more significant role in spreading pepper plants to other countries, especially to the South east and far east countries. The trade between the Malabar Coast and China reached its zenith during the middle ages with the voyages of Zheng He between 1405–1433. In those years the average pepper purchased by Chinese has been estimated as fifty thousand catties (1 catty equals 1½ lbs) i.e. almost equivalent to the total quantity imported into Europe during the first half of the 10th century (T'ien 1982). In China, pepper trade was an imperial monopoly even from early Ming times. The huge import of pepper into China led to a fall in its price, and during the fifteenth century the salary of soldiers were paid partly in pepper (and also sapanwood). It was mentioned that by 1425 all government officials and private soldiers in China received part of their salary as pepper (T'ien 1982). T'ien also recorded that by the end of the reign of the Yongle Emperor (1420–1424) the store of pepper in the imperial granaries had swollen to such proportions that it was no longer possible to dispose of it by substitution. When Renzoge became the Emperor in 1424 following the death of his father Chengzu, he distributed large quantities of pepper to all important people of the country depending on their status, the highest getting 5000 catties and the lowest a hundred catties. Records also indicated that Chinese imported pepper from the Malayan archipelago and Indonesia, indicating that pepper cultivation was already in progress in those countries. According to Marco Polo (1298) 10,000 pounds of pepper arrived in Hamgchon (a Chinese port) every day. He also described in graphic details the huge spice gardens in Java and in the

Malabar Coast of India. Among the praises Marco Polo showered on Chinese for their spectacular technological achievements, he also described the huge and handsome ships of Chinese capable of carrying 6000 baskets of pepper.

By the 12–13th century the production and trade of pepper in East Indies grew to considerable level. Java was the principal centre of the trade. Pepper cultivation was extensive in the islands of Sumatra and Java and from these islands Arab and Chinese traders were collecting pepper in large quantities. The East Indies gradually eclipsed the Malabar Coast of India as the most important source of various spices including pepper. This lure of spice attracted many sea farers and led to many global explorations and circumnavigations of earth.

The consumption of pepper was steadily increasing in Europe and England. In 1345 a guild of pepperers was organized in London. The pepperers were among the wealthiest of merchants, and one had to be a pepperer of Soper Lane or a spicer of Cheap in good standing to belong to the fraternity (Parry 1969). But the high prices put pepper and other spices beyond the reach of ordinary people. As for the Western people, the coming of the pungent and aromatic spices of the orient was the greatest boon to their cooking. New methods of preserving food quickly came into existence; "dishes took on a fullness of flavour previously unknown; beverages glowed with a redolent tang, and life experienced a new sense of warmth and satisfaction" (Parry 1969).

Today, it is difficult for us to imagine the profound effect pepper and other oriental spices had on world economy in the ancient and middle ages. The cities of Alexandria, Genoa and Venice owed their economic prosperity to the brisk trade in these expensive commodities (Rosengarten 1973). In fact it is recorded that the great demand for pepper in China was responsible for the spread of its cultivation in many of South East and Far East Asian Countries. This great demand for pepper waned off by the end of the Wanli reign (1572–1620), when pepper became a commodity for common use.

Modern History

The modern chapter in the colourful history of pepper begins with the advent of Portuguese on the scene, with the landing of the Portuguese sailor Vasco de Gama at Kappad beach near Kozhikode (Calicut) on May 20, 1498. This event, indeed, was also the beginning of the colonial era. The arrival of Gama in Kozhikode sealed the fate of Arab trade in Indian spices once and for all. Gama and his men returned to Portugal immensely rich. This financial lure led Dom Mannuel, the Portuguese King, to send a huge naval contingent with a fleet of 13 battle ships to India under the command of Pedro Alwarez Cabral in 1500 A.D. (Rosengarten 1973). He also declared sovereignty over India, along with other countries like Ethiopia and Arabia. This even led the western world to believe that Kozhikode was a city discovered by Portuguese, and this distorted perspective is evident from the following writing by Nicolas Dekanezio, a Genevan traveller in 1500 A.D.:

> Kozhikode is a great city discovered by King Mannuel of Portugal. Pepper, several other goods brought from distant places, spices like cardamom, ginger,

> turmeric and clove, and priceless treasures like pearls are available here in plenty.

The Portuguese concentrated their trading operations in the ports of Quilon, Cochin, Calicut and Cannanore. The Portuguese soldiers unleashed a reign of terror in these areas and the producers were compelled to sell their pepper produce to them at whatever price they gave. History of Kerala, is replete with the atrocities perpetrated by the Portuguese, unchecked for over a century. One benefit of the Portuguese entry was that they popularised cultivation of pepper in Kerala (Ummer 1989). Almost every acre of land capable of growing pepper and ginger was cultivated and the trade which before this time was mainly in the hands of a few big merchants, became a business of the people at large. Being ruthless exploiters, the Portuguese were bent upon extracting as much of the spice produce as they possibly could, and even went to the extent of coercing the local chieftains to go into both pepper and ginger cultivation (Mahindru 1982).

The scene changed during the first quarter of the 17th century, with the arrival of Dutch power. The Dutch also based their headquarters at Kozhikode. In 1625 A.D. they entered into a contract with the King of Kozhikode (Zamorin) and other Chieftains and rulers of central Kerala and Travancore. But they could not continue for long here, and their exit came through the defeat they suffered from the hands of Marthanda Varma, the powerful King of Travancore in 1741 A.D. By that time the French and the English were trying to establish their supremacy over the Malabar Coast and the Dutch had to retreat from the scene. But the Dutch made a great contribution. During their presence, the Dutch captain, Admiral Van Rheed, produced the first printed document on the plants of the Malabar Coast, *Hortus Indicus Malabaricus,* published between 1678 and 1703 A.D. in 13 volumes. This monumental publication was the result of gruelling hard work of Van Rheed and a team of *Ayurvedic* experts.

The Britishers entered the scene with the dawn of the 17th century. About this historical event Collins and Lapierre (1976) writes.

> Sometimes history's most grandiose accomplishments have the most banal of origins. Great Britain was set on the road to the great colonial adventure for five miserable shillings. They represented the increase in price of a pound of pepper proclaimed by the Dutch privateers who then controlled the spice trade.
>
> Incensed at what they considered a wholly unwarranted gesture, twenty four merchants of the city of London gathered on the afternoon of 24th September 1599 A.D. in a decrepit building on Leaden Hall Street. Their purpose was to found a modest trading firm with an initial capital of £72,000 subscribed by 125 share holders. Only the simplest of concerns, i.e. profit, inspired their enterprise, which expanded and transformed, would ultimately become the most noteworthy creation of the age of imperialism—the British Raj.

Thus started the British East India Company on 31st December 1600 A.D. Queen Elizabeth I granted monopoly rights of the trade to this company. Even before this on 24th August 1600 A.D, Hector, a 500 ton ship dropped anchor in the port of Surat, north of Bombay. In 1615 the British landed in Kozhikode and for the first time in 1636 A.D., they exported pepper from Cochin to England. Gradually the English entered into trade pacts with all local rulers. By an agreement with the Rani of Attingal (Queen who reigned the small Kingdom of Attingal) in 1721 the English acquired monopoly rights for the entire pepper trade in the state. In 1723 A.D. the English East India Company entered into a contract with Travancore and with this the Britishers established their hegemony in the trading of pepper and other spices. The British East India Company was mainly responsible for the organized cultivation of spices and developed plantations of tea, coffee and spices in the decades that followed. In due course large plantations were established especially in the hills of the Western Ghats. With better management the production increased substantially and India became a large scale producer of not only spices like black pepper and cardamom, but also other plantation crops such as tea and coffee.

The United States of America entered the spice trade as a major force during the last quarter of the 18th century. The first expedition for pepper was organised in 1795 by Cap. Jonatham Carnes and the ship *Rajah* sailed from Salem to East Indies and returned the next year with a cargo of 158,544 pounds of pepper from South Western Sumatra. It was recorded that the sponsors of this expedition made a profit of 700 per cent (Rosengarten 1973). Stimulated by the success of *Rajah,* other merchants plunged into spices trade and many trade expeditions followed. Pepper trade in USA flourished reaching its peak in 1810. The American pepper trade declined later during the second half of the last century with the onset of the civil war in 1861.

The Dutch East Indies witnessed tremendous progress in pepper production and emerged as the most important producer and exporter of pepper in the world, eclipsing the Malabar Coast of India. For e.g. in 1938 over 55,000 tons of pepper was exported from Indonesia, while the Indian export was a meagre 700 tons. Such rapid progress was the result of application of modern agricultural techniques by the Dutch planters in Java and Sumatra regions. This situation continued till the outbreak of world war II.

It was almost the same time pepper was taken to Brazil and large scale pepper plantations were established there. Gradually Brazil also entered the world market as a major producer and exporter of pepper.

Centres of Pepper Cultivation

Due to the heavy demand, efforts to grow pepper have been made in many tropical countries. Initially, black pepper was taken from the Malabar Coast to the Indonesian Islands, possibly by the first century A.D. itself or even before. From there black pepper might have been taken to various Pacific Island nations, South East Asian countries, and later to tropical Africa and America. Currently pepper is grown in about 26 countries (Table 1). The major pepper growing countries are the following.

India

Kerala state of India is the original home of pepper. This state accounts for nearly 95% of the country's area and production (Anon. 1998). The states of Karnataka and Tamil Nadu contribute the remaining. Pepper is grown under the following situations (Menon 1949).

1. As a village crop in almost every compound in the coastal and midland zones of west coast, as a mixed crop or intercrop trailed on various trees. Monocropping is not practiced at all in this set up. The number of vines vary from a few to a hundred or even more.
2. As a pure crop on slopes and in valleys of low hills in the midland zone.
3. As a mixed or pure crop in the foot hills of the Western Ghats.
4. As a mixed crop with coffee at higher elevations ranging from 700–1200 m.
5. As a mixed crop on shade trees of tea estates located at elevation ranging from 700–1300 m.
6. As a mixed crop in arecanut gardens in valleys and low lying areas.

Small quantities of pepper are also produced in the states of Goa, Andhra Pradesh, Orissa and Assam. Recently Andaman and Nicobar Islands are recognised as a very potential production centre.

Indonesia

Indonesia is the second most ancient pepper growing country. Nothing definitely is known about the arrival of pepper in Indonesia. Some reports indicate pepper occurring in Indonesia (Java) as early as the first century A.D. Marco Polo's travelogues mentioned pepper cultivation in Java during 12th century. The earliest possibility of pepper reaching Indonesian Islands was either through the Polynesian sea farers or through the ancient Babylonian-Chinese sea trade connections linking Malabar coast and many other Far East-South East Asian ports. Anthropological and sociological evidences suggest a Polynesian (Melanesian) connection with the Malabar Coast, during the first and second centuries. Close trade relationship is known to have existed between the Malabar Coast and ancient China from the 4–5th century. There is evidence about the visit of a Chinese envoy during the first century A.D. itself. The Chinese might have carried the pepper plants to the Far East and South East Asian countries, and because of the ideal climatic factors pepper might have thrived well in Indonesia.

Much later during the 10–11th century the powerful South Indian Chola Kings extended their influence to Java-Bali Islands of present day Indonesia. This was probably yet another route through which pepper might have reached the Indonesian islands. The religio-cultural connection between south India and the islands of Java and Bali is well known (Sastri 1978).

Prior to the second world war, Indonesia (then known as Dutch East Indies) was the largest pepper producing country in the world with an annual production of over 50,000 m. tons (metric tons). During the Japanese occupation of Indonesia, most plantations were abandoned and pepper production declined sharply. In the prewar days there were about 40,000 acres of pepper gardens in Sumatra, 20,000 acres in Bangka and about 2500 acres in Java (Lawrence 1981). Now pepper production is restricted to Sumatra, Bangka, east Kalimantan, West Kalimantan and Sulawesi areas. Currently the Indonesian government is trying to recapture the past glory through many developmental measures.

Brazil

Brazil entered the arena of commercial pepper growing in 1933, when a group of Japanese immigrants from Singapore owning the Nippon plantation company started pepper cultivation on a large scale. The initial plantations came up in Tome Acu near Belam in the state of Para (Henshall 1968) where the soil, climate and latitudes were similar to the pepper growing areas of the Far East. Pepper cultivation in Brazil witnessed a period of phenomenal success initially and Brazil rose to the position of a major producer and exporter and for Brazilian pepper there was a ready market in USA. Currently pepper is grown in Paraiba, Espirito Santo and Ceara in the state of Para, where the pepper estates are owned by the members of the Co-operative Agricola Mista (Mixed Agricultural Cooperative). In the areas of Belem and Tome Acu the pepper gardens are owned by individuals (Lawrence 1981).

Malaysia

Black pepper was introduced into Malaysia probably by the European settlers during the early 17th century. But in all probability pepper would have reached Malaysia even earlier during the 14th century through the Chinese trader Zheng He who organised a series of expeditions to the Malabar coast touching many sea coasts in between (T'ien 1981). In Malaysia, pepper cultivation is concentrated in Sarawak. Here pepper cultivation is in the hands of Chinese farmers and they evolved an intensive production technology which led Sarawak to achieve high productivity levels. Some pepper is also grown in the Malaysian main land, especially in the Johore region.

Sri Lanka

In Sri Lanka pepper is grown as a mixed crop in Cocoa plantations as well as in the house compounds. Cultivation is located in the mid and low countries, wet and semi dry zones at elevations less than 600 m. The most important growing regions are the Dumbara valley and the Matale district (Anon 1967). The foreign occupation of Sri Lanka was responsible for the expansion of pepper cultivation to other areas as well, especially to the province of Kandy. The cultivation practices are similar to those in India.

Malagasy Republic

Though pepper reached Malagasy Republic by the turn of the century, cultivation started only after the second world war when the pepper prices reached new heights. Here the cultivation is concentrated in the east and northeast coasts on the Comoro and Nossi-Be Islands and in plains of Sambirano and Mohavavy in Majunga province (Lawrence 1981). The present production is around 3000 tons from around 10,250 acres.

South East Asian Countries

Black pepper might have reached South East Asia many centuries earlier, but commercial production started only during the post war years. Pepper is grown in Thailand, Vietnam, Combodia, parts of South China and South Korea. Pepper productivity is highest in Thailand (around 4500 kg/ha dry). In Thailand pepper growing is concentrated in the districts of Thon Buri in the central plains, Trang in South and Chanthaburi in the South East, the latter being the most important region producing about 75 per cent of the country's production (Lawrence 1981).

Thailand practises an intensive production technology, probably copied from the Chinese growers in Sarawak. Though the per capita area is small, the growers are more united and they help each other with land preparation, raising of planting materials, harvesting etc. Hence, the pepper cultivating areas within a region are in compact blocks set up under an unwritten community mutual gain agreement (Anon 1970, Lawrence 1981). Currently Thailand produces about 10,000 m. tons annually.

Cambodia (Kampuchia) is another South East Asian country that started pepper cultivation in the post war years. The main regions are Kampot, Kompong-cham, and Tokheo (Marinet 1955). The civil war and military insurgency in the country had a devastating influence on Cambodian pepper production. The cultivation is in the hands of Chinese growers and currently the Cambodean black pepper production is around 2000 m. tons annually.

In Vietnam, pepper became popular during the postwar period, though the cultivation started much before that. Under the French occupation there was considerable progress in pepper production, though there was decline in the 60's and 70's due to the war. The current production is around 20,000 m. tons annually. Much area expansion is reported from Vietnam and this country is going to be a major producer in the years to come. Small quantity of pepper is also produced in South China and South Korea. In these regions pepper cultivation is of recent origin, and in South Korea the cultivation has not progressed much. China (P.R) on the other hand produces around 10,000 m. tons of pepper on an average and further increase in area and production are anticipated in the coming years. China has the potential to become a major producer of pepper through area expansion and productivity increase. Brunei Darus is a small country where small quantities of pepper (around 15 m. tons) are produced.

South Pacific Islands

A number of South Pacific nations have examined the possibility of growing pepper. Among them Micronesia, Fiji and Samoa have become successful in pepper cultivation. In Tahiti, Moorea, Raiatea, Huahini and the islands of Marquesas group, pepper cultivation did not progress much. In Micronesia pepper was introduced by the Japanese Tropical Industries Research Institute. Now the cultivation is concentrated in the islands of Palau, Ponape and Truk, the most important area being Ponape. The cultivation practises are similar to those adapted in Indonesia. The annual production is about 14 m. tons.

Fiji is the most important pepper growing South Pacific nation with an average annual production of about 176 m. tons. Some well maintained gardens were reported from Naduruloulou area (Sills 1962, Lawrence 1981). Philippines also produces small quantities of pepper, where it was introduced from Indonesia. The current production is around 170–180 m. tons per year. Some commercial plantations exist in the provinces of Lagun, Quezon, Negros occidental, Zamboanga and Davao; while in the Batangas province the cultivation is in the hands of small holders.

Latin America

In addition to Brazil, pepper is also grown in Mexico, Guatemala, Honduras Saint Lucia, Costa Rica and Puerto Rico. In all these places pepper vines, were taken from Brazil. In Mexico the cultivation has become some what successful, and the current production is around 1200–1300 m. tons. Guatemala produces around 375–380 m. tons while Saint Lucia and Costa Rica produce around 400 and 160 m. tons respectively.

African countries

A number of African countries have experimented pepper cultivation and some such as Madagascar, Malawi, Zimbabwe etc. have become successful in the commercial production of pepper. In addition, black pepper is grown in many other tropical African countries such as Benin, Kenya, Cote de Voire, Cameroon, Ethiopia, Zambia, Nigeria, Congo, Gabon, Dahomey, Sierra Leone etc. Madagascar produces about 2500 m. tons, Malawi 900 m. tons, Zimbabwe 750 m. tons, Kenya and Benin 300 m. tons each, while the other countries produce smaller quantities. In West Indies (including Grenada) pepper cultivation has not made a mark in spite of the favourable climate.

Recent History

The post second world war history of pepper is just a continuation. India, Malaysia, Indonesia and Brazil are the major producers and exporters of pepper, but this again is a history chequered by many ups and downs. Pepper cultivation has also spread to

Vietnam, China, Pacific Islands, Caribbean Islands, etc. It has become a commercial crop in Vietnam, Thailand and China. Currently pepper is grown as a commercial crop in an area of 404,000 ha, producing around 180,000 m. tons of pepper annually. Tables 1.1 and 1.2 give the present status in area, production, productivity and export of pepper in the world. The productivity is highest in Thailand, followed by Malaysia, Vietnam and China (Table 1.3). Though the largest producer is India (Ca. 60,000 metric tonnes in 1996–'97), the productivity is lowest in the world with just 303 kg/ha. India and Indonesia are the major exporters of pepper. Indonesia exported most of the pepper produced (95% of production in 1995, 87 per cent in 1996), while

Table 1.1 Pepper production in producing countries 1991–1996 (in tons).

Country	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*Avg.*
Asia & Pacific	**182,016**	**183,721**	**144,976**	**158,028**	**169,189**	**153,988**	**165,320**
India	55,000	60,000	55,000	50,000	55,000	60,000	55,833
Indonesia	61,000	62,000	23,500	42,500	59,000	39,200	47,867
Malaysia	29,000	26,000	17,600	16,000	13,000	12,000	18,933
Vietnam	8,900	7,830	18,500	20,000	20,000	20,000	15,872
China P.R.	13,108	12,321	10,461	12,409	5,000	8,000	10,217
Thailand	10,443	10,500	9,000	10,104	10,949	9,773	10,128
Sri Lanka	2,850	3,255	9,000	5,000	3,725	3,000	4,472
Cambodia	1,700	1,800	1,900	2,000	2,500	2,000	1,983
Brunei Darus	15	15	15	15	15	15	15
South Pacific	**158**	**159**	**164**	**168**	**168**	**168**	**197**
Fiji	140	145	145	150	150	150	176
Samoa	5	5	6	6	6	6	7
Micronesia	13	9	13	12	12	12	14
Latin America	**51,774**	**30,615**	**26,427**	**25,303**	**21,940**	**21,690**	**29,625**
Brazil	50,000	27,500	25,000	23,000	20,000	19,500	27,500
Mexico	894	2,395	734	1,363	1,000	1,250	1,273
Guatemala	360	370	380	380	380	380	375
Honduras	420	160	213	400	400	400	332
Saint Lucia	100	190	100	160	160	160	145
Africa	**5,427**	**4,543**	**4,665**	**4,565**	**4,565**	**4,565**	**5,833**
Madagascar	2,160	2,000	2,300	2,500	2,500	2,500	2,327
Malawi	1,000	900	700	700	700	700	900
Zimbabwe	700	800	900	700	700	700	750
Benin	894	150	150	150	150	150	299
Kenya	200	300	400	300	300	300	300
Cote di Voire	100	100	100	100	100	100	100
Cameroon	63	63	65	65	65	65	64
Ethiopia	100	200					50
Zambia	30	30	50	50	50	50	43
Total	**239,038**	**219,038**	**176,232**	**188,064**	**195,862**	**180,411**	**199,975**

Source: Proc. Pepper Tech. Meet, 1997.

Table 1.2 Export ('000t) and (%) production exported from major producing countries.

Country		*1992*		*1993*		*1994*		*1995*		*1996*
	E	*% production exported*	*E*	*% production exported*	*E*	*% production exported*	*E*	*% production exported*	*E*	*% production exported*
Brazil	25.70	93.45	24.12	96.48	21.10	1.74	21.25	106.25	15.30	78.46
India	19.40	32.23	47.23	85.87	34.11	68.22	24.54	44.62	35.07	58.45
Indonesia	61.44	99.09	25.80	109.79	35.13	82.66	56.13	95.14	34.00	86.73
Malaysia	21.93	84.35	15.73	89.38	22.27	139.19	13.98	107.54	14.80	123.33
Thailand	6.17	58.78	4.51	50.11	1.20	11.73	0.91	8.31	0.50	5.12
Sri Lanka	2.13	65.54	7.78	86.44	3.41	68.20	2.40	64.34	2.10	48.72
IPC Countries	**136.77**	**72.77**	**125.10**	**89.97**	**117.23**	**79.90**	**119.20**	**73.78**	**101.78**	**70.29**
Vietnam	22.36	285.57	14.80	80.00	15.00	75.00	15.00	75.00 15.00	75.00	
China (PR)	0.18	1.46	2.44	23.33	7.76	62.53	5.00	60.39	5.00	42.25
Madagascar	1.95	97.50	2.00	86.96	1.71	68.40	1.27	50.80	2.00	80.00
Mexico	3.44	143.33	2.30	315.07	2.60	191.18	2.50	200.00	2.50	200.00
Non IPC Countries	**27.93**	**113.77**	**21.54**	**65.29**	**27.08**	**81.37**	**23.77**	**74.21**	**24.50**	**69.01**
Total	164.70	77.03	146.71	85.75	144.30	74.50	142.97	73.81	136.28	70.04

Source: International Pepper Community, 1997, Pepper Statistical Year Book 1995–96, IPC, Kuningan, Jakarta.

Table 1.3 Average area, production and productivity of pepper (1992–1996).

Country	Area (ha)	Production (tons)	Productivity (Kg/ha)
Brazil	26,500	23,400	883
India	191,426	56,200	294
Indonesia	110,580	45,240	409
Malaysia	8,960	16,920	1,888
Thailand	2,808	10,091	3,594
Sri Lanka	12,080	5,058	419
Vietnam	15,700	17,266	1,100
China	13,170	11,045	839
Madagascar	4 ,228	2,160	511
Mexico	1,294	1,112	859
Total	386,746	188,492	487

the Indian export was 58 per cent of the production in 1996 and 44.6 per cent in 1995 (Table 1.2). Last year (1996–97) witnessed a sharp increase in Indian export and export earnings, reaching an all time high of Rs. 416.52 crores from an export of 47,770 m. tons (Anon. 1997).

This era of pepper history also witnessed the beginning of various research and development efforts in all the major producing countries. Research and development efforts on pepper were initiated in a very modest way in India in 1949, when the then Government of Madras started a pepper Research Scheme at Panniyur (in the present Cannanore district of Kerala state). In the early 1950's the Government of India, following the advice of Planning Commission, constituted a Spices Enquiry Committee (SEC) to suggest specific measures to develop production of spices in the country. Following the recommendations of the SEC submitted in 1953, research on spices was entrusted with the Indian Council of Agricultural Research (ICAR). A Central Spices and Cashewnut Committee was formed to assist the ICAR in planning and coordinating the implementation of recommendations of the SEC. Later in 1961 Indian Central Spices and Cashewnut Committee was formed. But an impetus to spices research was received only with the establishment of the Central Plantation Crops Research Institute (CPCRI) in 1969 in Kasaragod with mandates on palms, cocoa, cashew and spices. A major step in the direction of improvement of spice crops was the starting of All India Coordinated Spices and Cashewnut Improvement Project in 1971 with headquarters at CPCRI, Kasaragod. In 1975 ICAR established a regional station of CPCRI at Calicut (Kozhikode) in Kerala to conduct research on spices. This regional station was later upgraded as the National Research Centre for Spices (NRCS) in 1986 and later as the Indian Institute of Spices Research (IISR) in 1995. In India, IISR is vested with the prime responsibility of carrying out research on all aspects related to spice crops. In addition, it is also the headquarters of the All India Coordinated Research Project on Spices, coordinating spices research of 28 centres spread over the country mainly to carry out multilocational and adaptive testing of varieties and for conservation of germplasm of spices of the region. Out of these three centres are for pepper. The Central Food Technological Research Institute at Mysore, Karnataka state and the Regional Research Laboratory, Thiruvananthapuram in Kerala state, have evolved efficient processing techniques for pepper and for value addition through production of oleoresin, piperine and pepper oil. All of these research activities led to a number of remarkable achievements in pepper, some of which are:

1. Established the largest pepper germplasm conservatory in the world at the IISR, Kozhikode
2. Developed 10 high yielding elite cultivars, four by IISR, five by the Pepper Research Station, Panniyur, under Kerala Agricultural University (a unit of the AICRP on spices) and one by CPCRI
3. High production technology for black pepper
4. Integrated pest and disease management
5. Quality indexing of cultivars and selection of high quality lines
6. Biotechnological approaches, such as tissue culture, protoplast isolation and culture, etc.
7. Drought tolerant studies and selection of certain tolerant lines
8. Basic studies on *Piper* and related taxa, such as cytogenetics, taxonomic relationships, anatomical features, etc.
9. Developing techniques for efficient post harvest handling and processing, value addition and product diversification.

The second major centre where Research and Development work on pepper is going on is the Agricultural Research Station at Kuching, Sarawak, Malaysia. Here research on pepper was initiated in 1955, with the introduction of a few pepper varieties from India in 1957. The daunting problem which confronts Malaysia is the very narrow genetic base which seriously impinges on an ambitious crop improvement programme. Yet, there are reports that two new cultivars have been developed, one of which is tolerant to the devastating foot rot *(Phytophthora)* disease. Appropriate production technology has also been worked out by the Sarawak centre.

The third centre of pepper research is the Research Institute for Spice and Medicinal Crops (RISMC), Bogor, Indonesia. Here the major thrust is on the management of diseases and insect pests. An integrated disease management programme has been evolved at this center and also two new varieties. RISMC has also done pioneering work in developing on farm processing machinery for threshing and drying. Some sporadic research has been reported from Brazil where commercial level planting was started in early 1950s. Kuching was the only cultivar introduced at that time (introduced from Singapore, hence is called as “Singapura” in Brazil). Later, further introductions took place from Indonesia and India. Large pepper farms were established, but later the *Fusarium* wilt swept through large pepper areas with a very devastating effect. Studies conducted in Brazil identified *Piper colubrinum* as a source of resistance to *Fusarium* wilt and *Phytophthora* foot root. Efforts were also made there to standardize a grafting technique using *P. colubrinum* as the root stock, but without much success.

Sporadic research reports have also been made from Puerto Rico especially on the pollination biology and seed set, and also from Sri Lanka. The currently prevalent bamboo method of rapid multiplication of pepper was initially developed in Sri Lanka. Other pepper producing countries-Vietnam, Micronesia, Madagascar, etc. do not have much R & D efforts.

A major step in global marketing was the establishment of the International Pepper Community (IPC) in 1972 under the auspices of the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP). The IPC consists of seven pepper producing countries namely Brazil, India, Indonesia, Malayasia, Thailand, Sri Lanka and the Federal States of Micronesia and its headquarters is in Jakarta, Indonesia. IPC has the basic objective to promote, coordinate and harmonize all activities relating to pepper industry in the world.

Present Scenario

The International Trade Centre (ITC) Geneva, has put the current trade in spices at 400,000–450,000 m. tons valued at US $1.5–2.0 billion annually. The spice trade has registered an annual growth rate of 3.6 per cent in quantity and 8.4 per cent in value. Pepper contributes 34 per cent of the total trade in spices. Currently pepper is grown in 26 countries (Table 1.1), the Asia region being the most important producer contributing on average 82.68 per cent of world production, followed by Latin America (14.81%), Africa (2.42%) and Pacific region (0.10%) (IPC 1997).

Black pepper production witnessed a perceptible decline during the last few years (Table 1.1). Only India and Vietnam have registered a steady growth in production. This decline is mainly due to: (1) the unsteady prices, (2) shortage of farm labour due to migration of labour from the production centres to cities and from agricultural sector to economic and industrial sectors (3) high cost of production. This led to substantial reduction in export from producing countries, from the level of 164,696 m. tons in 1992 to 126,241 m. tons during 1996. Simultaneously, the domestic consumption of the producing countries has shown a significant increase from around 38,149 m. tons in 1994 to 53,148 m. tons per annum in 1995–96 (Darwis 1997). The El Nino effect has led to unprecedented drought in Pacific Ocean countries during the current year. Indonesia is one of the worst affected countries due to this phenomenon, and pepper production in that country may dip further in 1997–98 and may result in severe shortage in the international pepper market, resulting in further price rise in 1998–99.

Consumption of pepper has registered a steady increase during the past many years. The yearwise consumption pattern is influenced by many factors-size of population, per capita income, economic status of people, food and social habits. The annual per capita pepper consumption is highest in Denmark with 194 gm (Table 1.4). Europe and America are the two major pepper consuming sectors in the world, and the prices in the international market are controlled by the demands from these two sectors. The declining world production of pepper against the background of escalating consumption is cause for concern. As a result the pepper prices are soaring up, in the current year (1998) the prices in Indian market has broken all the past

Table 1.4 Pepper consumption in developed countries (in grams).

Countries	*1975*	*1980*	*1990–1995 (Average)*
1. Denmark	102	128	194
2. Germany	131	170	190
3. Belguim	90	127	181
4. USA	117	144	168
5. Netherlands	94	91	151
6. Austria	97	141	150
7. France	107	124	138
8. Sweden	90	96	122
9. Canada	100	87	112
10. Switzerland	121	139	112

records, and is still on the rise. Whether such phenomenal spurts in prices will correspondingly reflect in production is a matter for speculation.

Future

The pepper production scenario in the major producing countries will change as a result of the socio-economic changes that these countries are subjected to. Agriculture is no more attractive in the rapidly developing countries like Brazil, Malaysia and Thailand, where cost of agricultural labour is on the increase, precluding economically viable production-in fact these countries are too rich that labour intensive agriculture is expected to decline in the coming decades. Sri Lanka is not going to be a major producer because of limitation in area. China and Vietnam are likely to play greater roles in the world pepper trade and economy, and rapid area and production increase are anticipated in these countries.

In India the production cost is going up, but the attractive market, especially since 1996–97 has given a tremendous impetus to increase both area and production. Increase in production in Indonesia may also go up marginally. But the recent climatic upheaval in the region will dramatically affect, adversely, the production. India, Indonesia, Vietnam and China, hence, will most likely be the world suppliers of pepper during the coming decades.

The projected world consumption of black pepper by 2010 is estimated to be around 230,000 m. tons, and by 2020 it will be around 280,000 m. tons, from the present production and consumption of around 180,000 m. tons. A modest increase of 100,000 m. tons is required for the next two decades to balance the demand and use. This increase can only be achieved by the wide-scale cultivation of varieties which can withstand both biotic and stresses, including tolerance/ resistance to the onslaught of pests and diseases and maximally responsive to production technology inputs. Production of high quality pepper, both intrinsic and extrinsic in quality, is another area of great importance. Clean, organically grown pepper will be in much greater demand by the health conscious western world.

The recent advancements in the areas of biotechnology and genetic engineering will have their impact in spices production, both in the areas of variety evolution and production increase through the use of biocontrol and biofertilizer. But more than that, advancements in bioprocessing can lead to *in vitro* production and harvesting of spice flavours from bioreactors. Development of such technologies in highly industrialized countries can affect adversely the economy of the conventional pepper producing nations. But such changes are inevitable in a technologically fast expanding world, and calls for innovative and imaginative diversification strategies for pepper. Also, the developing nations must quickly profit from these advances, rather than remain as mere spectators to a fast changing technological revolution. It is better to let posterity decide the future. Right now and in the emerging decade, the prospects for pepper seem to be quite bright, brighter than that in the past.

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ANNEXURE I

PEPPER NAMES AROUND THE WORLD

Arabic	– Babary, Filfil uswud	Hindi	– Golmirch, Kalimirch
Brazil	– Pimenteira	Italian	– Pepe, Pepe nero
Burma	– Nayukon, Sayomai	Persian	– Filfilsvad, Pilpil
Combodia	– Mrech	Phillipines	– Pimienta
Chinese	– Fou Tsiao, Hu chaio, Hon Tsiao	Polish	– Pieprz
		Portuguese	– Pimenta, Pimenteira
Danish	– Peper	Roumanian	– Piper
Dutch	– Peper	Russian	– Peretz
English	– Black pepper, pepper	Sinhalese	– Gammiris, Kalumiris
French	– Poivre, Poivre noir	Spanish	– Pimentera
German	– Pfeffer	Swedish	– Pepper
Greek	– Peperi		

ANNEXURE II

PEPPER AND FALSE PEPPERS

Economically Important Species

True Pepper-Black pepper	*Piper nigrum* L.
Long pepper-Indian long pepper	*P. longum* L.
Java long pepper	*P. chaba* Hunter (*P. retrofractum* Vahl)
Tailed pepper, cubeb	*P. cubeba* L.
Kawa pepper, Kawa	*P. methysticum* Forster
West African pepper	*P. clussi* C.
Ashanti or Benin pepper	*P. guineense* Schum. & Thonn.
Japanese pepper	*P. kadzura* (ehoisy) Ohwi
Betel leaf	*P. betle* L.

Ornamental Pepper

P. angustifolium Lam	*P. metallicum* Hallier
P. auritum HBK	*P. ornatum* N.E. Br (Celebes pepper)
P. borneense N.E. Br.	*P. porphyrophyllum* (Linal) N.E. Br.
P. decurrens DC	*P. rubronodosum* Nichols
P. magnificum Trel. (Lacquered pepper)	*P. rubronervosum* hort.ex.Rodigas

False Peppers

African pepper or Ethiopian pepper	*Xylopia aethiopica* (Dunal) A.Rich. (Annonaceae)
Australian pepper tree	*Drimys lanceolata* (Poir.) Baill. (Winteraceae)
Bell pepper, Sweet pepper	*Capsicum annuum* L. (Solanaceae)
Bush pepper or Guinea pepper	*Clethra alnifolia* L. (Clethraceae)
Brazilian pepper (Pink pepper)	*Schinus terebinthifolius* Raddi (Anacardiaceae)
Californian pepper	*Schinus molle* L. (Anacardiaceae)
Chinese pepper	*Zanthoxylum acanthopodium* DC (Rutaceae)
Japanese pepper tree	*Zanthoxylum piperitum* DC (Rutaceae)
Indian pepper tree	*Zanthoxylum limonella (Dennst.) Alston (Z. rhesta)* (Rutaceae)
Jamaican pepper	*Pimenta dioeca* L. Merr. (allspice, Myrtaceae)
Melegueta pepper	*Aframomum melegueta* (Rosc) Schuman (Zingiberacae)
Red pepper, green pepper	*Capsicum annuum* L. and *C. frutescens* L. (Solanaceae)
South African Pepper tree	*Kirkia wilmsii* Engl. (Kirkiaceae)
Tree pepper	*Macropepper excelsum* (Forster f.) Miq (Piperaceae)
Wall pepper	*Sedum acre* L. (Crassulaceae)

2. BOTANY AND CROP IMPROVEMENT OF BLACK PEPPER

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GENUS *PIPER*

The genus *Piper* was established by Linnaeus (1753) in his *Species Plantarum* in which he recognised 17 species in the *Pipe* family, all of which were included in the same genus. The genus name *Piper* was derived, probably from the Greek name for black pepper, *Peperi* and according to Rosengarten (1973) most European names for black pepper were derived from the Sanskrit root *Pippali,* the name for long pepper *(Piper longum)*. The second genus in the family, *Peperomia,* was introduced in 1794 by Ruiz and Pavon. The family name Piperaceae was first used by L.C.Rich in Humboldt, Bonpland and Kunth's *Nova Genera et Species Plantarum* in 1815 (Yuncker 1958). In the years that followed a number of additional genera, mostly segregates from *Piper* were described by Sprengel, Kunth, Miquel and others. Among the early studies the important ones were those of Ruiz and Pavon (1798) on flora of Peru and Chile; Humboldt, Bonpland and Kunth (1815) based on their collections from South America and that of Blume (1826) on East Indian species. Kunth (1839) published an important paper on 136 Latin American species mainly on *Piper* and segregate genera. However the first monographic study was that of F.A.W Miquel. His classic, *Systema Piperacearum* (1843), included all the species known in the family at that time. Miquel subdivided Piperaceae into two tribes Pipereae and Peperomeae. The former consisted of 15 genera and 304 species and the latter 5 genera and 209 species. In 1869 De Candolle monographed the family in its entirety for the Prodromus. In this he recognized more than 1000 species in the two genera, *Piper* and *Peperomia*. De Candolle continued to work on Piperaceae till his death in 1918. The key to the family prepared by him was published posthumously in 1923, under the name *"Piperacearum Clavis Analytica"*. In this work keys were provided for over 3000 species and varieties. William Trelease took up studies on Piperaceae from where De Condolle left. He made extensive collections of American Piperaceae which led to the revision of the Piperaceae of the Northern South America by Trelease and Yuncker (1950). Thus Miquel, De Candolle and Trelease were mainly responsible for the systematics of Piperaceae for more than a century.

Taxonomic History of Indian *Piper*

The earliest record of the description of *Piper* of Indian subcontinent was by Rheede (1678). In his *Hortus Indicus Malabaricus,* the first printed document on plants of the Malabar Coast of India, he described five types of wild peppers including black pepper and long pepper. Linnaeaus (1753) included 17 species from India in his *Species Plantarum*. Roxburgh (1832) described seven species of *Piper* from Indian Peninsula. Miquel (1848) included seven wild species from India in his monograph on *Piper*. Wight (1853) in his *Icones Plantarum Indiae Orientalis,* illustrated 16 species, 15 of which were from Indian Peninsula. De Candolle (1869) included 52 species from India in his monographic work.

The first major study on the *Piper* spp. from Indian subcontinent was that of Hooker (1886) in his Flora of British India. Hooker divided the genus into six sections, namely: Muldera, Cubeba, Chavica, Pseudochavica, Eupiper and Heckeria. Black pepper is included in the section Eupiper. Floristic studies carried out at the centre of origin and diversity, namely the Western Ghats of Southern India, are of great significance because all the species closely related to pepper are present there and most of them are endemic to the region. Rama Rao (1914) was the first to enumerate the *Piper* species occurring in the Southern Western Ghats. He listed 12 species but without any taxonomic keys. The most authoritative floristic study of the Western Ghats was that of Gamble (1925) in his Flora of Presidency of Madras, in which the following species together with taxonomic keys were given: *P. argyrophyllum, P. attenuatum, P. barberi, P. brachystachyum, P. galeatum, P. hapnium, P. hookeri, P. hymenophyllum, P. longum, P. nigrum, P. schmidtii, P. trichostachyon* and *P. wightii*. After the publication of Gamble's flora, practically there was no addition to the list of *Piper* spp. till the 1980s. In 1981 Rahiman described a new species, *P. bababudani,* from the Bababudin hills of Karnataka, but this was never published validly. Ravindran *et al.* (1987) reported a new species, *P. silentvalleyensis,* the only bisexual wild species reported from Western Ghats. The other new reports were *P. pseudonigrum* (Velayudhan and Amalraj 1992) and *P. sugandhi* (Nirmal Babu *et al.* 1993). Rahiman *et al.* (1979, 1981) and Ravindran (1990, 1991, 1992a, 1994 b, 1996) carried out taxonomic and biosystematic studies on *Piper* taxa occurring in the Western Ghats of South India.

Ravindran (1991) suggested a taxonomic key for the *Piper* species occurring in Western Ghats. He subdivided the genus into two sections—Pippali and Maricha-based on the orientation of spikes, erect or pendent, these names were derived from the Sanskrit names for the type species, long pepper and black pepper respectively. Brief descriptions of the species closely related to pepper are given below.

Piper Species Closely Related to Black Pepper from The Centre of Origin

Piper Linn. Gen. Pl. ed. 1:333, 1737; Type species *P. nigrum* L. Species of this genus are perennial, scandent or woody climbers or creepers, shrubs or small trees. Branching dimorphic, not very distinct in the shrubby species as in the climbing ones. Leaves alternate, petiolate, simple, entire often unequal sided, petiole grooved. A single lateral prophyll present at flowering nodes, the prophyll often modified to form a cap like structure enclosing the shoot apex and spike. In most species the base of the leaves (petioles) at sterile nodes (in the runner shoots and orthotropic shoots) develops into a caducous or persistant sheath which protects the bud. In the erect growing orthotropic shoots as well as in the runner shoots, the leaves are borne on longer petioles, lamina often larger, ovate, widely ovate or cordate in shape; in certain species the juvenile leaves on the new growths are small and ivy-like. In the lateral shoots, the leaves are usually ovate, but variable to some extent, base round, acute or cordate, tip acuminate, margin straight or wavy, hairs present or absent, when present simple and multicellular. Leaves ribbed (veins originating from the base or near the base and ascending to the tip).

Most of the Indian species are dioecious, while the Central and South American species are mostly monoecious. Flowers borne on solitary leaf-opposed spikes, morphologically terminal, spikes erect or pendent; usually filiform, rarely cylindrical or globose; flowers bisexual or unisexual; each in the axil of a bract, sessile or shortly stipitate; bracts variable in shape depending on species. Perianth absent, stamens 2–4, filaments short, anthers two-celled, ovary one-celled, ovule solitary, placentation basal, style absent or if present short, stigmas 2–5, fruits drupaceous, small, ovoid or globose, one-seeded, seeds usually globose, surface smooth and glabrous. The species closely related to *P. nigrum* that are occurring in the centre of origin are treated under two sections, namely Pippali and Maricha. The major diagnostic character between them is the orientation of the spike-erect in the former and pendent in the latter.

The genus in general is characterized by very small, highly reduced flowers, closely packed to form spikes. Most of the South Indian taxa are dioecious but cultivated black pepper is bisexual. Hooker (1886) has included 108 species, grouped under six sections in his Flora of British India. Out of these, only eleven are from South India. Gamble (1925) had later described 13 species, mostly from the Western Ghats, but did not use subgeneric classification.

Piper Linn. Sect. **Pippali**. Spikes erect. Includes four species, *P. longum, P. hapnium, P. mullesua* and *P. silentvalleyensis*.

P. longum Linn. Sp. Pl., 29, 1753; Vahl, Enum., 1:334, 1804; Roxb., Fl. Ind., 1:154, 1832; Wight, Ic.t. 1838, 1853; Miq., Fl. Ind. Bat., 1 (2):440, 1859; CDC. in DC Prodr., 16 (1):355, 1869; Hooker f., Fl. British India, 5:93, 1886; Watt, Dic. Eco. Pro. India, 6:1892; Trimen, Fl. Ceylon, 3:424, 1895; Prain, Bengal Pl., 2:668, 1903; Cooke, Fl. Bombay, 3:19, 1908; Hains, For. Fl. Chotanagpur, 384, 1910; Rao, Fl. Plants of Travancore, 336, 1914; Fischer, Rec. Bot. Sur. India, 9 (1):151, 1921; Haines, Bot. Bihar & Orissa, 3:757, 1924; Gamble, Fl. Presi. of Madras, 843, 1925; Kanjilal *et. al.,* Fl. Assam, 4:34, 1940; Raizada. Suppl. Fl. Upper Gang. Plains, 242, 1976; Rahiman, *Piper* in Karnataka, J.Bombay Nat. His. Soc., 84:46, 1987; Huber, in Rev. Handb. Fl. Ceylon, 288, 1987.

Kattu Thippali—Rheede, Hor. Mal., 7:1678; *P. sarmentosum* Wall., Cat., 6641, 1832; *P. latifolium* Hunter, As. Res., 9:390, 1809; *P. turbinarium* Noronha, Verb. Batav. Gen., 5:1790

Chavica Roxburghii Miq., Hook. Lon. J. Bot., 4:433, 1845.

A slender, perennial creeping undershrub, dioecious. Vegetative branches creep and spread on the ground, fruiting branches erect, young branches puberulous, hairs minute, multicellular, deciduous, older branches totally glabrous; leaves distinctly dimorphic, those on creeping shoot cordate, glabrous, petiole very long, grooved; leaves approx. 7×5 cm. Leaves on the fruiting branches oblong, lanceolate, base unequally cordate, with pronounced auricle, tip acuminate, 3–4 pairs of lateral ribs arise right from the base, lower side puberulous or downy when young, petioles very short or even absent. Spikes cylindric, erect, about 2–4 cm long, creamy white to yellowish white when young, peduncle about 1–2 cm long, downy; male spikes much longer, about 6–10 cm long, yellow on maturity. Bracts peltate, orbicular, glabrous, pedicellate; flowers laterally fused; stamens 3–4, carpel single, ovary obovate, style absent, stigma 3–4 lobed, short, papillate. Fruits very small, fused laterally, spicy and pungent; seeds very small. Spikes on ripening turns from green to black, deciduous. Common in low land forests. Dried spikes and roots extensively used in indigenous medical systems (*Ayurveda, Siddha* and *Unani* medicines).

P. hapnium Ham. in Wallich Cat. 6650 D. 1832; J.Hooker, Fl. British India, 5:86, 1886; Rao, Fl. Plants of Travancore, 337, 1914; Lushington, Trees, Shrubs and Woody Climbers of Madras 2, 593, 1915; Gamble, Fl. Presi. Madras, 3:1203, 1925.
P. nigrum Walli. Cat. 6643 C. 1832 (Centre specimen); *P. siribea* Herb. Heyne in Walli. Cat., 6651, B 1832; *Chavica arnottiana* Miq. Syst. Pip., 268, 1843; ICON. *C. arnottiana* Miq., illust. Pip., 1, 40,1846 (not *C. arnottiana,* C. DC).

A slender, scandent dioecious climber, branchlets delicately puberulous, leaves on the runners broadly cordate, equal sided, palmately ribbed, tip acute-accuminate, leaves on the fruiting branches elliptic or oblong-lanceolate, densely puberulous along the ribs and veins on the ventral side, about eight cm long, five cm broad, 2–3 pairs of prominent lateral ribs, base unequal, one side cordate, other amplexicaul auricle, petioles puberulous. Female spikes cylindric, erect, three cm long, shining white, peduncle puberulous; mature spike green, 3–4 cm long, often curved. Bracts peltate, pedicelled, orbicular, glabrous above. Carpel single, ovary obovate, stigma astylous, 3–4 lobed short, papillate. Fruit small 1–2 mm in dia., obovate, pungent, turns from green to black on ripening. An endangered species, very rare.

P. mullesua Ham. Ex. D. Don., Prodr. Fl. Nep., 20, 1825; C. DC in DC. Prodr. 149C (1), 338,1869.
P. brachystachyum Wall., cat. 6656, 1832; Wight, IC.t. 1931, 1853; Hooker f., Fl. Brit. India, 5:87, 1886; Rao, Fl. Plants of Travancore, 336, 1914; Gamble, Fl. Presi. Madras, 1205, 1925; Fyson, Fl. South India Hill Stations, 1:1932; Fl. Nilgiris and Pulney Hill Tops, 1:334, 1935; Rahiman, *Piper* of Karnataka, J. Bombay Nat. His. Soc., 84:66,1987; Manilal, Fl. Silent Valley, 231,1988; Ravindran *et al., Piper* spp. of Silent Valley, J. Bombay Nat. His. Soc., 87:424–425,1990.
P. guigual Ham. Ex. D. Don., Prodr. Fl. Nep., 20, 1825; *P. vasculosum* Miq., Syst. Pip.,

280, 1843; Wall., Cat., 6660, 1832; *Chavica guigual* Miq., Syst. Pip., 280, 1843; *C. mullesua* Miq., Syst. Pip., 280, 1843; *C. sphaerostachya* Miq., Syst. Pip., 279, 1843.

A slender, extensively branched climber, branches glabrous; juvenile shoots puberulous or glabrous, juvenile leaves very small, ivy-like, cordate; leaves on the flowering shoots small, coriaceous, elliptic, approximately 8×3 cm; base acute and often oblique, tip acuminate; two pairs of prominent ribs, lower one from the base, upper one 1–2 cm above the base; veins prominent on the ventral side. Spikes filiform in male, 3–5 cm long; female globose or oblong, about one cm long, peduncle short, less than 0.5 cm; bracts orbicular, peltate and pedicelled. Stamens two, filaments short, anther lobes single, reniform, dorsifixed; pollen sacs two, dehiscing by longitudinal slits; carpel single, ovary ellipsoid, style absent, stigma 3-lobed, minute, papillate. Fruits very small, almost ellipsoidal, seeds minute, ellipsoidal, spicy and mildly pungent, turns from green to black on ripening. It is a high elevation species, occurring usually above 1000 m, the species often spreads through ground and climbs up shrubs and tree trunks or rocks. The leaves on the juvenile runner shoots and orthotropic shoots very small, typically cordate and ivy-like. The juvenile shoots often have crisp hairs which are deciduous; such shoots sometimes coloured light pink. Flowering time May-June, fruit ripening Feb.-March.

P. silentvalleyensis Ravindran et Asokan, J. Econ. Tax. Bot., 10:167, 1987 Slender climber, stem about 0.5–1.0 cm thick, swollen at the nodes, branches terete, entirely glabrous, petiole short, about 3–6 mm, grooved, sheaths minutely pubescent, leaves alternate, elliptic-lanceolate, somewhat coriaceous, lamina 5–8.5 cm long and 2.0–3.5 cm broad, glabrous on both sides, base acute, more or less asymmetric, tip caudate—acuminate, lamina prominently ribbed, lateral ribs two pairs, first from the base and the second about 0.5 cm above the base. Spikes 2.5–5.5 cm long, erect and flexuous, peduncle very short 0.1–0.3 cm long; glabrous, furrowed when dry, never longer than petiole, bracts orbicular, peltate, stalked, about 0.07 cm in diameter, flowers bisexual, stamens two, very short, anthers 2-lobed, reniform, attached transversely at the tip of the filament, dehiscing by longitudinal slit. Ovary globoid, style absent, stigma minute, 3-lobed; fruit very small, mature one about 0.1 cm. across, obovate with striations, spicy and mildly pungent.

A bisexual species resembling *P. mullesua* in external appearance, but differs from it in having elongated erect fruiting spikes and bisexual flowers. This is the only bisexual wild species reported so far from the Western Ghats. Rare and endangered, so far collected from only one locality.

Sect. **Maricha**: Spike pendent, almost always filiform, rarely cylindrical.

P. argyrophyllum Miq., Syst. Pip., 330, 1843; C.DC, in DC., Prodr., 16(1):365, 1869; Hooker f., Fl. Brit. India, 5:93, 1886; Wight. Ic.t. 1941, 1853; Trimen, Fl. Ceylon, 3:428, 1886; Rao, Fl. Plants of Travancore, 338, 1914; Gamble, F1. Presi. Madras, 1205, 1925; Fischer, Rec. Bot. Sur. India, 9(1):151, 1921; Saldanha & Nicholson, Fl.

Hassan, 53, 1976; Rao & Razi, Fl. Mysore, 177, 1981; Rahiman, *Piper* in Karnataka, J. Bombay Nat. His. Soc., 84:66, 1987; Ravindran *et al., Piper* spp. of Silent Valley, J. Bombay Nat. His. Soc., 87:424–425.
P. malamiri Wall., Cat., 664f2 E, F & I, 1832; *P. wightii* Miq., in Hook., Lond. J. Bot., 5:552, 1846; *P. walkeri* Miq., in Hook., Lond. J. Bot., 4:438, 1845.

A slender, scandent, perennial climbing shrub, dioecious, main stem and branches glabrous, young shoot puberulous; leaves thin, papery when dry, ovate to elliptic, about 12×7 cm, base round, often cordate in the leaves of the runner shoot, tip acuminate, 5-ribbed at the base, the outer pair of ribs running to two third of the leaf, the inner ones reaching the tip, glabrous or puberulous, younger leaves often minutely hairy, especially along the veins on the lower side of the leaf, silvery scales present on the lower side, petiole about 1–1.5 cm., grooved, glabrous or minutely puberulous. Spike thin, filiform, pendulous, length highly variable, male spikes 8–16 cm, female 5–10 cm, glabrous or puberulous. Bracts sessile, adnate and almost confluent with the rachis, obovate to elliptic; stamens three, anther dithecous, carpel single, style absent, ovary oblong, stigma 4-lobed, rarely 3-lobed, short, recurved and papillate. Berry (fruit) ovate, becomes spherical in full maturity, on ripening turns black directly from green, deciduous, taste bitter. The scars left by fallen fruits ciliate. Externally similar to *P. attenuatum,* but differs from it in having 5-nerved (ribbed) nature of leaf base and shorter, greenish white fruiting spike and silvery scales on the underside of the leaves. Flowering May–June; fruiting December– January, off season flowering common.

P. attenuatum Ham. Ex. Miq., Syst. Pip., 306, 1843; Fl. Indica Bat., 1(2):451, 1859; C. DC., in Prod., 16 (1):363, 1869; Wight, Ic. 5. 1933, 1853; Hooker, f., Fl. Brit. India, 5:92, 1886; Burkill, Rec. Bot. Sur. India, 10 (2):347, 1925:Gamble, Fl. Presi. Madras, 1205,1925; Kanjilal *et al.,* Fl. Assam, 4:37, 1944; Hains, Bot. Bihar and Orissa, 3:790, 1924; Rahiman, *Piper* in Karnataka, J. Bombay Nat. His. Soc., 84:66, 1987; Ravindran *et al., Piper* spp. of Silent Valley, J. Bombay Nat. His. Soc. 87:424–425, 1990.
P. diffusum Vahl, Enum., 1:333, 1804; *P. karok* Blume, Cat. Gew. Buitenz., 33. 1823; *P. malamiris* Roxb., Fl. Ind., 1:160, 1832; *P. sirium* C. DC., in DC Prodr., 16:160, 1869.

Dioecious, scandent climber, leaves thin, papery when dry, glabrous, ovate to elliptic in the fruiting branches, ovate to broadly ovate to cordate in the runner shoot, about 11×5 cm; petiole grooved, leaf base attenuate, tip acuminate, 7-ribbed from the base, the outer pair reaching only half to two third of the leaf, the others reaching almost to the tip. Spike thin, long, filiform, pendent; female 7–15 cm long, male 8–18 cm, peduncle about two cm, glabrous. Bracts sessile, adnate to the rachis, obovate to elliptic, margins free, glabrous; stamens 3–4 dithecous, dehiscing longitudinally, style absent, ovary single, oblong, stigma 3–4 lobed, recurved, papillate, ovule single. Developing fruit oblong, mature ones round to oblong, 0.25 to 0.4 cm; turns from green to black on ripening, deciduous, taste bitter. The scars left by fallen fruits ciliate. The flowering season is May–June, fruit ripen in December-January. Off season flowering very common. This species is very common in all the forests, except at higher elevations and in sea-level forests.

P. galeatum Miq., C.DC. In DC Prodr., 16(1):242, 1869; Hooker f., Fl. Brit. India, 5:80, 1886; Rao, Fl. Plants of Travancore, 336, 1914; Gamble, Fl. Presi. Madras, 1206, 1925; Saldanha & Nicolson, Fl. Hassan, 54, 1976; Fl. Karnataka 1:80, 1984; Rahiman, *Piper* in Karnataka, J. Bombay Nat. His. Soc., 84:66, 1987; Manilal, Fl. Silent Valley, 231, 1988; Ravindran *et al., Piper* spp. of Silent Valley, J. Bombay Nat. His. Soc., 87:424–425, 1990.
Muldera galeata Miq., In Hook. Lon. J. Bot., 5:557, 1846; *Muldera wightiana* Wight, Ic. t.1943, 1853 (right hand figure); *P. talbotti* C. DC., In Fedd. Report., 10:523, 1912.

A stout, woody climber, found at medium elevations of 500–800 m. Dioecious, leaves usually elliptic-lanceolate to lanceolate or elliptic; thick, glabrous, about 10×4 cm size smaller in male vines, base acute, two pairs of lateral ribs from the base, the third pair about 1–2 cm above the base, and often placed unequally, nervules more prominent on the lower side. Spike filiform, pendulous, young ones green or pale purple, mature yellowish white, glabrous, peduncle short, glabrous. Male spike long, about 10–15 cm, even longer, sometimes reaching upto 25 cm; bracts prominent, connate, forming a fleshy cup or boat shaped structure, shortly stipitate, and recurved; glabrous; style absent, stamens two, anther lobes two, carpel single, ovary obovate, stigma 3–4 lobed. Fruits green, on ripening turn bright yellow and then to orange red; oblong, or spherical, bold, taste bitter first and slightly pungent later.

P. hymenophyllum Miq., Hook. London J. Bot., 5:554, 1846; C. DC., in Prodr., 16 (1):364, 1869; Wight Ic. 6:2, t. 1942, 1853; Rao, Fl. Plants of Travancore, 336–337, 1914; C.D.C, Candollea, 1:220, 1923; Gamble, Fl. Presi. Madras, 1205, 1925; Mathew, Fl. Tamil Nadu Karnatic, 3:1351, 1983; Saldanha, Fl. Karnataka, 1:79, 1984; Huber, in Rev. Handb. Fl. Ceylon, VI:280, 1987; Rahiman, *Piper* in Karnataka, J. Bombay Nat. His. Soc., 84:66. 1987; Manilal, Fl. Silent Valley, 231, 1988; Ravindran *et al., Piper* spp. of Silent Valley, J. Bombay Nat. His. Soc., 87:424–425, 1990.
P. malamiris Wall., Cat., 6642, G & H, 1832; P. *nilghirianum* Cas. DC., in Prodr., 16 (1):364, 1869; *P. lanatum* Wight ex. Miq., Hook. Lon. J. Bot., V:533, 1846; *P. wightii* Miq., in Hook. Lon. J. Bot., V:552, 1846.

A scandent, slender climber, dioecious, having prominently pubescent branchlets and leaves, hairs more pronounced on the young shoots. Leaves thin, dried ones chartaceous, sometimes thinly coriaceous; shape and size much variable, ovate to obovate—elliptic, or elliptic—lanceolate; the leaves on the emerging juvenile shoot (runner shoot) small, cordate or semi-cordate. Leaves on the lateral shoots vary in size, around 9×3.6 cm on an average, base acute or obtuse; cordate or semi-cordate in the case of leaves on the juvenile shoots; tip acuminate; 2–3 pairs of lateral ribs arising from the base or near to it; both sides pubescent, petiole grooved, pubescent. Spike thin, filiform, male spike 5–13 cm long, female spike 6–16 cm long, lengthening in maturity, peduncle pubescent, bracts sessile, adnate to the rachis, obovate to elliptic; stamens three, anther dithecous; style absent, ovary oval, stigma 3–4 lobed, recurved and pappillate. Fruits oval, mature ones often becomes spherical, dark green, on ripening turns black; taste bitter. The scars left by fallen fruits ciliate.

P. nigrum Linn., Sp. Pl., 28, 1753; Vahl, Enum., 1:329, 1804; Roxb., Fl. Ind., 1:150, 1832; Miq., Syst. Pip., 330, 1843; Wall., Cat., 6643 A, B and C, 1832; C. DC., in DC., Prodr., 16 (1):242, 1869; Hook, f., Fl. Brit. India, 5:90, 1886; Watt, Dict. Econ. Prod. India, 6:1892; Trimen, Fl. Ceylon, 3:427, 1895; Prain, Bengal Pl., 668, 1903; Fyson. Fl. Nilgiris and Pulney Hill tops, 1:334, 1915; Fischer, Rec. Bot. Sur. India, 9 (1):151, 1921; Haines, Bot. Bihar & Orissa, 3:789, 1924; Burkill, Rec. Bot. Sur. India, 10 (2):347, 1925; Gamble, Fl. Presi. Madras, 1204, 1925; Kanjilal, *et al.,* Fl. Assam, 4:37, 1940; Trelease and Yuncker, Pip. N.S. Amer., 81, 1950; Backer & Backer, Fl. Java, 18, 1963; Rao, Bull. Bot. Sur. India, Suppl., 2:10, 1968; Howard, J. Arnold Arbor., 54 (3), 377, 1973; Saldanha & Nicolson, Fl. Hassan Dist., 54, 1976; Rahiman, *Piper* in Karnataka, J. Bombay Nat. His. Soc. 84:6, 1987; Ravindran *et al., Piper* spp. of Silent Valley, J. Bombay Nat. His. Soc., 87:424–425, 1990.
Molagukodi, Rheed, Hort. Mal., 7:23–24, 1678; *P. trioecum* Miq., Sys. Pip., 310, 1843; Hook, Lon. J. Bot., 4:438, 1845; Wight, Ic. T., 1935, 1852; *P. nigrum* var. *trioecum* C. DC., in Prodr., 16 (1):363, 1869; *P. baccatum* C. DC., ibid, 242, 1869; *P. colonum* Presl. Bot. Bemerk., 112, 1844; *P. fallax* Vahl, Enum., 1:335, 1804; *P. glyphicum* Hoffm., ex Kunth. Linnaea, 13:573, 1839; *P. malabarense* C. DC., in DC., Prodr., 16 (1):242, 1869; *P. spurium* Link, Enum. Hort. Berol., 1:37, 1821; *Muldera multinervis* Miq., in Hook. Lon. J. Bot., 5:557, 1846; *M. wightiana* Miq., ibid, 558; *P. rotendum nigrum* Casparus Fl. Mal., 54, 1696; *P. aromaticum* Lam. Illus., 1:1791.

The common black pepper, found extensively in the evergreen forests of Western Ghats, and in the adjoining areas, almost from sea level up to an elevation of 1300 m. Perennial climber, climbing by means of ivy-like roots which adheres to the support tree. Vigorous vine, old stem thick and rough, branches numerous, runner shoots arise from the base. Leaves thick, coriaceous, glabrous, shape much variable, commonly ovate, elliptic or elliptic-lanceolate; size varies from small to large, base round, acute or cordate, tip acuminate; lateral ribs two or three pairs, prominent, the upper most one 1–2.5 cm above the leaf base, upper surface dark green to light green, lower surface dull green; petioles short or long, grooved, leaf margins wavy or even. Pearl glands (wax glands) present on the under surface of leaves and on young shoots and petioles.

Spike filiform; pendulous, young ones green or whitish green, or light purple; mature ones green, pale purple or pale yellow, spike length varies much. Peduncle glabrous, bracts oblong, decurrent, sessile with free upper margin, develop into a shallow cup in female spikes, rachis and bracts glabrous; stamens two, anther dithecous, carpel single, ovary spherical, style absent, stigma 3–5 lobed, pappillate. Fruit a drupe, green when young changes to red on ripening, seed mostly spherical, pungent. Wild forms usually dioecious; cultivated ones bisexual.

P. pseudonigrum Velayudhan and Amalraj, J. Eco. Tax. Bot. 16:247–250, 1992.

Robust climber, stem terete, glabrous but rough, swollen at nodes. Leaves alternate, very broadly ovate, coriaceous and glabrous on both sides, dorsally shiny and ventrally glaucous, lamina up to 22×15.5 cm, tip acuminate, base round and equal, three pairs of prominent lateral veins-the two lower pairs almost opposite and upper pair alternate at about 3.5 cm from the base; petiole up to 3.2 cm. Male spike up to 20 cm long, purple to greenish purple, drooping, peduncle two mm thick with very minute hairs. Flowers in the form of hemispherical receptacles or small cups held on thin pedicels born alternately and perpendicular to the axis; pedicel and outer surface of the bract sparsely and minutely hairy. Flower 3.5 mm (pedicel 1.5 mm). Stamens two, anthers dithecous, protruding like two eyes from hemispherical cup, dehiscence linear. Female spike also purple to greenish purple, drooping, medium long, up to 10 cm, peduncle up to 2.4 cm, glabrous; ovary spherical subtended by a cupular bract, having minute hairs; stigma sessile, 3–4 lobed, lobes short and papillate. Fruits ripening through yellow to red. Less pungent than that of *P. nigrum,* diameter ca 0.8 mm. The plant resembles *P. nigrum* in habit and leaf morphology, but can be differentiated by the colour of the spike and pedicellate flowers. Seems to be the same as *P. sugandhi* var. *brevipilis*. Flowering season is February to April.

Piper sugandhi Ravindran, Babu *et* Naik J. Spices & Aromatic Crops, 2:26–33, 1993.

A stout woody climber, dioecious and perennial, reaching to a height of 10 m or more; branches terete, swollen at the nodes, glabrous, orthotropic shoot tips purple; leaves alternate, glabrous, coriaceous, ovate to ovate-lanceolate, acuminate, base round to acute and often oblique, margins slightly wavy, more prominent in young leaves; 7–13 cm long and 3–8 cm broad in the female, prominently 5–7 ribbed, more conspicuous on the lower side, the basal pair of ribs sub-opposite, others alternate. Petiole about 2 cm, grooved, margins modified as sheaths, sheaths caducous. Male spikes slender, fleshy, filiform and pendant or recurved, 10–14 cm long; female spikes slightly thicker than male spikes, 5–10 cm long. Flowers held at right angles to the rachis, stipitate, bracteate, bracts deeply cupular with free margins, stamens two, filaments short and thick, embedded in the cupular bract, anthers projecting out at maturity; dithecous, dehiscing by apical longitudinal slits. Ovary ovoid, monocarpellary, embedded inside the cupular bract except for the tip; style absent, stigma 3-lobed, fleshy, white when young. Fruits oblong, bold, 0.8–1.0 cm diam., pungent as in black pepper, turns yellow and then to red on ripening. Flowering season is April-May, fruits mature in December-January.

Allied to *P. nigrum* L., but differs from it in having stipitate flowers and deeply cupular bract. Allied to *P. galeatum* (Miq.) C. DC., but differs from it in the nature of bracts and in having pungent fruits as in black pepper. Also allied to *P. trichostachyon* (Miq.) D. DC., but differs from it in having stipitate flowers, nature of bract and in having pungent fruits.

P. trichostachyon (Miq.) C. DC. In DC Prodr., 16 (1):242, 1869; Hooker f., Fl. Brit.

India, 5:80, 1886; Cooke, Fl. Bombay, 18, 1903; Rao, Fl. Plants of Travancore, 336, 1914; Gamble, Fl. Presi. Madras, 1206, 1925; Fischer, Rec. Bot. Sur. India, 9 (1) 151:1921; Santapau, Rec. Bot. Sur. India, 18 (1):257, 1960; Rahiman, *Piper* in Karnataka, J. Bombay Nat. His. Soc., 84:66, 1987; Ravindran *et al., Piper* spp. of Silent Valley, J. Bombay Nat. His. Soc., 87:424–425, 1990.
Muldera trichostachya Miq., in Hook., Lon. J. Bot., 5:556, 1846; Wight, I.C.T., 1944, 1853.

A stout woody climber growing to a height of 10–12 m, common at elevations upto about 1000 m, leaves thick, coriaceous, glabrous, elliptic to elliptic-lanceolate, rarely ovate, much variable in size, length ranges from 8–18 cm, breadth from 6–10 cm; size larger in young plants, much smaller in older vines and in male vines, base round or acute, tip acuminate, margins often recurved. Leaves on the orthotropic shoot more or less cordate. Ribs 2–3 pairs, the upper most arises 1–2 cm above the leaf base. Spike filiform, minutely hairy, male spike about 4–10 cm, female 4–9 cm, lengthens in maturity; peduncle glabrous, bracts decurrent, connate, forming a fleshy cup or boat shaped structure, hirtellous; stamens two, short, dithecous, carpel—one, style absent, stigma 3–4 lobed, lobes short papillate. Fruits bold, spherical or oblong, taste bitter first, pungent later; colour changes from green to yellow and then to orange red on ripening; closely related to *P. galeatum*.

P. schmidtii Hooker f., Fl. India, 5,88, 1886; *P. arborescence* in part, Miq., Syst. Pip., 220, 1843; Wight Ic., T. 1940 (right hand figure) 1853; C. DC., Prodr., 16 (1):359, 1869; Saldanha, Fl. Karnataka, 1:80, 1984; Manilal, Fl. Silent Valley, 231, 1988
P. nigrum Wall. Cat., 6643 D (lower figure) 1823; *P. arcuatum* and *P. quintuplinervum* C. DC., in DC., Prodr., 16 (1):359, 1869.

Dioecious, vigourous vine found at elevations above 1500 m. Leaves very thick and coriaceous, venation very prominent; leaves small, ovate to ovate-elliptic, base round or acute, tip acuminate, entirely glabrous, ribs very prominent, lateral ribs two pairs, first from the base, second about 1.0 cm above the base, placed unequally; leaves about 9×4 cm in size, larger in the young vines. Spikes filiform, pendant, female spike thick 6–16 cm, male spikes thinner, about 10–15 cm in length; bracts peltate, with raised free margins; stamens two, filament thick, anthers opening by longitudinal slits. Ovary oblong, or conical, ovule single, style absent, stigma 3–4 lobed, papillous; fruits oblong, bitter in taste, turning to yellow and finally to orange on ripening. Flowering in July-August. Fruits mature in March-April.

P. wightii Miquel in Hook. Lon. J. Bot., 5:552, 1846, Wight Ic.t. 1939 (named as *P. wighitana* in the plate), 1853; *P. nigrum* Wall., Cat. 6643 D (Upper right hand specimen), 1832.
Vigorous, large vine, occur at elevation above 1500 m only, rooting ivy-like at first, later climbing up on trees, often grow to 10–12 m high. Leaves small to medium, approximately 9×6 cm, glabrous, shining ovate, base round or acute, ribs prominent on

the under side, 2 pairs of lateral ribs, first pair from the base and the second pair about 1.0 cm above the base, unequally placed and running to the tip; leaf margin often curved outwards, under side with sparse silvery scales. Spike filiform, pendulous, medium long, 4–8 cm, peduncle about 1–1.5 cm long, spikes sometimes reach about 15 cm, flowers arranged spirally, bracts oblong, narrowed towards the base, overlapping with the successive bracts, adnate to the rachis; margins free; ovary conical, stigma 4-lobed, persistent; style absent, anthers 2–3, stalked, filament thick, dehisce by longitudinal slits. Fruits conical, but almost spherical when mature, with persistent stigma.

Piper barberi Gamble, Kew Bull., 387, 1924, Nirmal Babu *et al.* J. Spices and Aromatic Crops, 1:88–93, 1992.
A very distinct species among the South Indian *Piper* having reticulately veined leaves and spikes borne on slender, long dangling peduncle. A perennial climber, glabrous, dioecious, branching dimorphic, juvenile shoots slender with persistent scale leaves, orthotropic shoots with small leaves, 5–7 cm long, 2–3 cm broad, fruiting branches with leaves 8–12 cm long, 2–5 cm broad, glabrous, lanceolate, tip acuminate, base unequally acute, pinnately reticulate. Male spikes narrow, 7–10 cm long, female spikes 4–7 cm, cylindrical, pendulous, borne on long, slender peduncle, ca. 8–10 cm, bracts peltate, orbicular, ovary 0.5–1.0 mm, sessile, 1-celled, 1-ovuled, stigma 3-lobed, pappillate, style absent, fruit fleshy drupe 5–6 mm across, red when ripe; seeds 2–3 mm, ovoid. Not related to any other known South Indian Species. Endangered.

Cultivated *P. nigrum*

The cultivars of black pepper might have originated from the wild ones through domestication and selection. Over hundred cultivars are known, but many of them are getting extinct due to various reasons like devastation of pepper cultivation by diseases such as, foot rot and slow decline; replacement of the traditional cultivars by a few high yielding varieties etc. Cultivar diversity is richest in the state of Kerala followed by the state of Karnataka. Most of the cultivars are bisexual forms, unlike their wild counterparts. The cultivar diversity of black pepper is represented in Tables 2.1–2.3. Once there were specific cultivars of black pepper identified with major growing tracts. However during the turn of the present century extensive plantations of tea, cardamom and coffee were established in the hilly tracts of Western Ghats, and there was lot of human migration from the plains to these hills mainly in search of land and work; carrying along with them, among other things, pepper cultivars. Such human activities influenced the selective spread of certain high yielding cultivars, and they became very popular in all pepper growing tracts. Further details on species and cultivar diversity are given in the following sections. Recent surveys by scientists of IISR in some areas of Western Ghats in Idukki district led to the discovery of intermediate populations, apparently composed of hybrids between *P. nigrum, P. sugandhi, P. trichostachyon* and *P. galeatum* and their segregating progenies. Various degrees of sexual dimorphism was also met with in

Table 2.1 Diversity in cultivated pepper in India.

Sl. No.	*Cultivars*	*Notes*
1	*Aimpiriyan*	Performs well in plains and hilly regions, not suitable for heavy shaded areas, late maturing, high yielder.
2	*Arakkulam Munda*	Early variety, medium yield and quality.
3	*Arimulaku*	Small ovate leaves, lobes unequeal, small fruits and spikes early maturity; poor yield, medium quality.
4	*Balankotta*	Tolerant to shade, performs well as mixed crop in arecanut gardens, large leaves, medium yield, bold fruit, medium quality.
5	*Cheppukulamundi*	Ovate, cordate leaves, medium long spikes, setting moderate, medium yield and quality.
6	*Cheriyakaniakkadan*	Small lanceolate leaves, tips accuminate, spikes short, fruits small; early maturity, poor yielder, quality medium.
7	*Cholamundi*	Small, lanceolate leaves, spikes medium, setting often poor, fruits small, medium quality, predominently female.
8	*Chumala*	Medium ovate leaves, spikes short to medium; good fruit set, fruits medium, medium yield and quality.
9	*Doddigae*	A cultivar grown in Karnataka state, leaves ovate, poor yielder.
10	*Jeerakamundi*	Small, lanceolate leaves, spikes small, setting poor, spiking intensity high.
11	*Kalluvally*	A hardy cultivar, minutely hairy in nature, medium yield and quality.
12	*Karimkotta*	A common hardy cultivar of Malabar, poor yielder.
13	*Karimunda*	Originally from south Kerala, now very popular through out Kerala; tolerant to shade, performs well as a mixed crop, widly adaptable, good yielder, medium quality.
14	*Karimundi*	Meduim long ovate leaves, spikes medium, setting moderate, yield medium.
15	*Karivilanchi*	Medium ovate leaves; predominantly female, fruit bold, oblong, medium quality, poor yielder.
16	*Kottanadan*	Performs well in plains and hilly regions up to 700–800 m MSL; widely adpated and high yielding, high quality.
17	*Kurimalai*	Performs well as inter crop in coconut and arecanut gardens. Not suitable for plains, good yielder, medium quality.
18	*Kuriyalmundi*	Elliptic to lanceolate leaves, good spiking, spikes very short, 5–6 cm, curved or twisted. Fruits very small, setting good, poor yielder.
19	*Kuthiravally*	A stable yielder, long spikes, good setting, high quality.
20	*Malamundi*	Leaves ovate with round base, spikes medium long, peduncle small; flowers bisexual and female almost in equal proportion. Fruits medium, good setting.
21	*Malligesara*	One of the most popular cultivars in the Karnataka, especially in the Malnad (hilly tracts) of Uttara Kannada and Shimoga districts; good yielder. Two types of *Malligesara* are commonly recognised – *Karimalligesara* and *Bilimalligesara*. Moderate yielder, medium quality.

Table 2.1 *continued*

Sl. No.	*Cultivars*	*Notes*
22	*Mundi*	Leaves ovate, spikes short to medium, fruit set moderate; fruits medium, quality medium.
23	*Narayakkodi*	Common in all pepper growing tracts; said to be field tolerant to *Phytophthora* foot rot, medium yield and quality, small fruits.
24	*Nedumchola*	Leaves are smallest among the cultivars, ovate to obovate, base round, spikes very short, 4–6 cm, berries very small, slightly obovate; poor yielder and chracteristically small statured vine.
25	*Neelamundi*	Reported to be field tolerant to foot rot. Suitable for high elevation areas, moderate yielder medium quality.
26	*Perambramunda*	Resembles Neelamundi, berries bold, medium long spikes, medium yield and quality.
27	*Perumkodi*	Leaves ovate to ovate-elliptic, spikes medium, setting poor, fruits bold, quality medium, alternate bearer.
28	*Poonjaran munda*	Leaves broadly ovate, base cordate, long spikes, moderate yielder, alternate bearer.
29	*Thulamundi*	Leaves ovate, base round, spikes medium in length, flowers (male, female and bisexual – mixed),alternate bearer, poor yield, quality medium.
30	*Thevanmundi*	Leaves moderately large, ovate, spikes medium, setting good, good spiking, berries medium oblong, good yield, quality medium.
31	*Thommankodi*	A vigourous cultivar, leaves ovate to widely ovate in the main stem, medium large in lateral; spikes long (13–14 cm) setting good, fruits medium, globose, closely resembles *Kuthriavally*; good yielder and quality.
32	*Uddaghere*	A popular and high yielding cultivar from the Uttara Kannada and Shimoga districts of Karnataka; good yield, moderate quality.
33	*Uthirankotta*	Predominantly female, poor yield.
34	*Vadakkan*	A natural triploid; vigourous vine; leaves ovate to ovate elliptic, long petioled, spikes medium, setting poor, fruit very bold, medium quality, spikes light purplish.
35	*Valiakaniakkadan*	Spikes medium to long, berries bold, medium yielder alternate bearer.
36	*Vattamundi*	Vigourous vine, leaves medium, widely ovate, spikes medium, setting moderate, berries bold, round, medium yield and quality
37	*Vellanamban*	Tolerant to drought, medium yield and quality.
38	*Velliyaranmunda*	Leaves large, ovate, base often oblique, or round, interveinal region raised dorsally; spikes medium long, fruits medium, round, medium yield and quality.

Table 2.2 Cultivar diversity: less important cultivars and land races.

1. *Aralumuriyan*	23. *Karimuratta*	45. *Orumaniyan*
2. *Aranavalan*	24. *Karivally*	46. *Padappan*
3. *Arasinagunda*	25. *Konnomkara*	47. *Perumkarimunda*
4. *Arasinamuratta*	26. *Kotta*	48. *Pirimundi (Pirimunda)*
5. *Arikotta*	27. *Kottan*	49. *Punchakodi*
6. *Arivally*	28. *Kudirugunda*	50. *Sagar Local*
7. *Champakkara*	29. *Kumbhachola (Kumbhakodi)*	51. *Shimoga*
8. *Chankupazhuppan*	30. *Kumbhanadan*	52. *Sullia*
9. *Charadupiriyan*	31. *Kuppakkodi*	53. *Thekkan*
10. *Cheruvally (Cherukodi)*	32. *Kuttiyanikodi*	54. *Thippali mundi*
11. *Chetten vally*	33. *Kuzhivelikkodi*	55. *Thottamundi*
12. *Dadisinikalu*	34. *Malanadan*	56. *Vally*
13. *Doddelae*	35. *Manjamundi*	57. *Varikkakodi*
14. *Ghantuvalli*	36. *Marampadathi*	58. *Vellamunda*
15. *Giddaghere*	37. *Marankodi*	59. *Velutha Kaniakkadan*
16. *Irumaniyan*	38. *Maramodiyan*	60. *Vokkalgunja*
17. *Kallubalancotta*	39. *Motaghere*	61. *Vokkalu*
18. *Kallumunda*	40. *Munda*	62. *Wyanadan*
19. *Kanjirakodan*	41. *Murithothan*	63. *Yohannankodi*
20. *Kanjiramundi*	42. *Nadesankodi*	
21. *Kapplangamundi*	43. *Nastigunda*	
22. *Karimkodi*	44. *Neyyattinkara mundi*	

these plants. These observations further support the view that pepper originated in the tropical evergreen forests of the Western Ghats and that it is a species that is still in evolution.

ECOLOGY AND POPULATION STRUCTURE

Distribution

Pepper is distributed extensively in the moist evergreen forests and to a lesser extent in semi-evergreen and moist-deciduous forests of Western Ghats of South India, growing from almost sea level to an elevation of around 1500 m. Most of the related species of *Piper* too occur at these elevations, but *P. schmidtii* and *P. wightii* occur above 1500 m only. Species like *P. longum* and *P. hapnium* occur in low elevations, below 500 m. *P. attenuatum* and *P. argyropyllum* occur from almost 200 m to 1000 m; while *P. hymenophyllum, P. sugandhi,* and *P. barberi* are found in 700–1000 m elevations. *P. mullesua* and *P. silentvalleyensis* occur around 1000–1500 m level. The high elevation species thrives best in sholas, where the soil is loose, moist and rich in humus. *Piper* plants grow as undergrowth and spread on the ground or climb on shrubs and trees. Some species—such as *P. nigrum, P. sugandhi, P. galeatum, P. trichostachyon* and *P. wightii* reach a height of 10–15 m. The

Table 2.3 Popular cultivars of other countries.

Malaysia	
Kuching	Most popular, high yielder
Sarikei	Small leaves, poor yielder
Miri	Average yielder
Indonesia	
Bangka	High yielder
Banjarmasin	Medium yielder, tolerant to foot rot
Belantung	Medium yielder
Beng Kayang	Poor yielder
Chunuk	Average yielder
Chunuk Kernuga (CK_2)	Average yielder
Djambi	Medium yielder
Duantebei	Medium yielder, tolerant to foot rot
Kerenci	Good yielder.
Kernuga (CK_1)	Average yielder
Korintji	Average yielder
LDK (Lampung Daun Kocil)	Medium yielder
LDL (Lampung Daun Lebar)	High yielder
Palulauta	Poor yielder
Petaling 1	Moderate yielder
Petaling 2	Moderate yielder
Merefin	Medium yielder, tolerant to foot rot
Natar 1	High yielding selection
Natar 2	High yielding selection
LDLN1 (Lampung Daun Lebar Namang 1)	Good yielder
LDLN2 (Lampung Daun Lebar Namang 2)	Good yielder
Sri Lanka	
Ceylon	Medium yielder
Madagascar	
Sel. IV. 1	Selections from cultivars introduced from
Sel. IV. 2	Indonesia.
Thailand	
Antique (Buffaloes Horning)	Low yield, short spikes, bold fruit
Ban keow	Average yielder, medium spike and fruit
Prang Thi	High yielder, short spike, medium fruit, high spiking intensity
Prang Thi Bai yick	Similar to the above, foliage more yellowish.
"thick leaf"	Low yielder, bold fruit – thick, narrow leaves.

distribution of *Piper* is denser along foot paths, animal tracks, rivulets and towards the periphery of the forests as well as where there is better light penetration. However in disturbed forests they occur in good number even in the interior, because of the increased light availability. Though *Piper* plants are not observed to climb on trees that shed barks (as in the case of *Eucalyptus*) no particular tree preference has been noted. Pepper plants are often found to grow over rocks, tree stumps, and also trail on the ground.

Population Structure

The population structure of any species is determined mainly by the breeding system of the species, the mechanism of pollen, fruit and seed dispersal and presence or absence of isolation mechanisms. In *Piper,* male, female and hermaphrodite forms exist. The cultivated *P. nigrum* is monoecious having hermaphrodite flowers, while the wild ones are mostly dioecious. Human selection might have played a major role in the directional evolution of hermaphroditism in the cultivated pepper. Pepper is predominantly self pollinated, and the pollen dispersal is aided by rain or dew drops, and also by the gravitational descending of pollen (geitonogamy). The flowers are protogynous, but in the absence of an active pollen transfer mechanism, protogyny becomes ineffective in ensuring outbreeding. Active and efficient pollen and seed dispersal mechanisms ensure gene flow within and between populational segments leading to the establishment of intergrading populations. The absence of any such mechanism in *Piper* thereby establishes effective isolation barriers among individuals and among population units. Within such units, variations can occur through segregation in the seedling progenies, accumulation of mutations and chance crossing followed by segregation. Any such variation arising in a population gets immediately fixed as a result of the prevalence of vegetative mode of propagation and such a unit may gradually diverge from other similar units. In *P. nigrum* dioecy occasionally can break down leading to the production of hermaphrodite flowers. Such a hermaphrodite plant climbing on a tree gradually spreads out by means of runners that climb on nearby trees, become separated from the mother vines in due course apparently because the runners get covered up by humus and soil, gradually leading to their degeneration. Simultaneously, the seeds germinate around the mother vine which also grow and climb up surrounding trees.

Thus gradually from a single vine a small population develops, consisting of the mother vine, its clonally developed progenies, sexual progenies (male, female and bisexual), the second generation progenies of the above vines, their clonal progenies and so on (Ravindran *et al.* 1990).

Sometimes more than one type of pepper vines (different types of *P. nigrum* or different species) climb up a single tree thereby increasing the chances of out crossing, resulting in hybrid seedlings. The progenies from such chance crosses grow, later climbing up the same or nearby trees and chance out crossing with parental vine or its clonal or other seedling progenies resulting in further back cross or hybrid progenies, leading to considerable variability within the population. These forces acting together in due course might have contributed to the evolution of many present day cultivars (Ravindran *et al.* 1990).

When male or female vines alone are present initially, the population developing out of it can be either a population of the vines of the same sex (clonal population of male or female vines), or a population of both sexes in the case of female vines. This population consists of the mother vine; its clonally propagated female vines, its seedling progenies consisting of both male and female vines, their subsequent progenies including intercrossed and backcrossed progenies (Ravindran *et al.* 1990).

Because of the absence of free gene flow, such populations will remain discrete and isolated from similar populations in neighbourhoods. Variations in such populations occur mainly by: (i) recombination and segregation (ii) chance crossing followed by segregation (iii) variation due to chance mutations, which will remain fixed as a result of the vegetative reproduction and (iv) isolation of discrete populational segments and the subsequent divergence of such units (Ravindran *et al.* 1990).

Quite often good fruit setting was noted in many isolated female plants of *P. attenuatum, P. argyrophyllum, P. hymenophyllum, P. nigrum,* etc. The absence of any pollen parent in the vicinity of such vines makes one to suspect apomixis as the probable cause of such high seed setting. This needs further investigation.

BIOSYSTEMATICS

Biosystematical studies were carried out in *Piper* spp. by Rahiman and Subbaiah (1984) who made a preliminary comparative flavonoid analysis of eight species of *Piper*, while Rahiman and Bhagavan (1985) reported a preliminary biometrical study using D^2 Statistics. Ravindran (1991), Ravindran *et al.* (1992) and Ravindran and Nirmal Babu (1994b, 1996) carried out detailed biosystematic studies on *Piper* spp. closely related to cultivated pepper, using numerical and chemical methods. They used 17 Operational Taxonomic Units (OTUs) comprising 10 species and seven accessions of *P. nigrum* and 30 characters to carry out Cluster Analysis and Principal Component Analysis for establishing similarity/dissimilarity among the taxa. Two cluster analysis techniques were used viz. the Average Linkage Analysis or the Unweighted Pair Group Method using Arithmetic Averages (UPGMA) for clustering the characters and the Centroid Linkage Analysis or the Unweighted Pair Group Centroid Method (UPGCM) for clustering the taxa. They reported highly significant correlations among certain characters, and the analysis led to six character clusters. They are:

1. Leaf length, leaf breadth, leaf size index
2. Fruit taste, presence of gall forming thrips
3. Leaf length/leaf breadth index, number of ribs on the leaf, ecological distribution, growth habit
4. Spike length, peduncle length, spike orientation, fruit shape
5. Leaf length/spike length ratio and spike shape
6. Leaf shape, leaf base.

The characters within each cluster are highly correlated (Ravindran 1991, Ravindran *et al.* 1992a). The clustering of taxa carried out by centroid linkage method led to six clusters. They are:

Cluster A – *P. attenuatum, P. argyrophyllum*

B – *P. schmidtii, P. galeatum, P. trichostachyon*
C – *P. nigrum, P. wightii*
D – *P. hymenophyllum*
E – *P. silentvalleyensis, P. mullesua*
F – *P. longum*

The first cluster consisted of *P. attenuatum* and *P. argyrophyllum.* Hooker (1886) included them under the section Eupiper. In a D^2 analysis by Rahiman and Bhagavan (1985) employing five characters these two species were found to cluster with *P. hookeri* (Syn. *P. hymenophyllum*). But in cluster analysis *P. hymenophyllum* forms an independent cluster. *P. galeatum, P. trichostachyon* and *P. schimdtii* clustered together. The first two are closely related and treated accordingly by Hooker (1886) and Gamble (1925). *P. schmidtii,* though a distinct high elevation species, shares certain morphological characters with the other two. Hooker (1886) included these three species in two sections the first two in section Muldera and the third one *(P. schmidtii)* in section Pseudochavica. The major character differentiating *P. schmidtii* from the other two is the nature of bracts, but also has thicker leaves and occupy a higher altitudinal niche.

All *P. nigrum* collections including *P. nigrum* var. *hirtellosum* were in one cluster together with *P. wightii*. Hooker (1886) included *P. nigrum* in the sect. Eupiper along with *P. attenuatum, P. argyrophyllum, P. hymenophyllum,* and *P. wightii*. But *P. nigrum* is quite distinct from all these species except *P. wightii* both morphologically and chemically. In other words the inclusion of *P. nigrum* with other species in one section is not supported by the cluster analysis. *P. hymenophyllum* forms the fourth cluster, which is distinct due to pubescence present throughout the plant body. *P. silentvalleyensis* and *P. mullesua* formed one cluster. The former is unique in having erect, flexuous, filiform spike and bisexual flower. *P. mullesua* is included in the section Chavica by Hooker (1886) and is the only species in the region having globose spikes. These two species resemble very much in most vegetative characters, and indistinguishable in the absence of spikes. *P. longum* forms the last cluster and is very distinct from all other species in having creeping habit (all others being climbers), erect cylindrical spikes and laterally fused flowers. This species is also distinct in its anatomical characters (Murty 1959). *P. hapnium* (though not included in the above study) is closely related to *P. longum* but differs from it in the climbing habit of the former.

Ravindran and Nirmal Babu (1996) using the principal component analysis identified seven Principal Components (PC) that accounted for almost all the variance observed among the OTUs. The first PC consists of leaf and fruit characters (leaf length, leaf breadth, leaf size index, petiole length, distance from the base to the second pair of ribs, plant type, fruit colour, fruit taste and thrips infestation). The second PC consists of spike length, peduncle length, spike orientation and fruit shape. The third PC consists of leaf length/leaf breadth index, rib number, growth habit and distribution. The fourth PC consists of bract type. The fifth PC consists of leaf length/spike length index and spike shape. The sixth PC consists of guard cell length, guard cell breadth, and leaf texture. The seventh PC consists of spike texture.

Distribution of OTUs between the PCs can give insight into the nature of divergence among species. *P. attenuatum* and *P. argyrophyllum* get differentiated from others mainly by PCs 2 and 4, while PC 6 differentiates *P. argyrophyllum* from others. *P. galeatum* gets separated from other taxa by PC 4. *P. hymenophyllum* gets differentiated by virtue of PCs 1 and 6. *P. longum* is distinct because of PCs 1 and 3. *P. mullesua* is distinct from all other species due to PCs 2, 3 and 5. PCs 1, 2, 3, 4, 6 and 7 are important in differentiating *P. schmidtii,* PC 4 being the most important. PCs 2, 3 and 5 are important in separating *P. silentvalleyensis* from all the other taxa. *P. trichostachyon* gets separated from other taxa by virtue of PCs 4 and 7. PC 1 is important in separating *P. nigrum* from other taxa, while PC 7 separates *P. nigrum* var. *hirtellosum* from *P. nigrum* itself (Ravindran 1991, Ravindran and Nirmal Babu 1996).

A comparative study using flavonoid profile by Ravindran (1991) and Ravindran and Nirmal Babu (1994 b) indicated the following chemical affinities:

P. galeatum	–	*P. trichostachyon*	87 per cent
P. attenuatum	–	*P. argyrophyllum*	79 per cent
P. argyrophyllum	–	*P. hymenophyllum*	78 per cent
P. galeatum	–	*P. sugandhi*	82 per cent
P. longum	–	*P. mullesua*	69 per cent
P. longum	–	*P. silentvalleyensis*	35 per cent
P. mullesua	–	*P. silentvalleyensis*	57 per cent

These chemical relationships by and large supports the taxonomical relationships arrived at by conventional tools. The members of the two sub genera are chemically very distinct, thereby lending support to the validity of the subgeneric classification (Ravindran and Nirmal Babu 1996).

Isozyme studies (Sebastian *et al.* 1996) showed three groups of closely related species. The first group included *P. nigrum, P. pseudonigrum, P. bababudani,* and *P. galeatum*. The second group consisted of *P. chaba, P. hapnium* and *P. colubrinum. P. argyrophyllum* and *P. attenuatum* formed the third group. *P. longum* and *P. betle* were distinct from all others. The reliability of isoenzyme studies in elucidating taxonomic relationships is doubtful, because a very distant species such as *P. colubrinum* is grouped with two other species which are morphologically and cytologically quite distinct. Moreover Sebastian and Sujatha (1996) found that the isozyme patterns of peroxidase and esterase are different in different plant parts and vary according to the developmental stage.

Morphometric Analysis of Black Pepper Cultivars

Cluster analysis

Ravindran (1991) and Ravindran *et al.* (1997a,b) reported cluster analysis of 44 major cultivars and seven wild collections of *P. nigrum* (51 OTUs) using 22 characters. The analysis led to the following groupings:

A: *Aimpiriyan, Kalluvally (Pulpally)*

B: *Poonjaranmunda, Thulamundi*
C: *Karivilanchy, Kallubalancotta, Uddaghere, Uthirancotta, Vellanamban, Valiakaniakkadan, Velliyaranmunda*
D: *Cheriyakaniakkadan, Neyyattinkaramundi, Arimulaku, Kaniakkadan, Thommankodi, Kuching, Mundi, Bilimalligesara, Vattamundi, Malamundi, Ottaplackal* 1, *Neelamundi, Perambramunda, Thevanmundi, Sugar Local, Perumkodi, Kalluvally* (2), *Kurimalai, Kottanadan, Arakkulam munda, Jeerakamundi, Cholamundi, Cheppukulamundi, Karimkotta,* Wild coll: 2077, 2060, 2071, 2015
E: *Balankotta,* Wild coll: 2059, 2062, 2009
F: *Narayakodi, Kuriyalmundi*
G: *Karimunda*
H: *Vokkalu, Nedumchola*
I: *Kuthiravally*
J: *Vadakkan*
K: *Panniyur* 1

The pattern of grouping shows that 28 of the 51 cultivars fall in just one group, and four groups have just one cultivar each. Thus *Karimunda, Kuthiravally, Vadakkan* and *Panniyur* 1 are in unique groups. Among these *Panniyur* 1 is a hybrid, and *Vadakkan* a natural triploid. *Karimunda,* the original home of which is the Kottayam district of Kerala, is the most popular cultivar. *Kuthiravally* is also a popular cultivar in certain areas. Twenty eight cultivars clustered into a single group (D) and the differences among them for the 22 characters studied are small and they are very difficult to be distinguished when grown together in a field. Computation of intercluster D^2 values showed that cluster D is closely related to clusters A, B and C, indicating that though these cultivars are included in separate groups based on cluster analysis, all of them probably could have derived from common ancestors. On the other hand 23 cultivars are in ten groups thereby indicating significant morphological divergence among them. The very distinctive nature of these cultivars (which also include very popular ones) probably indicates that domestication of black pepper from the forest grown wild plants could have started at many centres isolated in space and time (Ravindran and Nirmal Babu 1988, Ravindran 1991).

Principal component analysis

Ravindran (1991) and Ravindran *et al.* (1997a, b) carried out principal component analysis to bring out the characters that are mainly responsible for the divergence among the cultivars. They identified eight Principal Components (PC) that accounted for most of the variations occurring among the cultivars and thus are involved in their divergence. The eight principal components are:

1. Leaf size index, leaf length, leaf breadth
2. Leaf thickness, lower epidermal thickness, upper epidermal thickness
3. Leaf length- spike length ratio, spike length, peduncle length

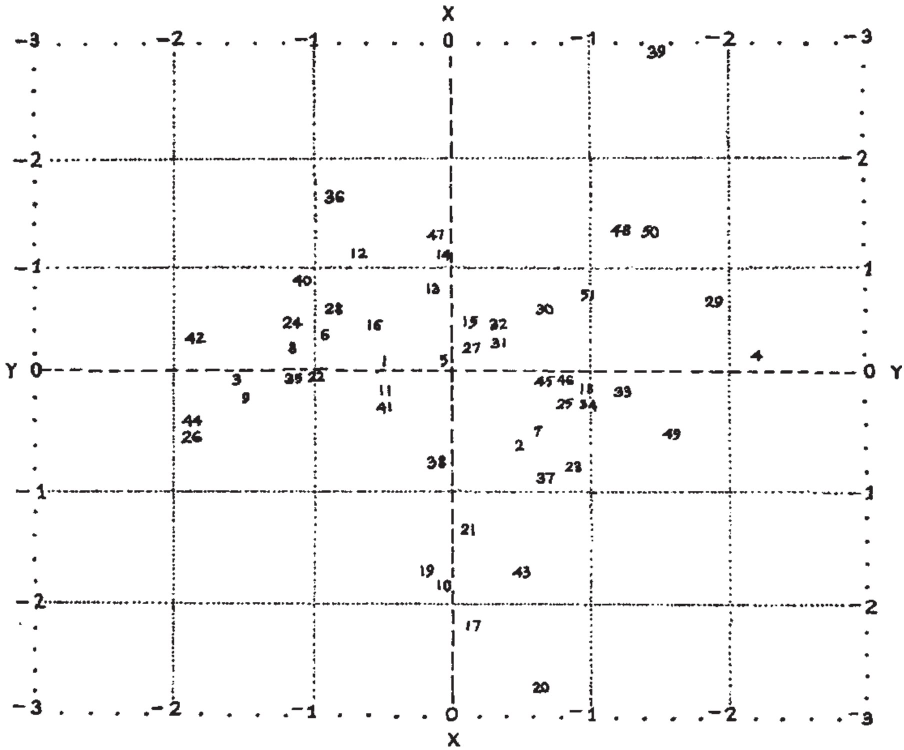


Figure 2.1 Distribution of OTUS between the 1st and 2nd principal components 1. Aimpiriyan; 2. Arakkulammunda; 3. Arimulaku; 4. Balancotta; 5. Bilimalligesara; 6. Cheriyakaniakkadan; 7. Cheppukulamundi; 8. Cholamundi; 9. Jeerakamundi; 10. Karimunda; 11. Kaniakkadan; 12. Karivilanchy; 13. Karimkotta; 14. Kalluvally (Pulpally); 15. Kalluvally (2); 16. Kallubalancotta; 17. Kottanadan; 18. Kuching; 19. Kuriyalmundi; 20. Kuthiravally; 21. Kurimalai; 22. Malamundi ; 23. Mundi; 24. Narayakkodi; 25. Neelamundi; 26. Nedumchola; 27. Neyyattinkaramundi; 28. Ottaplackal (No. 812); 29. Panniyur-1; 30. Perambramunda; 31. Perumkodi; 32. Poonjaranmunda; 33. Sagar Local; 34. Thevanmundi; 35. Thommankodi; 36. Thulamundi; 37. Udakkere; 38. Uthirancotta; 39. Vadakkan; 40. Valiakaniakkadan; 41. Vattamundi; 42. Vellanamban; 43. Velliyaranmunda; 44. Vokkalu; 45. *P. nigrum* (wild); (Acc. 2077); 46. *P. nigrum* (wild) (Acc. 2071); 47. *P. nigrum* (wild) (Acc. 2009); 48. *P. nigrum;* (wild) (Acc. 2059); 49. *P. nigrum* (wild) (Acc. 2060); 50. *P. nigrum* (wild) (Acc. 2015); 51. *P. nigrum* (wild) (Acc. 2062).

4. Guard cell length and guard cell breadth
5. Fruit size and fruit shape
6. Leaf shape and leaf base
7. Stomatal frequency and mesophyll thickness
8. Leaf shape (orthotropic shoot) and colour of the emerging runner shoot tip.

In order to study the relative positioning of the cultivar in relation to the PCs, it is worthwhile to plot the cultivars against the PCs taken two each at a time. Such a PC plot gives a visual idea on the contribution of each of the PC in differentiating the different OTUs. Fig. 2.1 gives the dispersion of the 51 cultivars (OTUs) between first and second PCs. This dispersion diagram indicates that: OTU 29 (*Panniyur* 1) has large difference both with regard to X and Y coordinates indicating that both first and second PCs are important in differentiating this cultivar from others. OTU 4 *(Balancotta)* exhibits large differences from X-coordinate thereby indicating that the first PC is important in differentiating this cultivar. OTUs 39 and 49 (*Vadakkan* and wild acc: 2060) have large differences with regard to X-coordinate thereby showing that these cultivars get differentiated from others mainly due to first PC. OTU 42 *(Vellanamban),* 26 *(Nedumchola),* 44 *(Vokkalu)* and 3 *(Arimulaku)* show large negative differences from the X-coordinate, indicating that these characters forming the first PC are important in differentiating them from other OTUs. OTU 5 *(Bilimalligesara)* has large negative difference in the Y-coordinate representing the second PC, while OTU 37 *(Uddaghere)* has large positive difference from the Y-coordinate. This PC therefore is important in differentiating the OTUs 5 and 37 from all others.

Similar studies also indicated that *Karimunda* gets differentiated from other cultivars based on leaf anatomical and stomatal characters; cultivar *Kuthiravally* gets delineated from others by leaf and spike characters, and the natural triploid cultivar *Vadakkan* is divergent from others by virtue of leaf morphology, leaf anatomy, spike and stomatal characters. This cultivar has the broadest stomata and the boldest fruits. Inter and intra cluster D^2 analysis led to the following conclusions. (Ravindran 1991; Ravindran *et al.* 1997a, b).

1. PC 1 delineates the cluster H from the group of clusters E, I, J and K, also from the group of clusters A, B, C, D, F and G. The group of clusters E, I, J and K can be considered as distinct from the group of clusters A, B, C, D, F and G though the distinction is only marginal.
2. PC 2 joined the clusters B and C and separated them from the rest (A, D, E, F, G, H, I, J and K). In other words, the nine cultivars represented in cluster B and C are distinct from the remaining OTUs as far as PC 2 is concerned.
3. PC 3 joined the cluster F and H and delineated them from the remaining OTUs.
4. PC 4 delineated the original group of 11 clusters into four groups, where the cluster F and J are quite distinct between themselves as well as from others. The clusters G and I could be joined with respect to PC 4 and the rest (ie, A, B, C, D, E & K) could be joined as another group of clusters.
5. PC 5 delineated cluster H and F and also these two clusters from the rest.
6. PC 6 could join the cluster E and G and separate them from the rest.
7. PC 7 could show cluster K as a separate group from the rest
8. PC 8 formed three major groups of clusters, A & K, B, I and F and clusters C, D, E, H & J.

Thus the original 11 clusters were grouped into 8 individual PCs as summarized below:

PC1	(A, B, C, D, F, G) (E, I, J, K) (H)
PC2	(B, C) (A, D, E, F, G, H, I, J, K)
PC3	(F, H) (A, B, C, D, E, G, I, J, K)
PC4	(A, B, C, D, E, H, K) (G, I) (F) (J)
PC5	(A, B, C, D, E, G, I, J, K) (F) (H)
PC6	(A, B, C, D, F, H, I, J, K) (E, G)
PC7	(A, B, C, D, E, F, G, H, I, J) (K)
PC8	(A, K) (B, F, I) (C, D, E, G, H, J)

This study helps to recognize the underlying similarities among the cultivars. At the same time, the existence of distinct groups also pointed out the fact that all the cultivars could not have originated from a common stock but that their origins were probably separated in space and time, as indicated earlier (Ravindran *et al.* 1997a, b).

Chemical Affinity Among Cultivars

Ravindran (1991) has carried out a comparative chemical study on pepper cultivars based on flavonoid profiles in which he analysed forty four cultivars and seven wild *P. nigrum* collections to find out the chemical relationships among them. The chemical similarities worked out among all the combinations of 51 OTUs have shown that only three combinations gave more than 90 per cent chemical affinities: they are *Karivilanchy* and *Sugar Local, Arimulaku* and *Valiakanikkkadan, Kuthiravally* and *Thommankodi*. Reasonably high chemical affinities were noticed (>80%) in the following cases:

Mundi and *Narayakodi, Neyyattinkaramundi* and *Perambramunda, Jeerakamundi* and *Thevanmundi, Karimkotta* and *Vadakkan, Kalluvally* and *Thulamundi, Mundi* and *Thevanmundi, Mundi* and *Thulamundi, Mundi* and *Vokkalu, Mundi* and wild acc. 2077, *Mundi* and wild acc. 2071, *Malamundi* and *Vellamunda, Narayakkodi* and *Thulamundi, Narayakkodi* and wild acc. 2071, *Sagar Local* and *Thulamundi, Thommankodi* and *Vokkalu, Thommankodi* and wild acc. 2074, *Kalluvally* and *Sagar Local, Neelamundi* and *Thevanmundi, Thulamundi* and *Vellanamban*.

Many of these combinations showing high chemical affinity are in fact included in the same cluster in the cluster analysis. The lowest chemical affinities were noticed between *Cholamundi* and *Kurimalai, Vadakkan* and *Velliyaranmunda, Kuthiravally* and wild acc. 2062. In all these cases the affinity was below 30 per cent (Ravindran 1991, Ravindran *et al.* 1997a, b).

GENERAL MORPHOLOGY AND ANATOMY

Black pepper is a perennial climber, climbing on support trees with the help of aerial clinging roots. As the pepper plant grows over a support tree it produces two developmentally different types of branches i.e. pepper exhibits dimorphic branching. They are the straight, upward growing, monopodial, orthotropic branches, and the sympodial, laterally growing, plagiotropic fruiting branches. The main stem or orthotropic shoot climbs up the support, it has indefinite growth and undergoes branching producing fruiting lateral branches. Each node provides clinging roots and they help in anchoring the climbing plant onto the support tree, and these roots in presence of copious rain fall can grow in length, and when come into contact with a rooting medium can develop into normal underground roots. The orthotropic shoots grow in thickness by an anomalous type of secondary thickening. From the axils of leaves of orthotropic shoot, lateral plagiotropic branches arise and they have sympodial growth habit. As the shoot grows the terminal bud gets modified into a spike and the growth is further continued by the axillary bud. As the axillary branch develops, it pushes out the developing spike which then becomes leaf opposed. The lateral branches do not produce aerial roots and the leaf size and shape often show variations from those of the orthotropic shoot. Because of the strong tropophysis, these two branches behave differently when planted; the orthotropic shoot produces a normal pepper plant climbing on a support and producing laterals from the base itself, while the plagiotropic shoot produces a bushy plant producing further plagiotrops, flowers and fruits.

The orthotropic shoots occasionally produce axillary branches that exhibit monopodial growth habit. They do not undergo branching as the orthotropic shoot, and do not usually produce any clinging roots on the nodes. They are positively geotropic, grow downward and hence called hanging shoots. When they come into contact with soil and if moisture is available, they produce roots at the nodes and trail on the ground or climb up neighbouring trees or shrubs. When used for propagation they grow lanky and produce lateral branches only at the top.

Pepper plants also produce adventitious runner shoots from the base especially during the rainy season or when the soil moisture availability is high. They have prominent aerial root initials on the nodes and on coming into contact with soil, strike root quickly. These shoots trail on the ground and climb up when they come into contact with a support. These runner shoots are the common planting materials and used extensively for clonal propagation.

Leaves

Pepper leaves are variable both in size and shape; still these characters are major features distinguishing the various cultivars and hence useful in cultivar identification. In most cases the juvenile leaves on the emerging orthotropic and runner shoots differ from the normal leaves found on the lateral fruiting branches, both in shape and size. Leaf is dorsiventral, having prominent veins (often described as ribbed), the veins starting from the base or near the base and ascend to the apex. Leaf size varies much among the cultivars, length varying from an average 8.8 cm (cv. *Nedumchola*) to 19.0 cm (cv. *Balankotta*) or more; leaf breadth from 4.7 cm (cv. *Nedumchola*) to 10.2 cm (cv. *Panniyur* 1) or more. Leaf size index is highest in cv. *Balankotta* (81.45) and lowest in cv. *Nedumchola* (40.0). Leaves are glabrous, thick coriaceous, upper surface dark green, lower surface lighter green. Kanakamony *et al.* (1985) used the differences in the green shades of the abaxial and adaxial surfaces for cultivar classification. But when the cultivars are grown under identical conditions the distinction in leaf colour among the cultivars is quite insignificant except in a few cases such as *Balancotta* or *Panniyur* 1.

Leaf sheath and prophyll

In runner shoots and orthotropic climbing shoots the young shoot tips are protected by the sheathing petiole of the leaf. While in the plagiotropic flowering shoots, the shoot tip and spike emerge from within a cap like structure.These structures are the prophylls, which are the modified first leaf of the axillary branch. Generally dicots have two prophylls, but *Piper* has only one. The prophyll subtends the axillary branch and the emerging spike. Prophyll is associated with the sympodially growing, flowering node, while the leaf sheaths are characteristic of the vegetative node (Fig. 2.2). The prophyll falls off with the emergence of the bud and spike. The leaf sheaths, which are extensions of the petiole are caducous in black pepper and the related taxa

Figure 2.2 Vegetative and flowering nodes (1) shoot tip of monopodial branch showing sheathing petiole and emerging apical bud; (2–4) prophyll and the emerging spike p—prophyll, sp—spike, If—leaf, bu—bud growing from the axil of leaf.

but are persistent in certain species. The prophylls are microscopically hairy in certain cultivars, while in others they are not. Leaf sheaths are absent in certain species such as *P. colubrinum*.

Burger (1972) in his study on Central American *Piper* observed that in majority of the new world species of *Piper,* the prophyll formed a protective cap at the flowering nodes and came to the conclusion that the presence of prophylls may not be indicative of species closeness, as they may have originated independently more than once within the genus. He also distinguished two types of prophylls among the Central American species. One type is glabrous or less often puberulent throughout the abaxial surface and oblique apically. The more common type of prophyll is acute at the apex and usually minutely puberulent along the mid rib abaxially. Among the South Indian taxa of *Piper,* the prophylls are acute at the apex and microscopically hairy in certain species such as *P. longum, P. argyrophyllum, P. trichostachyon* and *P. galeatum,* while in *P. hymenophyllum* the prophylls are profusely hairy. In *P. nigrum* cultivars the prophylls are microscopically hairy in some while in others they are glabrous.

The sheathing leaf base in *Piper* has been described as adnate stipules by many workers (Rahiman 1981, Chandy *et al.* 1984, Ibrahim *et al.* 1985f). But Majumdar and Pal (1961) provided anatomical evidence to show them to be leaf bases. Stipules when present are outgrowths at the base of the leaf and their vascular supply (stipular trace) normally derives from the laterals of a three bundle leaf trace. This view was supported by Mitra (1945, 1949), Mitra and Majumdar (1952), Majumdar (1956), Majumdar and Pal (1958, 1961) and Pal (1961). It has been shown that in *Piper* (including *P. nigrum*) leaves, the foliar base completely encircles the stem and the free margins overlap each other to from the “wrap over” and the margins receive their vascular supply directly from the nodes below. The free tip of the leaf sheath may be considered a ligule and not as a stipule, because the extreme end of the free tip does not get any vascular supply (Murty 1959).

Leaf morphological variation

The shape and size of leaf lamina are very variable in *Piper*. Mainly five lamina shapes viz. ovate, ovate-elliptic, ovate-lanceolate, elliptic-lanceolate and cordate can be distinguished (IPGRI 1995). The lamina shape differs between the orthotropic and plagiotropic branches in most cases. Again in the juvenile shoot also the size and shape are distinctly different in certain species, as in *P. mullesua* and *P. silentvallyensis,* where the leaves on the emerging juvenile shoots are very small and cordate. The leaves on the plagiotropic fruiting laterals show more stable characters and the description of varieties and species are based on them. In *P. barberi* the juvenile shoots are leafless, only minute scale leaves are present on the nodes.

The leaf bases are either round, cordate, acute or oblique and in certain cases attenuate. Leaf tip is usually acute or acuminate. Leaf margins are either even (entire) or wavy (repand). Leaf texture can be glabrous coriaceous, glabrous membraneous, glabrous sarcous, downy membraneous, downy coriaceous or downy along the veins. Leaves can be hirtellous, or pubescent all over the leaf or the hairs are restricted along

Table 2.4 Leaf morphological characters of *Piper* species.

Species	*Leaf shape*	*Leaf base*	*Leaf texture*	*Leaf nature*
P .attenuatum	Ovate to ovate elliptic	Round to attenuate	Glabrous	Membraneous
P. argyrophyllum	Ovate to ovate elliptic	Round	Sparsely hairy on ribs	Membraneous
P. galeatum	Ovate to lanceolate	Round	Glabrous	Coriaceous
P. hymenophyllum	Ovate-to-elliptic	Round	Hirsute	Membraneous
P. longum	Cordate	Cordate	Glabrous	Membraneous
P. mullesua	Elliptic to elli-lanceolate	Acute	Glabrous	Membraneous
P. schmidtii	Ovate to-elliptic	Round	Glabrous	Coriaceous
P. silentvalleyensis	Elliptic to elli-lanceolate	Acute	Glabrous	Membraneous
P. sugandhi	Ovate	Round	Glabrous	Coriaceous
P. sugandhi var.*brevipilis*	Ovate	Round	Glabrous	Coriaceous
P. trichostachyon	Ovate to lanceolate	Acute	Glabrous	Coriaceous
P. wightii	Ovate	Round	Glabrous	Coriaceous

the veins. (Table 2.4) Silvery scales are present in a few cases, while absent in most. Leaf venation can be classified as either acrodromous, campylodromous or eucamptodromous, the first one is seen in *P. attenuatum* and the last one in *P. barberi,* in most other species the second type of venation in seen.

Leaf anatomy

Pepper leaf is glabrous, thick and coriaceous. The leaf is dorsi-ventral, dark green on the upper surface, lighter green on the lower surface. The leaf epidermis is made up of small rectangular cells, beneath which is a hypodermis made of 2–3 layers of large rectangular cells. The hypodermis on the abaxial (lower) surface consists usually of two layers, while on the adaxial surface it is usually 3-layered. The adaxial (upper) hypodermal cells are larger than those in the abaxial surface. The cuticle over the epidermis is corrugated in T.S. The palisade is relatively narrow, composed of just one row of cells. The spongy tissue is composed of 3–4 rows of round to irregularly shaped cells. Both palisade and spongy cells contain discoid chloroplasts, 5–10 per cell in the former, 2–5 in the latter. Mucilage canals filled with mucilage are seen inside the mesophyll, often close to the vascular supplies.

Wax glands or pearl glands (pearl gland trichomes) are present on the upper and lower surfaces of the leaf. Each gland located inside a depression in the epidermis consists of a stalk and a globose head (Fig. 2.3). The gland contains dark contents. When the leaves are young, the glands are active and secrete white, shiny wax globules,

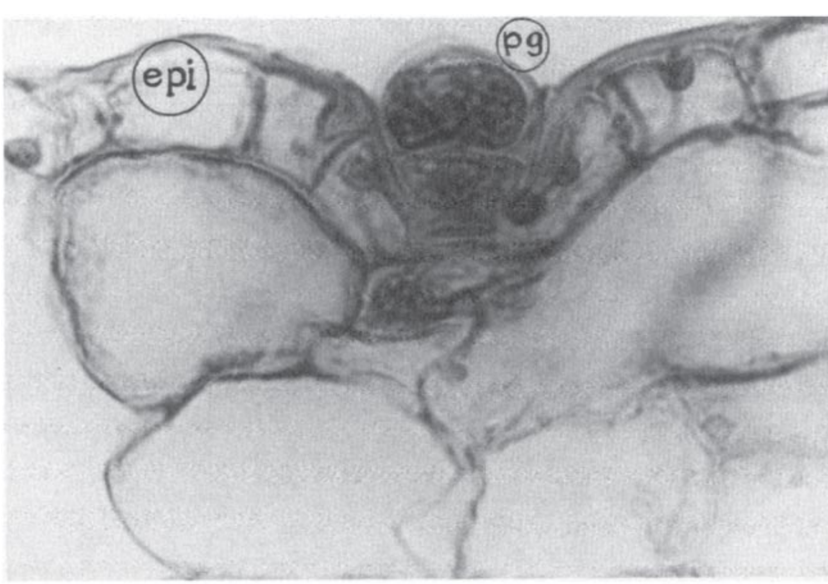


Figure 2.3 A pearl gland (wax gland) trichome. epi—epidermis, pg—pearl gland.

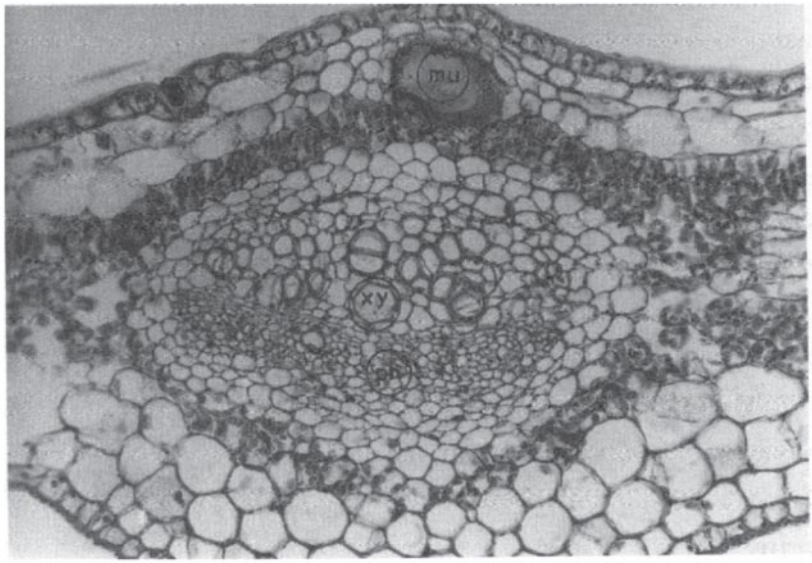


Figure 2.4 T.S. of leaf through the vein showing the vascular elements and the mucilage canal, xy—xylem, ph—phloem, mu—mucilage canal.

which in course of time turns black. The wax secretions are found to be profuse in certain cultivars such as *Panniyur* 1, but very scanty or absent in many others.

The T.S. through the vein shows vascular cylinder, having a distinct bundle sheath, 5–7 rows of xylem elements and a small group of phloem. In between the xylem and phloem there are 2–3 layers of well developed cambial cells. The xylem consists of tracheids and xylem parenchyma (Fig. 2.4).

Leaf anatomical features of other Piper spp.

Datta and Dasgupta (1977a, b) studied the leaf anatomical features of *P. nigrum, P. longum, P. cubeba* and *P. betle* and found that basically they share the same anatomical features, the differences noticed are all minor ones only. Table 2.5 gives the comparative leaf anatomical features of these four economically important *Piper* species.

Stomata and Stomatal Ontogeny

Stomata occur only on the lower side of the leaf (hypostomatic). Stomata are anisocytic and amphicyclic, surrounded by 1–2 rings of subsidiary cells (Fig. 2.5), but 5–6 cells are also commonly encountered. Pant and Banerji (1965) studied the stomatal ontogeny in *Piper betle*. They described the development as mesoperigenous but variations do occur commonly. They reported the stomatal

Table 2.5 Comparative leaf anatomical features of economically important *Piper* species.*

Characters	*1* *P. nigrum*	*2* *P. longum*	*3* *P. cubeba*	*4* *P. betle (a)*	*5* *P. betle (b)*
Epidermis	1-layered, normal	1-layered, papillose on the abaxial surface of major vein	1-layered, normal	As in 2	As in 2
Epidermal cells	Rectangular	Elliptical	Rectangular	Elliptical	Rectangular
Stomatal index (mean)	3.44	7.51	3.22	10.84	5.51
Hypodermis (abaxial)	1–2 layered	1-layered	Absent	2–3 layered	2–3 layered
Hypodermis (adaxial)	2–3 layered	1-layered	1-layered	2–3 layered	2–3 layered
Palisade	1-layered	1-layered	1-layered, 2-layerednear veins	1-layered	1-layered
Spongy tissue	Less compact with small intercellular spaces	As in 1	Compact, little intercellular space	As in 1	As in 3
Vein region chlorenchyma	Multi layered chlorenchyma	As in 1	Absent	As in 1	Absent
Abaxial sclerenchyma cap	Absent	Present	Small patch only	Small patch only	Present
Chlorenchymatous adaxial hypodermis	Present, 4–6 layers	Present, 1–2 layers	Absent	Absent	Present, 4–6 layers
Vascular bundles	Open, collateral	As in 1	As in 1	As in 1	As in 1
Cambium zone	3–4 layered	3–4 layered	2–3 layered	3–5 layered	1–2 layered
Tracheary elements in T.S.	± 20	± 30	± 20	± 25	± 20
Tracheary elements per bundle	± 14	± 14	± 74	± 8	± 8
Phloem: xylem	Equal	Equal	Smaller phloem	Equal	Equal
Central mucilage canal	Present	Absent	Absent	Absent	Absent

*Source: Datta and Dasgupta (1977a, b)

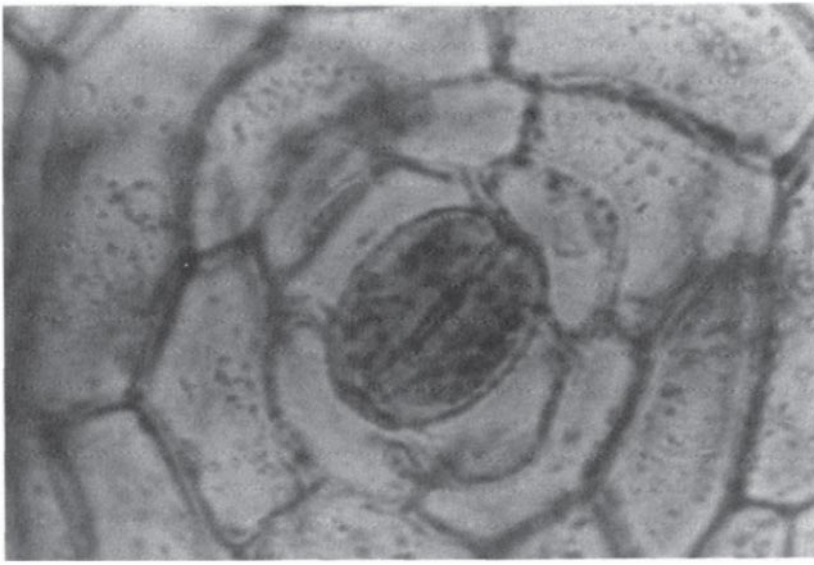


Figure 2.5 A stoma showing guard cells and four subsidiary cells.

formation as "mixed type" where new meristemoids differentiating in successive waves between older ones or between mature stomata. In this mesoperigenous development the meristemoid divides unequally to form a large and a small cell. The latter shows a prominent nucleus and darker staining cytoplasm and it divides once again by a wall placed at right angles to the first to form two smaller cells which are more or less rectangular. One of these becomes the guard cell mother cell and the two other mesogene cells formed by the above divisions become the neighbouring cells flanking the two sides of the guard cell mother cell. The subsidiary cells for the other two sides are provided by the perigene neighbouring cells. The guard cell mother cell now enlarges and divides medianly to form two guard cells. Meantime the mesogene and perigene neighbouring cells divide to form the characteristic rosette of cells found in the mature stomata.

Ravindran (1991) studied the stomatal development in black pepper. Here the stomatogenesis begins when one of the protoderm cells enlarges and gets differentiated into a meristemoid having an iso-diametric shape. This undergoes an anticlinal division giving rise to two cells one of which becomes subsidiary cell and the other undergoes a periclinal division. One of the daughter cells becomes the second subsidiary cell and the other cell undergoes another periclinal division. The daughter cell formed towards the outside becomes the third subsidiary cells. Now the inner cells undergo a transverse division, the outer cell then becomes the fourth subsidiary cell and the inner cell become the guard cell mother cell. This guard cell mother cell enlarges and divides periclinally producing the guard cells. The enlargement of the guard cell pushes apart the subsidiary cells which then becomes a whorl surrounding the guard cell. The subsidiary cells may undergo anticlinal or periclinal divisions or both in some cases thereby increasing the number of cells as well as the whorls of cells. Here the stomatal development in mesogenous as the guard cells and subsidiary cells develop from the same meristemoid.

Variation in stomatal characters

The stomatal frequency in pepper cultivars varies much from 61/mm^2 in cv. *Karimunda* to 130/mm^2 in cv.*Vadakkan*. The cultivars with high stomatal frequency are *Vadakkan* (130), *Bilimalligesara* (125), *Kaniakkadan* (129), *Uthirancotta* (127), *Vattamundi* (127), *Vokkalu* (126), *Nedumchola* (122), *Perambramunda* (125) and *Sagar Local* (123). The low frequency group includes *Karimunda* (61), *Arakkulammunda* (79), *Balancotta* (82), *Karimkotta* (86), *Malamundi* (85), *Neelamundi* (85), *Ottaplackal* (80), *Thulamundi* (81) and *Valiakanikkadan* (81). Among the related taxa the highest stomatal frequency is in *P. schmidtii* (104), the lowest in *P. attenuatum* (68) (Table 2.6)

The length of guard cells varies form 0.022 mm in cv. *Kottanadan, Kuriyalmundy* and *Kuthiravally* to 0.028 mm in *Thulamundi*. The guard cell breadth varies from 0.015 mm in cv *Velliyaranmunda* to 0.025 mm in *Vadakkan*. In the related taxa the length varies from 0.023 mm in *P. longum* to 0.033 in *P. hymenophyllum* and guard cell breadth from 0.16 mm in *P. schmidtii* and *P. trichostachyon* to 0.02 mm in *P. hymenophyllum*.

The Petiole

The petiole is grooved on the upper surface. The epidermis is made of hexagonal cells, the cuticle is thick and corrugated in appearance. Below the epidermis there is a band of collenchyma, followed by 10–12 rows of parenchymatous cells. The central position is occupied by a mucilage cavity. The vascular bundles are distributed in semi circular fashion. They are open, collateral and enclosed in a parenchymatous bundle sheath. The bundles just below the groove are very small (usually three in number) and each of them consists of 4–5 xylem elements only. On the two corners adjacent to the middle groove, there are two bundles larger than the others. Here the protoxylem elements are oriented towards the central mucilage cavity (endarch). The bundle opposite the groove is the largest, which along with the two adjacent bundles is located slightly towards the interior compared to the rest of the bundles. The xylem consists of vessels and tracheids, phloem of sieve tubes, companion cells and phloem parenchyma. Cambial zone consists of 2–3 layers of narrow elongated cells. Pearl glands are seen on the petioles. In the vegetative node the petioles are sheathed, which are extension of petiole towards the sides and these sheaths are caducous (Fig. 2.6)

Stem Anatomy

The dimorphic branches of pepper exhibit minor variations in their anatomical features, though the basic structure remains the same in both. The orthotropic stem

Table 2.6 Spike (female) characters of *Piper* spp. closely related to pepper.

Species	*Spike length (mm) (Mean)*	*Peduncle length (mm) (Mean)*	*Spike shape*	*Spike orientation*	*Spike texture*	*Bract type*
P. argyrophyllum	83.0	25.2	Filiform	Pendulous	Glabrous	Adnate
P. attenuatum	120.0	20.0	Filiform	Pendulous	Glabrous	Adnate
P. barberi	50.0	90.0	Cylindrical	Pendulous	Glabrous	Peltate, orbicular
P. hapnium	30.0	15.0	Cylindrical	Erect	Glabrous	Peltate, pedicelled
P. hymenophyllum	73.0	22.0	Filiform	Pendulous	Glabrous	Peltate, pedicelled
P. galeatum	105.0	17.4	Filiform	Pendulous	Glabrous	Connate, fleshy cup
P. longum	38.0	14.0	Cylindrical	Erect	Glabrous	Stalked, peltate, orbicular
P. mullesua	9.0	2.3	Globose	Erect	Glabrous	Stalked, peltate, orbicular
P. nigrum	105.0	10.7	Filiform	Pendulous	Glabrous	Shallow cup below the ovary
P. schmidtii	125.0	20.0	Filiform	Pendulous	Glabrous	Obconical, angular free margins
P. silentvalleyensis	40.0	1.3	Filiform	Erect	Glabrous	Stalked, peltate, orbicular
P. sugandhi	71.0	14.6	Filiform	Erect	Glabrous	Deeply cupular, stipitate
P. sugandhi var. *brevipilis*	69.0	14.0	Filiform	Pendulous	Hirtellous	Deeply cupular, stipitate
P. trichostachyon	76.0	15.3	Filiform	Pendulous	Hirtellous	Connate, fleshy cup
P. wightii	65.0	12.0	Filiform	Pendulous	Glabrous	Adnate with free margins

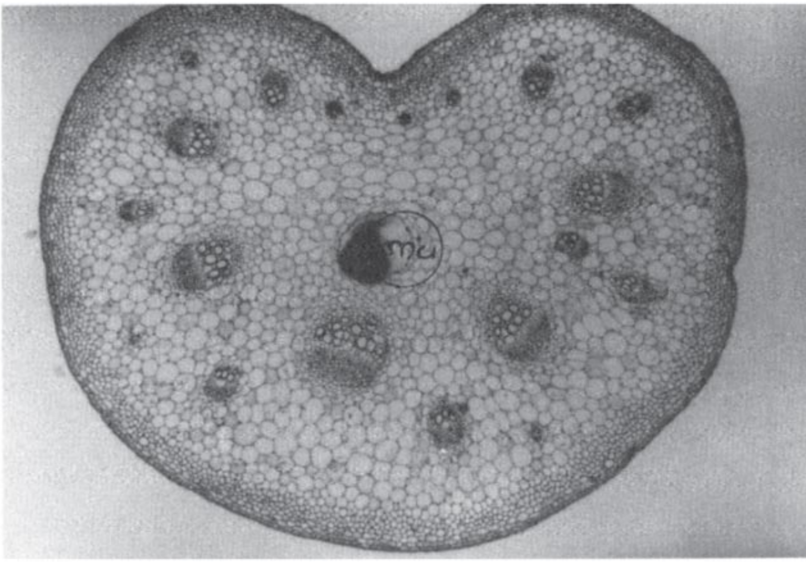


Figure 2.6 T.S. of leaf petiole showing the central mucilage canal (mu) and the vascular bundles.

(the monopodial main stem that climbs over support trees) exhibits faint longitudinal striations, resulting probably from the wavy band of vascular bundles and sclerenchyma. The anatomy of this stem is typical of that of Piperaceae and is the one studied most frequently (Metcalfe and Chalk 1950, Murty 1959, 1960, Pal 1961). The T.S. of the orthotropic stem reveals the following structure. The epidermis is made of rectangular cells over which there is a corrugated layer of cuticle. Below the epidermis there are 2–3 layers of collenchymatous hypodermis with many sclereids distributed in between the cells. A discontinuous band of sclerenchyma is seen inner to the collenchymatous hypodermis and this band consists of 4–6 rows. Just below the sclerenchyma band 2–3 layers of chlorenchymatous cells and 4–6 parenchymatous layers are present. The vascular bundles are scattered in pith region as in monocot stem and this according to Hutchinson (1959) is an indication of the Ranalean ancestry. The innermost row of the cortex consists of smaller cells arranged compactly forming an endodermis. A pericycle is visible in certain regions. The endodermis exhibits casparian thickening.

The most distinguishing feature of the pepper stem anatomy is the distribution of vascular bundles (Fig. 2.7). There is an outer ring of vascular bundles (cortical or peripheral bundles) and an inner ring of regular bundles (central or medullary bundles). The outer ring consists of small and large bundles arranged often alternatingly, they are collateral and open, and consist of a sclerenchymatous cap at the phloem end, below which lies phloem, cambium and xylem. There are 35–40 such bundles, each covered by an indistinct bundle sheath. The xylem consists of vessels, tracheids and fibres. The cambium consists of 3–4 rows of narrow elongated cells. The phloem is

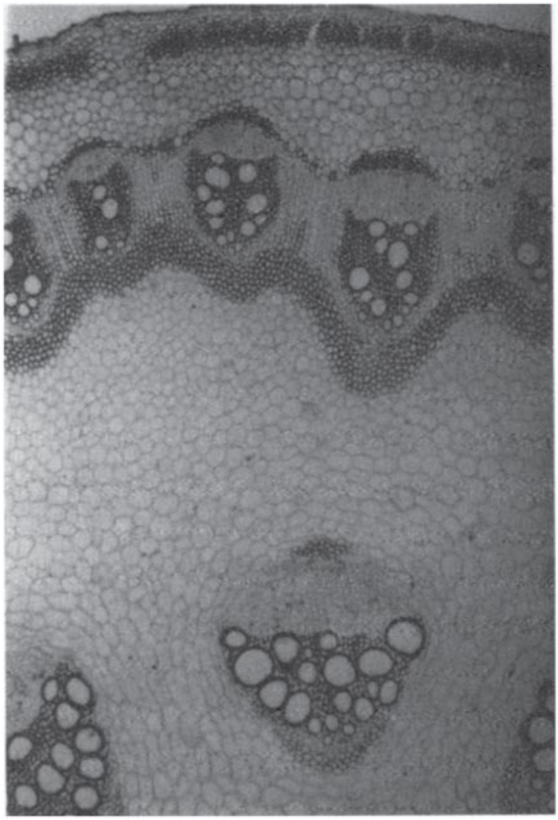


Figure 2.7 T.S. of stem showing the outer ring of vascular bundles and larger inner ring (medullary) of bundles.

comprised of sieve tubes, companion cells and phloem parenchyma. Below the peripheral vascular ring, there is a wavy band of sclerenchyma consisting of 5–6 rows of cells. The parenchymatous pith lies inside the wavy sclerenchymatous band, and consists of closely arranged parenchyma cells. Inside this region the medullary bundles are arranged. There are 8–10 bundles, larger than the cortical bundles. Each bundle has sclerenchymatous cap on either end. These bundles are also collateral and open. The xylem consists of vessels, tracheids and fibers. The average vessel and tracheid ratio is 8:3. Vessels are with pitted thickening and simple perforation plates, whereas tracheids are of scalariform and annular thickening type. Vessel ends vary from transverse to oblique and tails are absent at both sides. The cambium is 3–4 layered. The phloem consists of sieve tubes, companion cells and phloem parenchyma. The pith is very small, and at the centre of the pith there is a mucilage canal which forms a continuous canal traversing the entire plant body. This mucilage canal is lined with secretory cells similar to the pearl gland trichomes (Fig. 2.8)

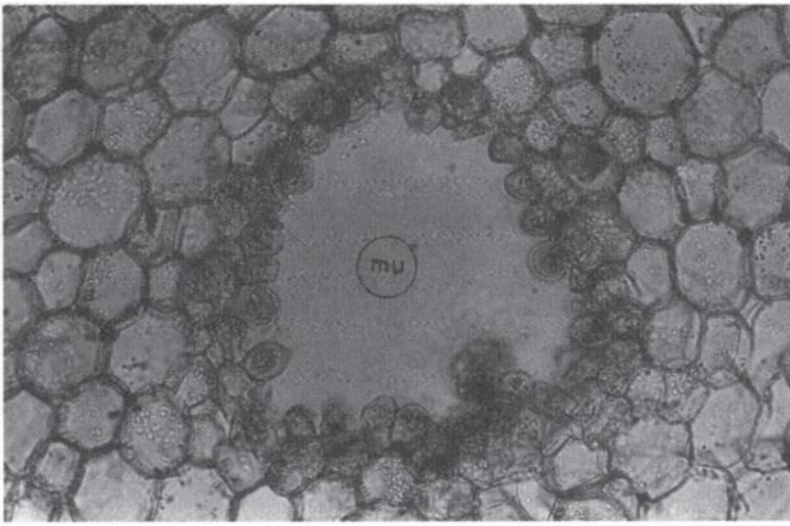


Figure 2.8 A mucilage canal (mu) showing the secretary cells lining the canal.

The primary anatomical structure of the plagiotropic shoot (lateral shoot) differs from the orthotropic shoot in the following features.

1. continuous band of sclerenchyma in the outer cortex, whereas in the orthotropic stem this band is discontinuous
2. there are no sclerenchymatous caps over the peripheral (cortical) vascular bundles
3. lesser number of peripheral bundles (18–24) as compared to orthotropic stem (30–40)
4. lesser number of central bundles (4–6) compared to 8–10 in the orthotropic stem
5. fewer number of xylem elements both in peripheral and central bundles than that in orthotropic stem.

Shoot apex

The shoot apex shows the dome shaped apical meristem, leaf initials and axillary bud initials. The central mucilage canal is seen a little below the apical portion. During the very early stage of development itself the pearl gland trichomes get differentiated and they are present in plenty, giving a corrugated appearance to the cut edges of the developing leaves (Fig. 2.9).

Normal and Aerial Root Anatomy

Pepper plants possess adventitious root system as they are developed from stem cuttings. Even when plants are grown from seeds, the primary root (tap root) ceases to

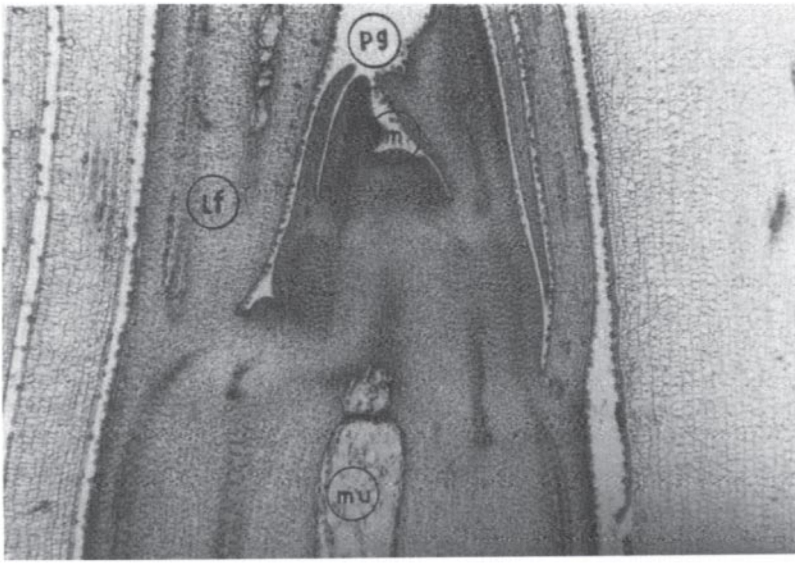


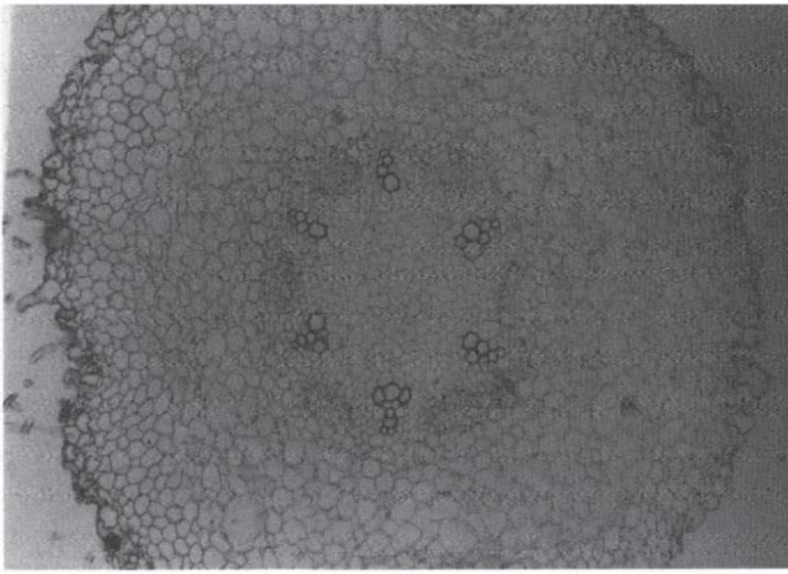
Figure 2.9 L.S. of an orthotropic shoot tip showing dome shaped meristem, leaf initials, central mucilage canal and numerous pearl glands, m=meristem, mu=mucilage canal pg=pearl glands, If=leaf initials.

grow after some time, and further development of the root system is through secondary roots only. Though aerial roots and underground roots of clonal pepper plants are adventitious, they differ in anatomical features. The normal underground root has a typical dicot root structure, consisting of an epidermis, a broad cortex and stele bound by an endodermis. The vascular tissue consists of 5–8 groups of xylem and phloem arranged radially, and there is also a relatively large pith, which is not very common in dicot roots. There is no central mucilage canal in the root. The metaxylem elements of each xylem group range from 1–3 and the protoxylem 5–8 (Fig. 2.10).

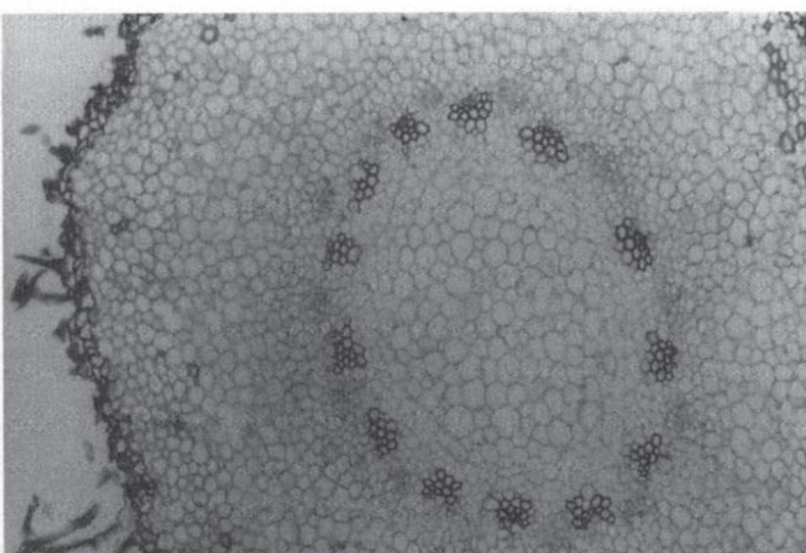
The aerial root differs from the normal root in having more number of xylem and phloem groups (12–15). The cortex is made of irregularly shaped, closely packed cells. The xylem elements are arranged as flattened discs, and their number is more but are smaller in size.

Peduncle

The black pepper inflorescence is a catkin (spike) which is leaf opposite and is the transformed apical bud. The T.S of the peduncle shows a structure similar to that of stem, consisting of an epidermis of rectangular cells, below which there is a band of sclerenchyma, 3–4 rows in width (hypodermis). The cortex consists of 7–8 rows of closely arranged parenchyma, the inner most layer is the endodermis. Below the endodermis there is the ring of bundles, which are associated with a band of



a



b

Figure 2.10 T.S. of normal and aerial roots, a. normal underground root, b. aerial root.

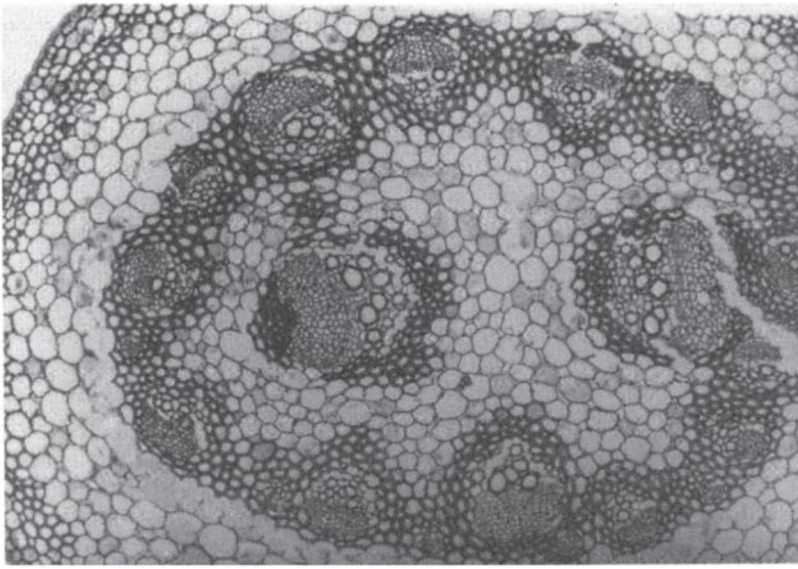


Figure 2.11 T.S. of peduncle showing two central bundles and the ring of outer bundles.

Sclerenchyma. The arrangement of bundles is similar to that in the stem, larger and smaller bundles usually alternate. The vascular bundles are collateral and open, consisting of phloem, one or two layers of cambial cells and a few endarch xylem elements. The central bundles are two in number, larger in size and are arranged in opposite direction, ie. their protoxylem facing the outside. They are also open, collateral with prominent phloem, a row of cambium and xylem arranged in endarch manner. An important feature is the absence of central mucilage canal in peduncle. Oil storage cell are found in the ground tissue (Fig. 2.11).

Anatomical Features of Other Closely Related *Piper* Spp.

The anatomical features of *P. attenuatum, P. hymenophyllum, P. trichostachyon, P. sugandhi* and *P. longum* exhibit much similarities except for minor variations (Ravindran 1991). In *P. hymenophyllum,* the stem (plagiotropic shoot) epidermis has large number of multicellular uniseriate hairs. There is a broken ring of sclerenchyma all around the stem which is followed by 1–2 layers of chlorenchymatous hypodermis. The cortical bundles are 16–18 in number, they differ in size, some very small, others larger. The larger bundles consist of 7–10 tracheary elements while the smaller bundles have only 2–3 elements. The medullary bundles are six in number, larger than the cortical bundles. Each bundle consists of 6–10 xylem elements. All the vascular bundles are conjoint, collateral, endarch and open. A mucilage canal is present at the centre of the stem. Pearl glands (wax glands) are absent. The stem structure of *P. attenuatum* is more or less the same as that of *P. hymenophyllum*. In the plagiotropic shoot, the epidermis is followed by 2–3 layers of chlorenchymatous hypodermis. Large number of sclereides are found distributed in the outer cortex. There are 22–26 cortical bundles and six medullary bundles which are larger. Bast fibers are found inside the phloem of the medullary bundles. There is a central mucilage canal and 8–10 cortical mucilage cavities. Wax glands are absent.

The stem structure in *P. sugandhi, P. galeatum* and, *P. trichostachyon* is more or less similar. They have microscopic hairs on the young orthotropic shoot and these hairs are uniseriate, multicellular. The sclerenchymatous bands below the epidermis are discontinuous at a few places. Endodermis is conspicuous in *P. sugandhi* and *P. trichostachyon,* more prominent in *P. galeatum*. The number of cortical bundles are 23–24 in *P. trichostachyon* and *P. galeatum* and 26 to 28 in *P. sugandhi*. The medullary bundles are 7–8 in *P. sugandhi* and 6–7 in *P. galeatum* and *P. trichostachyon*. One major difference between these species is the presence of central mucilage canal in *P. sugandhi* and its absence in *P. trichostachyon* and *P. galeatum*. The medullary bundles have sclerenchymatous caps at the protoxylem ends. A few bast fibers are found in the phloem tissues. The structure of the plagiotropic shoot is more or less similar. In *P. longum* the epidermis has minute hairs, which are either unicellular or multicellular, uniseriate. Below the epidermis there are patches of sclerenchyma forming a broken ring. There are 18–20 peripheral and six medullary bundles. Two to four bast fibres are seen in phloem. In the middle there is a prominent mucilage canal. The runner shoot has very similar structure, but the medullary bundles do not have a sclerenchymatous cap at the protoxylem end.

Some preliminary observation on the comparative anatomy of the orthotropic stem of five species of *Piper* viz. *P. galeatum, P. hymenophyllum, P. trichostachyon, P. barberi* and *P. colubrinum,* was also carried out by Menachery (1993). The general anatomical features are same as given above, while no mention is made about the plagiotropic stem. In *P. barberi,* Menachery (1993) reported a large central mucilage canal surrounded by a ring of six others embedded in the pith region outside the medullary bundles and that these mucilage canals have a lining of epithelial cells. Menachery (1993) also studied the morphology of vessel elements in some species. A wide range of forms such as, short to long, narrow to wide, oblique to transverse perforation plate, simple to scalariform pitting etc. occur in these species. Vessels with spiral and reticulate thickening and scalariform pits are common in the various species. The basic pattern of pitting is scalariform, opposite and multiseriate. *P. galeatum* and *P. trichostachyon* have vessels with alternate pitting.

Conversion of Aerial Roots to Normal Roots

Ravindran and Remashree (1998) studied in detail the structure of aerial roots and the changes occurring during its conversion to normal roots in *Piper colubrinum,* a South American species, resistant to most diseases and insect pests. This species produces aerial prop roots from the lower nodes. The aerial root is externally bound by the epidermis with a thick cuticle over it. A hypodermis of 2–3 layers followed by sclerenchymatous patches are present. The cortex consists of 20–25 layers of chlorenchyma and parenchyma. Mucilage canals are present. The endodermis is present and the cells possess distinct casparian strips. In primary growth stage, vascular bundles are radially arranged with 40–46 groups of phloem and xylem. During secondary growth a cambial strand is formed below the phloem first, then above the protoxylem and the strands later get connected so that a continuous cambial ring is produced. This cambial ring cuts off xylem towards the inside and phloem towards the outside, thereby later giving the appearance of conjoint, collateral and open type of vascular bundle. The phloem consists of sieve tubes, companion cells and phloem parenchyma and xylem consists of vessels and tracheids.

When an aerial root enters soil, it gradually gets converted into a normal root. As the aerial root grows in the soil, root hairs develop, the sclerenchyma and chlorenchyma

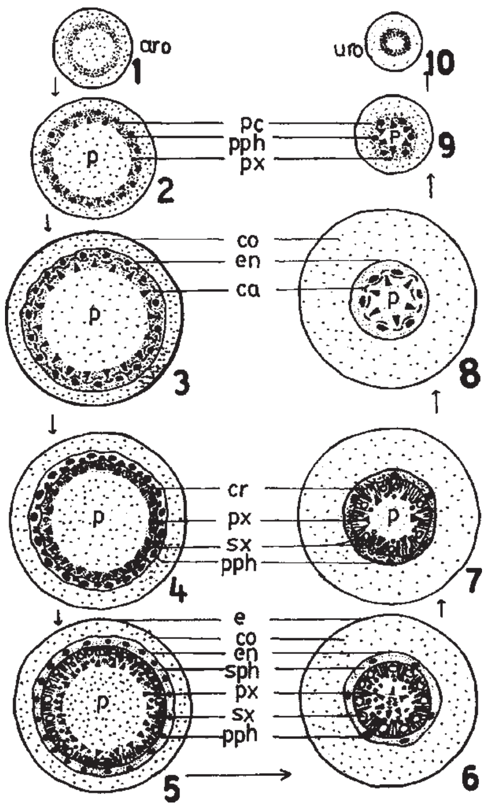


Figure 2.12 Structural changes during the conversion of aerial root to normal underground root in black pepper. 1–10 Different stages in the conversion of aerial root, aro—aerial root; uro—underground root; p—pith, pc—primary cortex, pph—primary phloem, px—primary xylem, co—cortex, e—epidermis en—endodermis; ca—cambium, cr—cambial ring; sx—secondary xylem, sph—secondary phloem.

present in the aerial region gradually disappear, the size of cortex increases, pith size gets reduced. The number of radial vascular groups gets reduced and finally reaches to about six radially arranged xylem and phloem groups. This conversion from a polyarch situation with 40–46 groups of vascular elements to the hexarch condition of normal underground root is the most important change taking place during the transition form aerial to normal root. The process of transition from aerial to normal underground root is represented in (Fig. 2.12).

Spike, Flower and Fruit Characters of *Piper* Spp.

The spike characters of *P. nigrum* and its closely related species are given in Table 2.6. The spikes are either pendulous or erect. Erect spikes are seen only in a few species such as *P. longum, P. silentvalleyensis, P. mullesua* and *P. hapnium*. Based on shape the spikes can be either filiform, cylindrical or globose. Globose spike is found in *P. mullesua,* cylindrical spike in *P. longum* and *P. hapnium.* In all the other species the spikes are filiform. *P. longum* and *P. hapnium* are also exceptional because here the flowers are laterally fused while in other species the flowers are free. Spike length in various *Piper* spp. ranges from about 1 cm in *P. mullesua* (mean 9.0 mm) to 18.0 cm in *P. attenuatum* and *P. galeatum.* In wild collections of *P. nigrum,* spike length varies from 5.7 cm to 13.5 cm. Length of the spike stalk (peduncle) also varies among the species from 0.2 cm in *P. mullesua* to 2.5 cm in *P. argyrophyllum*. In *Piper barberi* the peduncle is very long approximately 8–10 cm, much more than the spike length itself. Spikes are glabrous in most of the species, except in *P. trichostachyon,* in a collection of *P. nigrum* (*P. nigrum* var. *hirtellosum*) and in *P. sugandhi* var. *brevipilis*.

Pepper flower is sessile, bracteate, achlamydeous, uni or bisexual. Cultivated pepper has bisexual flowers. Bracts oblong, decurrent with free upper margin, develop into a shallow cup in female spikes. Stamens 2, dithecous, carpel single, ovary spherical, style absent, stigma 3–5 lobed, papillate. (Fig. 2.13)

Bract type is important in species delimitation of South Indian *Piper* spp. In *P. attenuatum, P. argyrophyllum* and *P. hymenophyllum* the bracts are sessile and adnate to the rachis. In *P. longum, P. mullesua* and *P. silentvalleyensis* bracts are peltate, stalked and orbicular. In *P. galeatum* and *P. trichostachyon* the bracts are connate, transformed into fleshy cup like structures. In *P. nigrum* the bracts are cupular with decurrent base. In *P. sugandhi* and in *P. sugandhi var. brevipilis* the bracts are deeply cupular and shortly stipitate with adnate base. In *P. schmidtii* the bracts are circular with raised, free margins. In *P. wightii* the bracts are oblong, narrowed towards the base and adnate with free margins. Stamens are 2 in *P. nigrum, P. mullesua, P. trichostachyon, P. galeatum, P. schmidtii* and *P. silentvalleyensis,* 2 or rarely 3 in *P. wightii;* 3 in *P. attenuatum* and *P. hymenophyllum,* 3–4 in *P. argyrophyllum* and *P. longum*. In *P. argyrophyllum* and *P. hymenophyllum* the male spikes possess a gentle lemony fragrance. The colour of the inflorescence is purple in certain collections of *P. nigrum,* in other species the spikes are white or light yellow or green.

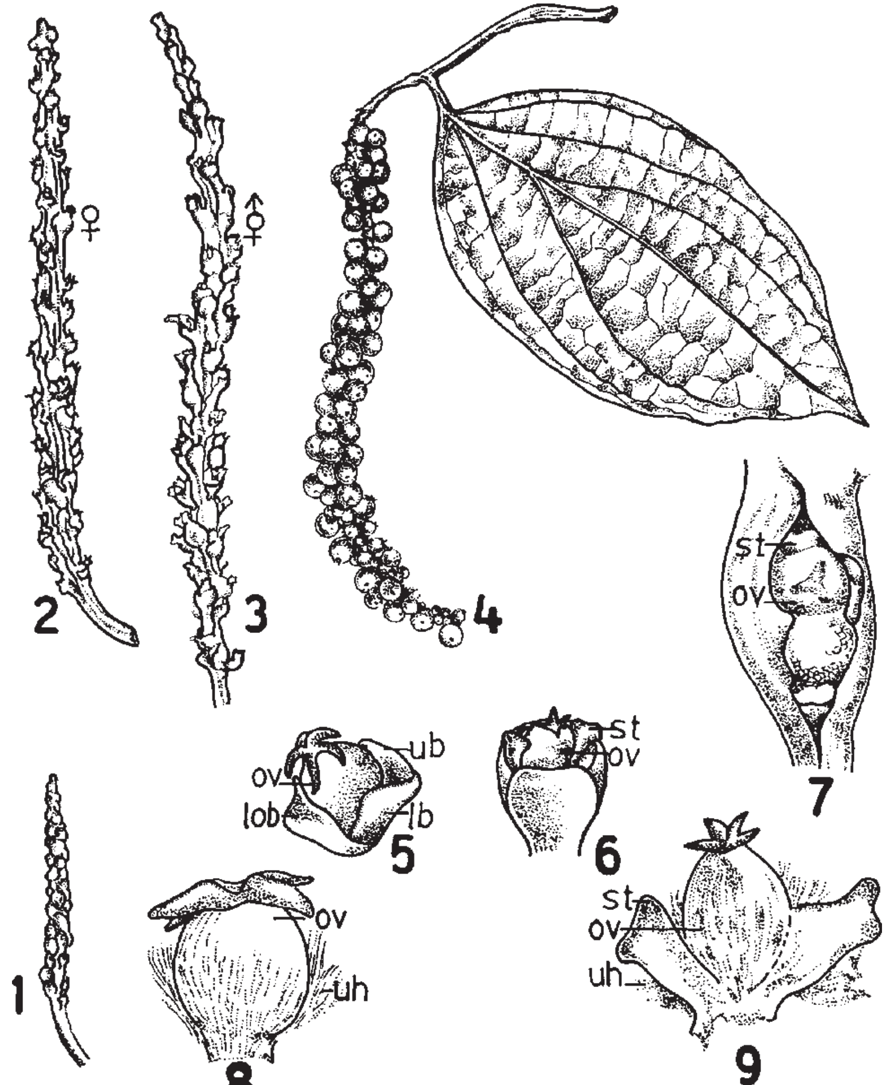


Figure 2.13 Flower morphology of black pepper. 1. A young spike 2. A mature spike with pistillate flowers. 3. Spike with bisexual flowers. 4. Fruiting spike. 5. Pistillate flower 6. Bisexual flower. 7. Two bisexual flowers enclosed in a common bract. 8. Ovary with sessile stigma. 9. Ovary and stamens, b—bract; uh—uniseriate hair; ov—ovary; st—stamen; lob—lowest bract; lb—lower bract; ub—upper bract.

Spike Variations Among Cultivars

The spike characters of cultivars are given in (Table 2.7). The smallest spike is found in the cv. *Vokkalu* (3.4 cm), a collection from the Sagar area of Karnataka state. The longest spike is in the cv. *Kuthiravally* (17.0 cm) a central Kerala cultivar. The other long spiked cultivars are *Poonjaranmunda* (16.4 cm), *Karimkotta* (15.6 cm) and *Panniyur* 1 (14.0 cm). The peduncle length ranges from 0.5 cm in *Vokkalu* to 2.1 cm in *Karimkotta* (Fig. 2.14). The spikes of majority of cultivars are straight, while some cultivars have characteristic curve or twisting of the spike. These include *Aimpiriyan, Kalluvally (Pulpally), Kuriyalmundi, Narayakkodi* and *Kottanadan*. The main reason for such twisting is the closeness of the flower arrangement and the high setting as a result of which the spikes become twisted or curved.

Leaf-spike relationship has shown that in the majority of cultivars the spike length is more or less equal to the leaf length (x+S.D=0.99–1.8). In a few cultivars the leaf length/spike length is less than one, and here the mean spike length is greater than the mean leaf length. These include *Karimkotta, Kuthiravally, Poonjaranmunda, Thommankodi* and *Vellanamban* (x+S.D<0.99). In some cultivars spike length is much shorter than leaf length (x+S.D>1.8). They include *Kalluvally (Pulpally), Kuriyalmundi, Vokkalu* and a few wild collections.

Composition of Spikes

The wild *Piper nigrum* is dioecious, while most of the cultivars are monoecious and have bisexual flowers. The origin of monoecious character is thus associated with

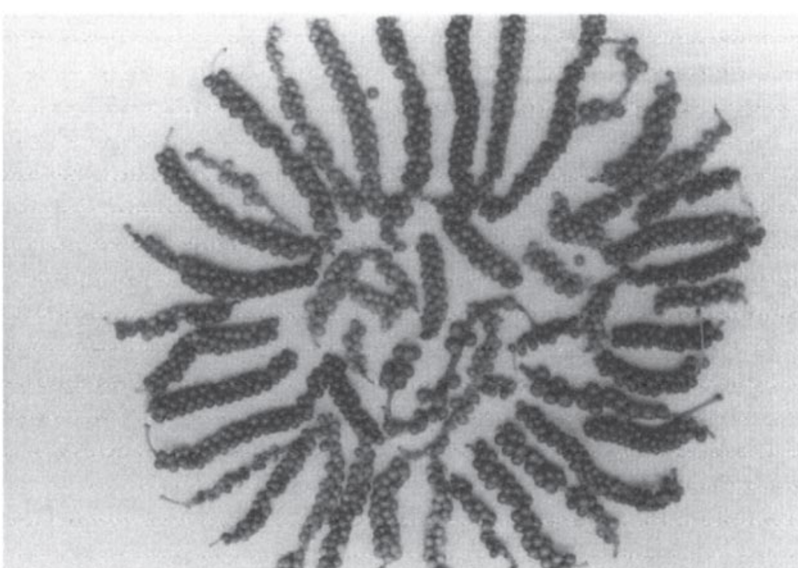


Figure 2.14 Spike variability in black pepper cultivars.

Table 2.7 Spike and berry (fruit) characters of pepper cultivars.

Sl. No.	*Cultivars*	*Spike length (mm) (Mean)*	*Peduncle length(mm) (Mean)*	*L.L. Sp.1.*	*Spike shape*	*Berry shape*	*Berry size*
1	*Aimpiriyan*	115.60	12.20	1.20	Curved	Round	Bold
2	*Arakkulammunda*	114.00	13.10	1.34	Straight	Round	Medium
3	*Arimulaku*	80.35	13.23	1.20	Straight	Round	Small
4	*Balancotta*	127.40	17.20	1.55	Straight	Round	Bold
5	*Bilimalligesara*	105.60	8.60	1.13	Straight	Round	Medium
6	*Cheriyakaniakkadan*	105.40	9.20	1.13	Straight	Obovate	Small
7	*Cheppukulamundi*	120.30	19.00	1.21	Straight	Round	Medium
8	*Cholamundi*	111.30	6.40	1.24	Straight	Round	Small
9	*Jeerakmundi*	103.60	6.00	1.16	Straight	Round	Small
10	*Karimunda*	78.00	10.00	1.51	Straight	Round	Medium
11	*Kaniakkadan*	92.50	9.00	1.38	Straight	Round	Medium
12	*Karivilanchy*	104.30	10.00	1.21	Straight	Oblong	Bold
13	*Karimkotta*	156.30	21.00	0.88	Straight	Round	Bold
14	*Kalluvally* 1	69.17	12.00	2.05	Curved	Round	Small
15	*Kalluvally* 2	124.90	10.60	1.90	Straight	Round	Medium
16	*Kallubalancotta*	136.36	10.50	1.02	Straight	Round	Medium
17	*Kottanadan*	106.90	11.10	1.20	Curved	Round	Medium
18	*Kuching*	91.00	9.70	1.51	Curved	Oblong	Medium
19	*Kuriyalmundi*	53.20	10.10	2.22	Curved	Round	Small
20	*Kuthiravally*	171.60	10.50	0.67	Straight	Round	Medium
21	*Kurimalai*	126.13	14.73	1.03	Straight	Round	Medium
22	*Malamundi*	96.70	7.90	1.34	Straight	Round	Medium
23	*Mundi*	86.30	9.10	1.56	Straight	Round	Bold
24	*Narayakkodi*	82.30	7.90	1.25	Curved	Obovate	Small
25	*Neelamundi*	96.97	7.40	1.60	Straight	Round	Bold
26	*Nedumchola*	51.70	9.60	1.71	Straight	Obovate	Small
27	*Neyyatinkaramundi*	71.00	7.00	1.26	Straight	Round	Small
28	*Ottaplackal* 1	113.80	12.40	1.03	Straight	Round	Medium
29	*Panniyur* 1	140.00	13.70	1.02	Straight	Round	Bold
30	*Perambramunda*	119.00	10.00	1.25	Straight	Oblong	Medium
31	*Perumkodi*	117.60	13.10	1.30	Straight	Round	Bold
32	*Poonjaranmunda*	163.90	12.20	0.81	Straight	Round	Bold
33	*Sagar Local*	90.00	10.80	1.70	Straight	Round	Bold
34	*Thevanmundi*	96.50	8.71	1.46	Straight	Oblong	Medium
35	*Thommankodi*	127.60	15.50	0.80	Straight	Round	Medium
36	*Thulamundi*	95.00	10.60	1.30	Straight	Round	Medium
37	*Udakkere*	128.80	11.65	1.17	Straight	Round	Bold
38	*Uthirancotta*	105.60	12.60	1.35	Straight	Round	Bold
39	*Vadakkan*	117.30	14.60	1.41	Straight	Round	Bold
40	*Valiakanikkadan*	97.50	13.80	1.77	Straight	Oblong	Bold
41	*Vattamundi*	99.70	12.45	1.14	Straight	Round	Bold
42	*Vellanamban*	122.40	9.60	0.84	Straight	Round	Bold
43	*Velliyaranmunda*	100.06	8.46	1.45	Straight	Round	Medium
44	*Vokkalu*	33.70	5.30	2.12	Straight	Round	Medium

domestication. Among the cultivars variations do occur with regard to the relative per cent of male, female and bisexual flowers. The cultivars vary from dominantly female to purely bisexual. The composition of some of the important cultivars and

Table 2.8 Sexual composition of flowers of some pepper varieties and cultivars.*

Name	*Bisexual Fls (%)*	*Female Fls (%)*	*Male Fls (%)*
A. Improved varieties			
Panchami	95.50	4.00	0.50
Panniuyr 1	99.20	0.07	0.01
Panniyur 2	96.70	3.30	0.00
Panniyur 3	99.90	0.10	0.00
Panniyur 4	96.40	3.60	0.50
Pournami	84.00	15.00	1.00
Subhakara	99.00	0.50	0.50
Sreekara	98.00	1.00	1.00
B. Cultivars			
Aimpirian	96.39	0.45	3.16
Bilimalligesara	93.69	5.75	0.56
Cheriyakanniakadan	1.64	98.36	0.00
Jeerakamuundi	86.83	11.76	1.41
Kalluvally	78.56	21.44	0.00
Karimkotta	90.99	2.65	6.36
Karimunda	94.25	0.00	5.75
Kottan	97.35	0.52	2.13
Kottanadan	99.49	0.21	0.30
Kuriyalmundi	94.00	5.32	0.60
Kuthiravally	88.58	10.65	0.77
Malamundi	86.04	13.61	0.35
Manjamundi	36.00	63.49	0.51
Mundi	21.98	77.66	0.36
Narayakodi	46.65	53.35	0.00
Neelamundi	99.02	0.87	0.11
Perambramunda	19.46	79.66	0.36
Perumkodi	26.89	73.05	0.06
Poonjaranmunda	98.69	0.00	1.31
Thevanmundi	96.14	2.48	1.38
Thommankodi	97.06	2.59	0.35
Thulamundi	94.18	5.35	0.47
Vadakkan	98.49	1.27	0.24
Valiyakaniakadan	78.55	21.45	0.00
Vellamunda	97.45	1.78	0.77
Vellanamban	96.00	4.00	0.00

* Unpublished data from IISR.

improved varieties is given in (Table 2.8). High percent of bisexual flowers are essential for good fruit set.

Fruit

The pepper fruit is botanically a drupe, but often referred as a berry. The fruit is single seeded, having a fleshy pericarp and hard endocarp. The seed has little endosperm but copious perisperm. The fruit differs in size and to some extent in shape also. Some cultivars have bold fruits (berries) (*Panniyur 1, Balancotta, Vadakkan, Uddhaghere* etc.), while in other cases the fruits are either medium or small. *Jeerakamundi* and *Kuriyalmundi* have the smallest fruits, and the largest are those of *Vadakkan*. The fruits are spherical in shape in most cases, obovate in a few and oblong in others. Fruit (berry) characters of pepper cultivars and *Piper* spp. are given in Table 2.7 and 2.9.

The fruits can be either free as in most species, or fused laterally as in *P. longum* and *P. hapnium*. Fruit shape is obovate-oblong in *P. attenuatum, P. argyrophyllum, P. hymenophyllum, P. galeatum, P. wightii, P. sugandhi* and *P. schmidtii;* elliptical in *P. longum* and *P. mullesua;* obovate in *P. silentvalleyensis* and spherical or rarely oblong in *P. nigrum* and *P. trichostachyon*. The fruits are minute in *P. longum, P. mullesua* and *P. silentvalleyensis,* bold in *P. galeatum, P. trichostachyon, P. sugandhi* and in certain *P. nigrum* collections; and medium in other species. The various species of *Piper* can also be subdivided on the basis of colour change of fruits on ripening. The two basic types are green turning to black on ripening; and green turning to yellow, orange or red on ripening. *P. attenuatum, P. argyrophyllum, P. hymenophyllum, P. longum, P. mullesua,* and *P. silentvalleyensis* belong to the first group. *P. galeatum, P.*

Table 2.9 Fruit (berry) characters of *Piper* species.

Species	*Fruit nature*	*Fruit shape*	*Fruit taste*
P. argyrophyllum	Free	Obovate-oblong	Bitter
P .attenuatum	Free	Obovate-oblong	Bitter
P. barberi	Free	Spherical	Bitter
P. hapnium	Fused	Elliptical	Bitter/spicy*
P. hymenophyllum	Free	Obovate-oblong	Spicy
P. galeatum	Free	Elliptical	Spicy
P. longum	Fused	Elliptical	Bitter
P. mullesua	Free	Obovate-oblong	Spicy
P. schmidtii	Free	Obovate	Bitter/spicy*
P. silentvalleyensis	Free	Spherical	Spicy
P. trichostachyon	Free	Obovate-oblong	Pungent
P. sugandhi	Free	Obovate-oblong	Pungent
P. sugandhi var.*brevipilis*	Free	Obovate-oblong	Pungent
P. wightii	Free	Obovate-oblong	Bitter

* Bitter initially, gently spicy later.

trichostachyon, P. sugandhi, P. wightii, P. schmidtii and *P. nigrum* belong to the second group.

Fruits taste bitter in *P. attenuatum, P. argyrophyllum, P. hymenophyllum, P. schmidtti* and *P. wightii.* In *P. galeatum* and *P. trichostachyon* fruits taste bitter first and somewhat pungent later. The fruits of *P. longum, P. mullesua* and *P. silentvalleyensis* taste spicy and aromatic, while the fruits are pungent in *P. nigrum* and *P. sugandhi*.

DEVELOPMENTAL MORPHOLOGY

The origin and development of vascular system in *Piper* was studied by Pal (1961) on which the following discussion is mainly based. The tunica is two layered in *P. longum, P. nigrum* and in *P. betle;* while it is three layered in *P. ornatum*. The tunica cells show high chromaticity and divide anticlinally. The foliar foundation initiates at the second tunica layer. The corpus cells are generally larger in size than the tunica cells and they divide at various planes.

The free apex in transverse section is almost round and it becomes oval as the foliar initials develop on one side. The primary meristem ring appears at the junction of the axis and the newly organized leaf primordium. The leaf traces are differentiated in this region. This primary meristem ring breaks up into 4–6 strands, each of which organizes into a separate bundle forming the central ring of vascular bundles. At this stage the leaf traces of the newly organized leaf primordium form an outer ring of vascular bundles in the stem (Fig. 2.15).

The leaf primordium is initiated in the second tunica layer by periclinal division. By subsequent divisions of the tunica layers and the corpus cells, the foliar foundation is laid down at one side. The newly formed leaf primordium extends laterally to form the collar. The vascular supply of the leaf primordium differentiates in the primary meristem ring and it develops acropetally. The peripheral ring of vascular bundles comprise of the leaf traces and the additional vascular bundles (Pal 1961). The leaf traces are the branches of the medullary bundles and on approaching a node they become laterally extended and give out branches. The number of leaf traces is never constant, this also depends on the number of medullary bundles. The "additional vascular bundles" (peripheral or cortical vascular bundles) are organized from a separate meristem which appears *de novo*. This meristem at first appears at the second internode between the leaf trace bundles. The cells situated between leaf traces become highly meristematic and gradually get differentiated into vascular bundles. They ultimately form small bundles between the leaf traces. The number of peripheral bundles situated between the two lateral traces varies from 1–2. The two satellite leaf traces which run by the side of the medium bundle are organized in this peripheral meristem. Thus the peripheral ring of vascular bundles is made up of leaf traces and the cauline bundles. The leaf traces move out into the collar and they finally leave the axis when they enter into the adjacent leaf. In the node the peripheral bundles become laterally expanded and become meristematic in nature. They move *inside and become continuous with the peripheral meristem of the upper* internode.

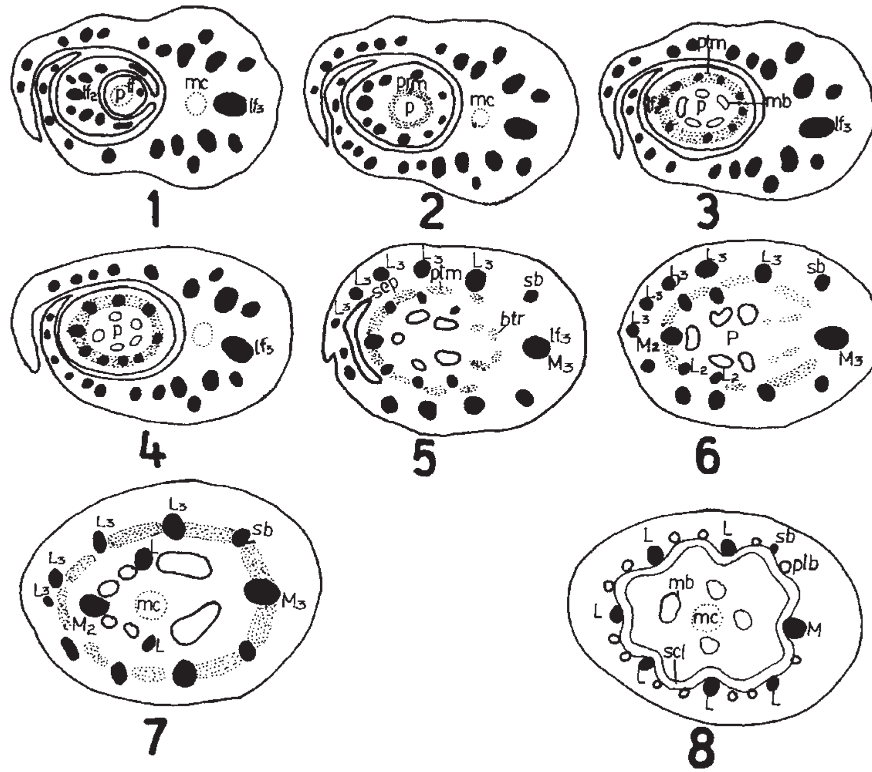


Figure 2.15 Diagrammatic representation of origin and development of vascular system in black pepper. 1. T.S. of the shoot apex showing the primary meristematic ring with first leaf (lf1) primordium having the median leaf trace at one end. 2. T.S of shoot apex showing the primary meristematic ring and the peripheral leaf traces of second leaf (lf_2); 3 and 4. T.S of shoot apex showing the internode below lf2 and leaf sheath of lf3. Internode shows the differentiation of medullary bundles from the primary meristematic ring and the development of peripheral meristem in between the leaf traces. 5, 6, 7. T.S. through node showing the behavior of leaf traces of lf2 and the origin of bud traces. 8. T.S. of internode showing the leaf traces of lf2 and peripheral cauline bundles lying on the selerenchymatous band, four medullary bundles and central mucilage canal. (After Pal 1961).

The medullary bundles have been found to organize in the primary meristem ring. When they approach the nodes they become laterally expanded and then join each other and give out branches which diverge outward and form the leaf traces. After giving out the leaf traces they repair themselves into the medullary bundles. Thus the leaf traces are the branches of the medullary bundles. At certain stage of development in the nodal region three rings of bundles are noticed—the peripheral ring composed of leaf traces and the peripheral bundles, the intermediate ring composed of leaf traces just given out by the medullary bundles and the central ring of medullary bundles. As soon as the leaf traces leave the peripheral ring for the adjacent leaf, the peripheral bundles move inside and join the middle ring. At the fourth internode the cells below the peripheral meristem ring become highly chromatic and they divide into small cells. They form a complete ring of small cells, 4–7 cells deep, which later differentiate into a sclerenchymatous zone.

The axillary bud primordium appears first in the axil of third leaf. The process of development seems to be similar in all species of *Piper*. The medullary bundle after giving rise to the median leaf traces gives out the bud traces from its free ends. These two traces break down into smaller branches which form the vascular supplies to the axillary bud. The first leaf given out by the axillary bud always develops into a prophyll.

The development and distribution of the mucilage canals in *Piper* spp. was described by Van Teighem (1908). He grouped plants into three categories viz. species having one central canal accompanied by peripheral canals, those having only the central canal and in the third group they are absent. The central mucilage canal is present in *P. nigrum, P. betle, P. hymenophyllum, P. attenuatum, P. sugandhi, P. longum,* etc. The mucilage canal is absent in *P. triochostachyon* and *P. galeatum* (Ravindran 1991).

Inflorescence and Flower Development

No detailed information is available on the inflorescence and flower development of pepper. The only detailed study is that of Tucker (1982) on the inflorescence and flower development in *P. aduncum, P. amalgo* and *P. marginatum* and the process of development is believed to be similar in other species also. The inflorescence in its early stage of development has a convex apical meristem, subtended by a vegetative leaf and a bract. The inflorescence meristem appears to be terminal; so that the growth is sympodial. As the inflorescence grows in length its apical meristem diminishes. The early apical meristem is zonate, usually with two tunica layers, a large central initial zone, a peripheral zone, and a massive pith rib meristem. The apical meristem of the inflorescence grows extensively in length, before any organs form. The bracts are initiated close to the apex by periclinal division in the second tunica layer on the flanks of the apical meristem. When the bract is 40–50 μm in size, pearl gland trichomes form at or near the tip. One or two large oil cells differentiate at the tip of the bract. Further studies using SEM could not be done because the view was totally masked by the profuse growth of hairs (Tucker 1982).

Each flower arises in the axil of a bract. Cells in the axils remain meristematic and the cells in the outer layer divide anticlinally; the next two layers undergo intensive cell divisions, including periclinal divisions before a protuberence forms. Cells elongate anticlinally in the outer two layers and the protuberance is then visible.

This enlarges further and differentiates into a flower bud (Tucker 1982). Each flower is apetalous, asepalous and subtended by a sessile bract. The number of stamens varies among species. In pepper there are two stamens. The gynoecium in *Piper* is tricarpellate, syncarpous, uniloculate, uniovulate with basal placentation and a three or four-parted stigma.

Tucker (1982) described in detail the floral development in *Piper amalgo* and the process is regarded as similar to pepper, except for the number of stamens. As the primordium (protuberence) mentioned above grows, cell divisions become more numerous at three sites, two lateral and one central. The two lateral sites represent areas where stamens are being initiated. As the three sites develop, the floral primordium becomes triangular in frontal view. The stamens are initiated at either end of the wide floral meristem. As the stamen primordia enlarge to 40–50 μm high, they become almost globose. Each stamen is uniformly meristematic, and gradually the stamens show cell enlargement and vacuolation at the base on the adaxial side. Growth in height is the result of generalized cell divisions at the summit rather than specific apical or subapical initials. Vacuolation and enlargement continue in the cells of the filament and connective region; while the meristematic activity is now largely restricted to the sporangial sites. Endothecium and pollen grains are present at 300 μm height from the base.

In *Piper* the gynoecium has three carpels; two lateral posterior and one median anterior. The initiation of the three carpels appears to be simultaneous. They form high points along a gynoecial ring. The three carpels are initiated by periclinal divisions in the sub surface layer on the side of the small floral apex. Soon the carpels form a ring meristem with three low protuberances. The procambium present at the growing point differentiates acropetally, and the adaxial thickening meristem becomes active adding to the thickness of the carpel; while cell vacuolation and differentiation occur abaxially. The syncarpous gynoecium grows in height by intercalary growth below the level of the carpel lobes. Ovule initiation begins by a periclinal division in the second tunica layer at the centre of the floral apex. The solitary, basal, orthotropous ovule uses up the apical meristem during its initiation and thereafter fills the locule (Tucker 1982).

The later stages in the development of ovule and embroysac were reported by Johnson (1910) in *P. betle,* Joshi (1944) in *P. longum*; Swamy (1944) in *P. betle* and Kanta (1962) in *P. nigrum*. Some confusion exists on the carpel number in *Piper*. The carpel number was reported to be one (Baillon 1872), two (Joshi 1944) and three (Johnson 1902, Eckardt 1937, Murty 1959). The proponents of the tricarpellate gynoecium support their argument on the number of stigmas and/or carpellary vascular bundles. Tucker (1982) provided evidence for tricarpellary nature from developmental studies. In *Peperomia* developmental evidence supports the interpretation of gynoecium as unicarpellate. *Peperomia* with its single carpel and unitegmic ovule is generally thought to be specialized through reduction from *Piper* like ancestor with three carpel and tritegmic ovule (Tucker 1980). The gynoecium of *Piper* according to this author initiates as three lobes, but develops as a cup shaped syncarpous structure with three free styles.

Megasporangium and Female Gametophyte

Johnson (1902) reported that in *P. medium* and in *P. aduncum* and also in two species of *Hekeria* (the related genus), there was only one primary archesporial cell and the embryosac development was that of the "Lilium type". The megaspore mother cell was found to form no tetrad of megaspores but as a result of three free nuclear divisions followed by cell formation gave rise to a 7-celled, 8-nucleate embryosac (currently called the Adoxa type of embryosac). Later Johnson (1910) studied the embryosac of *P. betle* var. *monoicum* and found the same type of embryosac development in this species also. Fischer (1914) and Palm (1915) investigated the embryosac development in *P. tuberculatum* and *P. subpeltatum* respectively and their results agreed with those of Johnson. But later workers (Schnarf 1936,

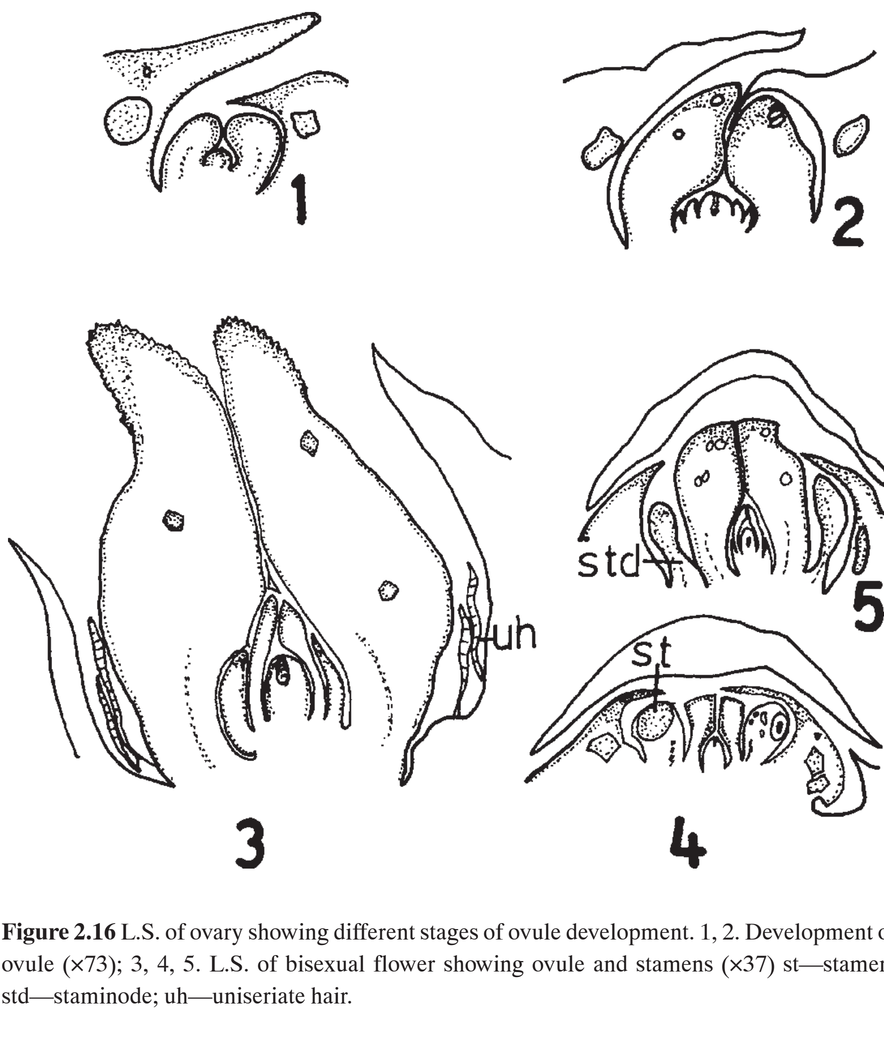


Figure 2.16 L.S. of ovary showing different stages of ovule development. 1, 2. Development of ovule (×73); 3, 4, 5. L.S. of bisexual flower showing ovule and stamens (×37) st—stamen; std—staminode; uh—uniseriate hair.

Maheswary 1937) suspected the "Adoxa" type of embryosac and based on published literature, they came to the conclusion that the embryosac development followed the "Fritillaria type". This was later supported by Swamy (1944) in *P. betle,* Joshi (1944) in *P. longum* and Kanta (1962) in *P. nigrum*.

Maugini (1950) studied the female gametophyte in *P. geniculatum* and *P. ungiculatum* and interpreted the development to be "Euphorbia dulcis type" characterized by triploidy in its chalazal half and that the 8-nucleated gametophyte originated from the secondary tetra-nucleated gametophyte. Later Kanta (1962) studied the development of female gametophyte in black pepper in detail on which the following discussion is mainly based. The ovary in black pepper is unilocular and contains a single ovule, and the placentation is basal (Fig. 2.16). The ovule is tritegmic, crassinucellate and orthotropous. The ovular primordium arises at the base of the ovary when the ovary wall is still developing. Further development of the ovary and ovule proceeds simultaneously. The integument and archesporium differentiate more or less at the same time. By the time the embryosac reaches the 4-nucleate stage the micropyle appears to be fully developed. The integuments are generally 3–5 layered while the tips are made up of 7–9 layers and appears swollen.

Usually a single hypodermal cell gets differentiated as an archesporial cell. This undergoes a periclinal division giving rise to the parietal cell and the megaspore mother cell. The sporogeneous cell enlarges and function as the megaspore mother cell. The nucleus then undergoes meiotic division resulting in a 4-nucleate embryosac, where the cells are arranged either in linear fashion or in a cross-wise manner. Gradually the central nuclei move towards the enlarged end, leaving only one nucleus at the micropylar end (1+3 arrangement). Then all the nuclei simultaneously undergo meiotic divisions. During this division the spindles of the three nuclei situated at the chalazal end fuse and a secondary 4-nucleate stage results in which the two micropylar nuclei are haploid and the two chalazal nuclei are triploid. The four nuclei undergo another mitotic division giving rise to the 8-nucleate embryosac. Thus the embroysac is the "Fritillaria" type. The mature embryosac shows the normal 3+2+3 arrangement of nuclei; i.e. two synergids and the egg nucleus are at the micropylar end, 2 nuclei (secondary nucleus) in the middle and the three antipodals in the chalazal end. Kanta (1961) also observed that in about 50 per cent of the ovules the embroyosac degenerates and the ovule collapses. The ovules may abort before or after fertilization. The unfertilized ovule may abort at the primary 4-nucleate stage, but more frequently at or after the 8-nucleate stage (Kanta 1961). The process of development of the female gametophyte is shown in Fig. 2.17.

Microsporangium and The Male Gametophyte

Usually anther is bithecous with 4 microsporangia. Occasionally one or more microsporangium may be suppressed. The development of microsporangium and male gametophyte was studied by Kanta (1962). The fertile microsporangium has 4–6 layers of compactly arranged microspore mother cells. No wall is laid down between the daughter nuclei after the first reduction division. Wall formation occurs

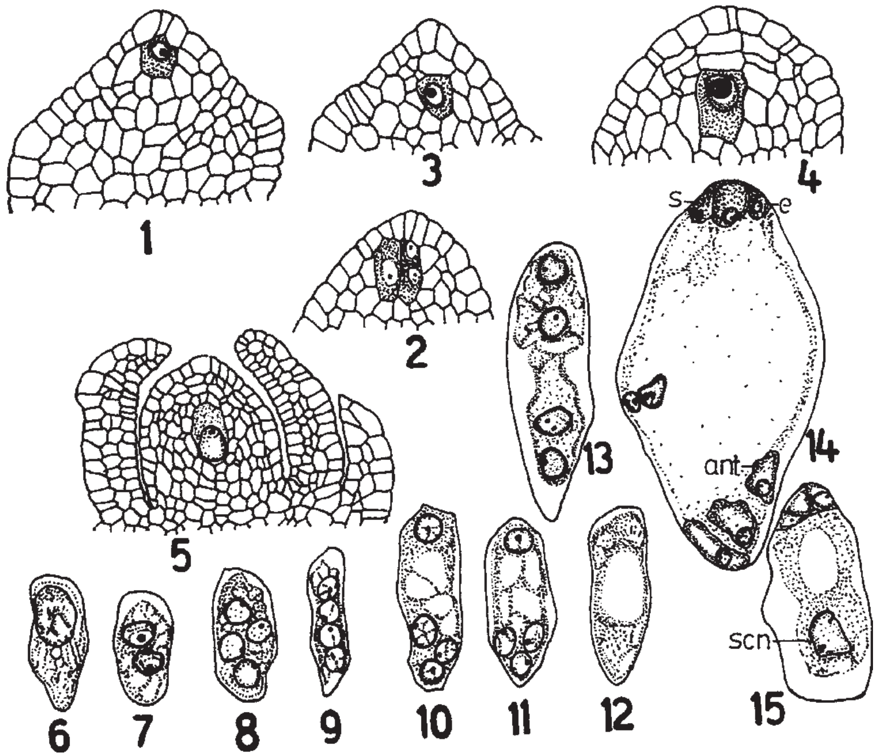


Figure 2.17 Development of megasporangium and female gametophyte. 1. L.S. of nucellus with a hypodermal archesporial cell. 2. Multicelled archisporium; 3. Megaspore mother cell with primary parietal cell. 4. Periclinal division of the parietal cell; 5. L.S. of ovule with a megaspore mother cell and three parietal layers; 6. Megaspore mother cell; 7. Two nucleate embryosac; 8–9, primary 4—nucleate embryosac; 10–11. Megaspore showing 1+3 arrangements of nuclei; 12. Same with nuclei at metaphase; 13. Secondary 4 nucleate embryosac; 14. A mature embryosac; 15. Micropylar portion of a mature embryosac showing egg apparatus and secondary nucleus (All×1184) e—egg; s—synergid; ant—antipodals; scn—secondary nucleus. (After Kanta 1962).

after meiosis II resulting in tetrahedral or occasionally in bilateral tetrads. On separation the microspore become more or less spherical. The nucleus divides into a large round vegetative nucleus and a small spindle shaped generative nucleus, separated by a wall. The mature pollen grains have smooth exine.

The anther wall consists of the epidermis, endothecium, 2–3 middle layers and the tapetum. The tapetal cells often become binucleate. The endothecium develops thickenings at the tangential walls. As the anther matures, the tapetal cells lose contact with one another and finally disintegrate. Thus the mature anther wall consists only of epidermis and the fibrous endothecium. The anther dehisces by an apical slit.

Development of Embryo

The embryo development was outlined by Kanta (1962). The synergids are evanescent. The zygote divides simultaneously with the primary endosperm nucleus. The first wall is obliquely longitudinal or transverse. The terminal cell resulting from the above division is larger and richly cytoplasmic, the basal cell smaller and with scanty cytoplasm. Further developmental stages have not been clearly studied. In 50 per cent of the ovules (in the material studied by her) the zygote did not develop further but degenerated due to the deposition of calcium oxalate crystals (Kanta 1962).

The suspensor of the developing embryo has larger, highly vacuolated cells having scanty cytoplasm; while the cells toward the tip of the embryo are rich in cytoplasm and are smaller in size. The embryo has prominent ridges and furrows and when seen

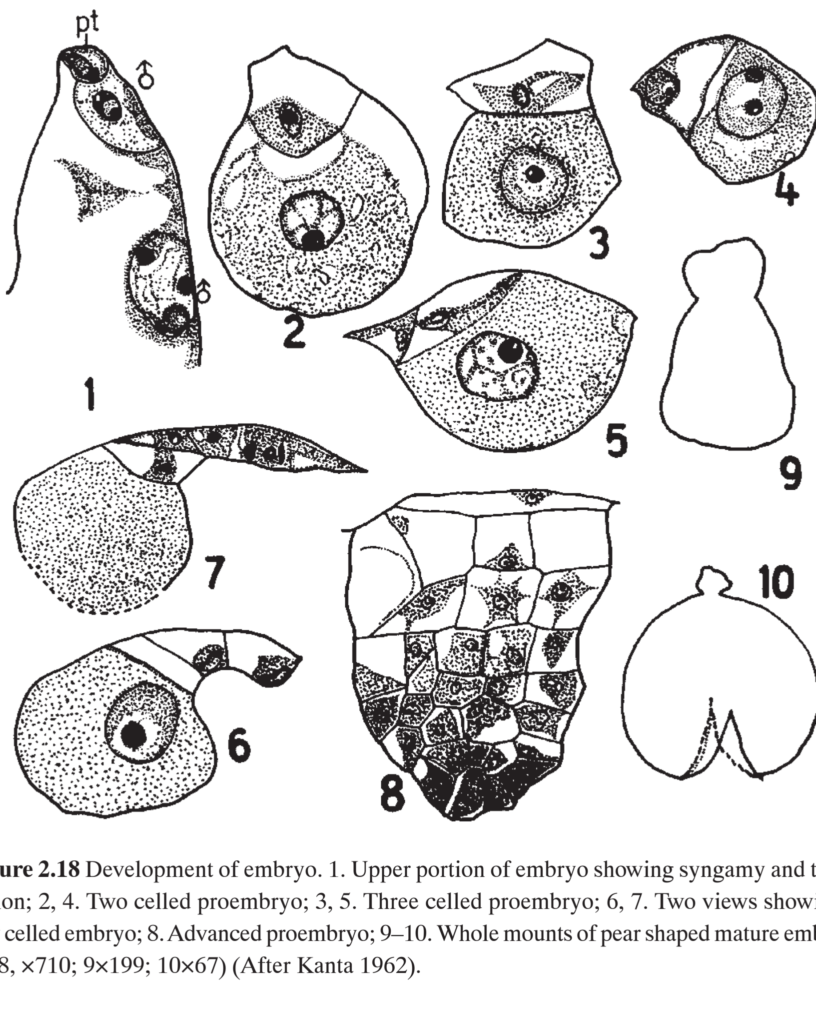


Figure 2.18 Development of embryo. 1. Upper portion of embryo showing syngamy and triple fusion; 2, 4. Two celled proembryo; 3, 5. Three celled proembryo; 6, 7. Two views showing a few celled embryo; 8. Advanced proembryo; 9–10. Whole mounts of pear shaped mature embryo. (1–8, ×710; 9×199; 10×67) (After Kanta 1962).

from the top it has a hexagonal appearance (Kanta 1962) (Fig, 2.18). The embryo is not fully differentiated even in fully ripe seeds. Further differentiation takes place during the process of germination when the cotyledons develop fully.

Endosperm

The endosperm is of the nucellar type. The endosperm nuclei divide and arrange themselves along the periphery of the embryosac (Fig. 2.19). Cell formation is

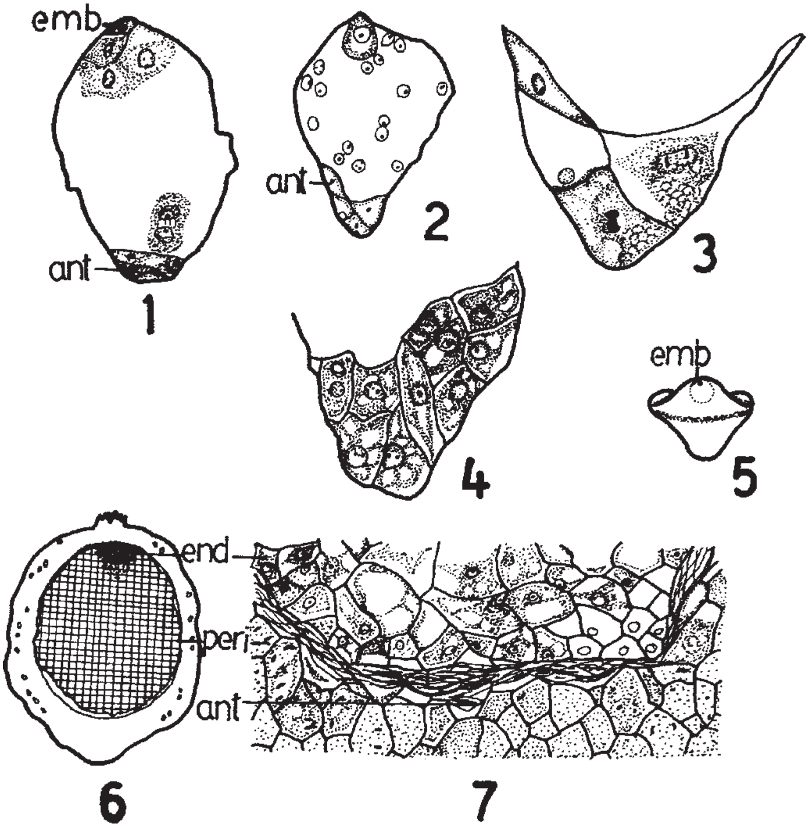


Figure 2.19 Development of endosperm. 1. Four nucleate endosperm. At one end is 2-celled proembryo and at the other end is seen the antipodal cells (×298); 2. Outline of the embryosac with 16 endosperm nuclei and the dividing antipodal cells (×57); 3. Magnified view of the chalazal part of the embryosac (×533); 4. Chalazal end of an embryosac with many antipodal cells (×533); 5. Whole mount of top-shaped endosperm (×35); 6. Diagram of l.s. of fruit at preglobular stage of embryo; 7. Chalazal portion of fig. 6, magnified to show cellular endosperm, crushed antipodal cells and the perisperm cells filled with starch grains (×342). emb—embryo, end—endosperm, anti—antipodals, peri—perisperm (After Kanta 1962).

initiated near the periphery and proceeds towards the centre. The cells situated near the periphery are richly protoplasmic and those towards the centre are larger and highly vacuolated. Only a part of the endosperm is consumed by the developing embryo, the bulk of it persists in the mature seed (Kanta 1962).

Antipodal Cells

A mature embryosac of pepper has three antipodal cells (triploid) and they divide many times forming a tissue at the chalazal end of the embryosac. They are seen distinctly when the endosperm is in nuclear stage, but when the endosperm turns cellular the distinction between the two tissues vanishes. By the time the embryo becomes globular the antipodals are crushed by the growing endosperm.

Perisperm

Black pepper seed contains a massive perisperm tissue. The perisperm develops from the nucellar tissue. The cells situated just below the embryosac divide rapidly, and these divisions are followed by cell enlargement giving rise to the perisperm tissue. The walls between some of the cells of the perisperm disintegrate and their nuclei fuse. Such composite cells are large and densely cytoplasmic and store oil globules. The nucellar cells surrounding the embryosac, the nucellar epidermis and adjacent layers become filled with starch grains, the quantity of which increases from the chalazal end towards the base of the embryosac. The bulk of the mature fruit (about 95%) is formed by the perisperm (Kanta 1962). West *et al.* (1995) carried out TEM studies on perisperm of pepper and found that it contains naturally electron dense globoids. Energy dispersive X-ray analysis of globoids from the perisperm tissue revealed varying levels of phosphorous, potassium, magnesium and calcium.

Seed Coat

Kanta (1962) studied the formation of seed coat in pepper. The outer and inner integuments consist of 3–5 layers of cells each. The cells of the innermost layer of the inner integument become densely cytoplasmic. Near the micropylar region they give out finger-like projections which meet similar processes directed outward from the nucellar epidermis, so that the two fit together against each other. The cells lining the micropyle as well as those belonging to the outer most layer of the inner integument near the micropylar region become filled with tannin.

Just after fertilization the outer integument begins to get crushed as also the outer layer of the inner integument. On the other hand the inner most layer of the inner integument becomes thick walled and filled with tannin. In the mature fruit the seed coat is represented by a narrow, dark wavy streak and serves for mechanical protection. A few layers of cells lying just below the perisperm at the base of the ovule also become thick walled and are filled with tannin (Kanta 1962).

Pericarp

At mature embryosac stage the ovary wall consists of 17–19 layers of cells with several oil cells distributed among the cells. The hypodermal layer consists of radially elongated cells. Just after fertilization, the cells of the ovary wall divide actively, the outermost layer of cells becomes heavily thickened on the surface, the next two or three layers of cells become lignified and pitted. The cells of the following 15–17 layers enlarge appreciably. The outer layer of the pericarp up to the vascular strand forms the epicarp. Those just below it show tracheidal pitting and constitute the mesocarp and those lying next constitute the endocarp. The inner epidermis develops thickening on its inner as well as radial walls.

On the outer surface there are small lenticel like openings formed by the meristematic activity of the cells of the hypodermis. If the fruit gets injured, cambium like cells appear all along the wounded part and even in the perisperm when the injury is deep. By their activity protective layers are developed. Groups of calcium oxalate crystals are present in the pericarp (Kanta 1962).

Structural Features of Pepper Fruit Powder

Jackson and Snowdon (1990) described the structural features of pepper fruit powder. These features include the following aspects. The pericarp is always adherent to the sclerenchymatous layers of the mesocarp. In surface view the cells cannot readily be distinguished, but the layer is recognized by the areas of dark brown pigment in which are embedded calcium oxalate crystals. The sclereids of the outer mesocarp occur in groups separated by parenchyma. The sclereids are usually polygonal to rectangular with numerous pits. The parenchyma of the mesocarp is composed of large polygonal thin walled cells associated with thin walled oil cells. Pieces of vascular strands with spiral or annular thickening occur in groups. Groups of large fibrous sclereids also occur rarely. The endocarp is composed of single layered lignified cells. In sectional view the cells are seen to be strongly thickened on the inner tangential walls. In surface view the cells are polygonal with pits. The testa is composed of a narrow outer region containing reddish brown pigment and the inner hyaline layer composed of thin walled cells. The perisperm is composed of thin walled polygonal or ovoid cells and filled with starch granules. Oil cells occur scattered in the tissue.

Growth and Differentiation of Flower

The pepper inflorescence is leaf opposite and are produced on the lateral plagiotropic branches. These flowering lateral branches have sympodial mode of growth, the apical bud develops into the inflorescence and the growth is continued by the activity of the axillary bud. As the axillary bud develops the inflorescence is pushed out so that it becomes leaf opposed. The flowering starts usually in June–July following the monsoon rains. Pepper vines can be induced to flower by copious irrigation for about 20 days (KAU 1978). The number of apical buds eventually transforming into functional inflorescence varies among cultivars, in one particular year the figures were 20, 43 and 73 per cent in three cultivars, *Panniyur* 1, *Karimunda* and *Kalluvally* respectively (CPCRI 1979). The number of spikes occurring in a lateral branch varies, usually from 2–5. At the early stage of development, the developing spikes and the leaf opposite to it are enclosed in a prophyll and it takes three to four weeks for the full spike emergence. In the developmental sequence, the next event is the emergence of stigma and the time interval depends on the cultivars. Generally, the stigma emergence can be noticed in 10–20 days, though there are cultivars where the stigma emergence takes place in around five days after full spike emergence. It takes about 5–15 days for completion of stigma emergence. The period of receptivity of stigma varies from 3–9 days, and the receptive period of stigma in the first opened basal flowers is longer and the period gradually decrease in flowers opening later in the developmental stage (KAU 1978). Protogyny exists in most of the cultivars, in a few, synchronous maturity of male and female phases are noticed while rarely protandry is also met with. In protogynous flowers male and female phases are separated by 1–14 days. Anthers emerge on either side of the ovary and from emergence to anthesis 2–4 days are required. Under Sarawak condition, cv.

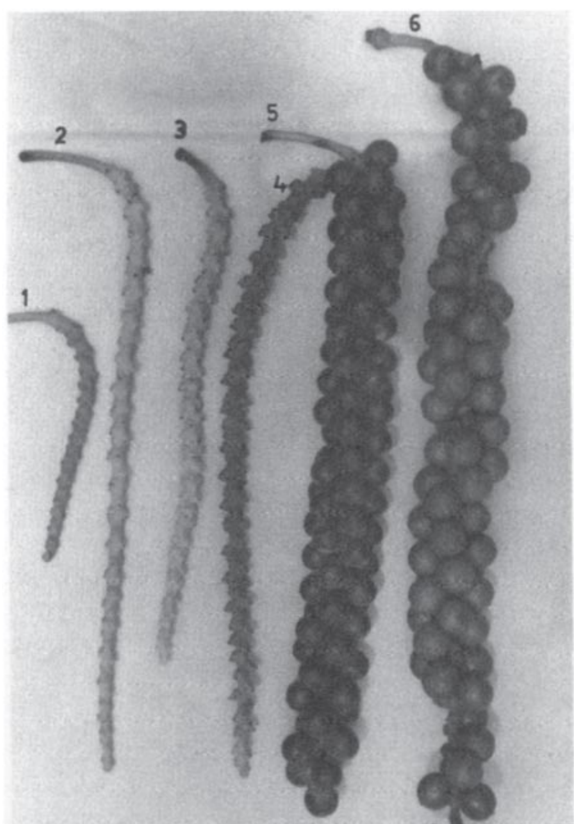


Figure 2.20 Spikes of black pepper—stages of growth.

Kuching takes 16 days for emergence of stigma from spike emergence; 22 days for appearance of receptive stigma and 27 day for anther emergence (Anon. 1979). The stages in the development of spikes are shown in Fig. 2.20.

The flower composition of the spike varies among cultivars. Some are completely bisexual as in *Karimunda,* while in others varying number of unisexual flowers occurs. In *Panniyur* 1 97 per cent are bisexual flowers and the rest pistillate (Table 2.8).

Flower bud differentiation

Only some preliminary studies exist on flower bud differentiation (KAU 1984). Differentiation of vegetative buds occur mainly in June–July, with the onset of monsoon. Three stages were recognized: (i) appearance of conical undifferentiated vegetative primordia surrounded by leaf sheath, (ii) elongation of primordia, (iii) differentiation of the tissues into an outer "dermatogen-like layer" and an inner "periblem-like zone". Five stages were also identified in the development of flower buds: (i) two undifferentiated conical primordia surrounded by leaf sheath were observed at this stage, indicating the commencement of bud differentiation, (ii) towards the later half of the previous stage, one of the primordia broadened and elongated and a dome shaped structure appeared at the apex of the broadened primordium, (iii) an elongated structure comparable to a pepper spike is visible, (iv) differentiation of floral parts, and (v) differentiation is completed with the appearance of stamen and ovary. The whole process takes about 20 days.

Pollen Morphology, Germination and Pollination Biology

Piper spp. exhibit much uniformity in pollen morphology, except for the variation in size. Pollen grains are small, the diameter along the equatorial axis ranges from 8.0–18.0 μm and along the polar axis, between 6.5–15.0 μm. Grains are monosulcate, the sulcus extending upto the lateral extremities. Very rarely the grains are non aperturate or porate (Rahiman 1981). The sulcus is in the form of a narrow slit with thick borders all along the periphery. The exine surface is reticulate, the bronchi being large and irregular on the distal polar surface. In *P. nigrum* the pollen grains measure along the equatorial axis from 9.5–13.0 μm, the mean being 11.0 μm; and along the polar axis 7.0–10.5 μm having a mean of 8.84 μm (Rahiman 1981). Here the grains are spheroid to suboblate, rarely pyramidal, sulcus measures 7.0–11.0 μm in length and 1.0–2.0 μm in breadth. Iljas (1960) and Martin and Gregory (1962) also reported that pollen grains are small, the mean diameter being approximately 10 μm irrespective of cultivars. Pollen morphology of *Piper* was also reported by Mitrou (1970).

Anther dehiscence

Anther dehiscence is controlled to a very great extent by temperature and relative humidity (Iljas 1960, Martin and Gregory 1962). De Waard and Zevan (1969) found that in Sarawak the opening usually takes place between 12.00 and 14.00 h on days when relative humidity of 60 per cent is attained and at a temperature of 32°C, combined with bright sunshine. He also mentioned that the mass of pollen may spill freely over adjacent stigmas and other parts of the spike. Under Kerala conditions anther dehiscence takes place around 4 PM.

Pollen production

The total amount of pollen per anther varies with the cultivar. Marinet (1953) reported that in Indian cultivars each spike yielded 500,000–700,000 pollen grains, each 10 μm in diameter. Martin and Gregory (1962) estimated 100,000–300,000 pollen grains per spike.

Pollen dispersal and mode of pollination

Barber (1906) and Anandan (1924) attributed pollination to splashing of rain, the latter reported that rain drops help in scattering pollen grains in different directions, either wash down the pollens to lower spikes or carry them to neighbouring vines. He ruled out the role of insects in pollination. In Sarawak, in the cv. *Kuching,* fresh pollen appeared in glutinous clusters dispersable in water (De Waard and Zevan 1969). Accumulation of dew may cause the disintegration of the pollen lumps (Martin and Gregory 1962). Drops collected from the spikes were reported to contain considerable quantities of pollen (De Waard and Zeven 1969). It appears that water is a medium for pollen distribution. Iljas (1960) on the other hand reported the presence of dry, powder like pollen in the cv *Bangka* and suggested the possibility of direct gravitational distribution (geitonogamy).

Barring a couple of reports there are very little studies on the pollination biology of pepper. One of the earliest reports was that of Martin and Gregory (1962) who studied the mode of pollination and factors affecting fruit set in Puerto Rico. Semple (1974) made a study on pollination in Piperaceae in Costa Rica. The following probabilities exist for natural pollination.

Insect pollination

Pepper flowers are not adapted for insect pollination. However presence of insects have been reported by Martin and Gregory (1962) and Semple (1974) suggestive of their role in pollination. Semple (1974) found that in Costa Rica several species of *Trigona* bees are the most common visitors on *Piper* spp. and that they were found to collect “large amount of pollen in their baskets” by working up and down the spikes collecting pollen and then flying from spike to spike. No direct evidence for insect pollination came from other sources, though Marinet (1953) reported poor yield following insect control operation. However studies conducted in Kerala, the centre of diversity for black pepper, rule out the role of insects in pollination. Insect activity is rare in pepper plants except for ants and certain other crawling insects and insect pests such as pollu beetle. Bees do visit male spikes of certain *Piper* species. The spikes of certain species are fragrant; male spikes of *P. hymenophyllum* and *P. argyrophyllum* have faint aromatic small, while a *Piper* sp. maintained in the germplasm conservatory of IISR has fragrant spikes.

Wind pollination

Studies have shown that pollen transportation by wind is negligible under Indonesian situation (Iljas 1960) and practically absent under Indian condition. But Martin and Gregory (1962) based on their study in Puerto Rico, indicated that 32–64 per cent of the pollen on the spike may be dispersed to the air within 24 h after exposure.

Geitonogamy

Geitonogamy is a self pollination mechanism which involves gravitational descending of pollen grains combined with action of rain water or dew drops. This is an effective mechanism in plants having long pendent inflorescences. Heavy rains often have an adverse effect on pollination. Similarly lack of rain during the flowering period result in poor fruit set. (Anandan 1924, Govinda and Venkateswaran 1929, Marinet 1953). Iljas (1960) reported geitonogamy from Indonesia. He found that free hanging spikes isolated inside polyethylene bags displayed good fruit set, irrespective of insects or rain water. Pepper is adapted for such a mode of pollination. Pendent hanging spikes, spiral arrangement of flower, sequential ripening of stigmas and prolonged receptivity of stigmas are all favourable to geitonogamy.

The protogynous condition of pepper affects fruit set. The temporal separation of female and male phases can vary very much in bisexual cultivars from 0–30 days or even more, and it was found to be season and climate dependent. Suppression of anther emergence was noticed in certain high elevation areas where the temperature is low. Fruit setting and yield are reduced considerably in such areas (Ravindran, unpublished). In cultivars where male and female phases mature simultaneously autogamy may result. Inter-spike pollination may also be of frequent occurrence, as it is inevitable in a pepper plant that produces large number of spikes.

Apomixis

The first report of a possible case of apomixis in black pepper was that of Gentry (1955). He found fruits on male sterile cv *Uthirankotta* without the presence of pollen source in the neighbourhood. But his finding was not supported by later workers. Such situation as reported by Gentry does occur frequently in nature. It is commonly observed that in forests, isolated female plants exhibit good fruit set in the absence of any pollen source. This is common in many related species as well; indicating that apomixis could be playing an important role. Such fruiting has been recorded in female plants of *P. longum* and *P. chaba* growing in the germplasm conservatory of IISR. Incidentally in the case of *P. chaba* only female pants are present in the conservatory and they fruit profusely and produce viable seeds. In *P. longum* also pollen source is not required for fruiting, indicating that apomixis may be the rule in this species. In the Western Ghat forests, small populations of either male or female plants are met with quite frequently and in such female populations good fruiting is also noticed. All evidences tend to point to the presence of apomixis in the South Indian species of *Piper*.

But this is not the situation in the case of cultivars, which are mostly bisexual. Apomixis seems to disappear or at least gets suppressed to a great extent with the gain of bisexuality. In a study conducted by Sasikumar *et al.* (1992) many aspects of the pollen biology of pepper were brought out. Highest fruit setting was observed under open pollination in the three most popular cultivars, *Karimunda, Panniyur* 1 and *Aimpiriyan*. Spike setting was complete (100%) in all the three cultivars under selfing, bagging, hand pollination and open pollination. Self fertilization was highest in cv. *Aimpiriyan* followed by cvs. *Panniyur* 1 and *Karimunda*. Under water-free pollination, highest spike and fruit set was observed in cv. *Panniyur* 1. Though *Karimunda* registered a slightly higher spike set than *Aimpiriyan* under water-free pollination, the fruit set in general was higher in *Aimpiriyan*. In all the three cultivars fruit set was less under water-free condition than under open pollination. However the magnitude of reduction in seed set was very much in *Karimunda*. The above authors have calculated the extent of autogamy in three cultivars, 86 per cent in *Karimunda,* 92 per cent in *Panniyur* 1 and 95 per cent in *Aimpiriyan* and the percentage self compatibility was 84 per cent, 91 per cent and 86.5 per cent respectively. These results indicate that selfing is the predominant form of fertilization in cultivated bisexual pepper. Though protogyny occurs, it appears ineffective to prevent selfing as the pendent spike is abundantly assured of pollen from upper flowers. In cv. *Karimunda* emasculation and bagging resulted in 7.0 per cent spike setting and 8.2 per cent fruit setting indicating the occurrence of apomixis to a small extent. The fruit setting in predominantly female cultivars such as *Cholamundi, Uthirancotta* and *Karuvilanchy* may be entirely due to apomixis.

Assisted pollination, hybridization

Intervarietal hybridization is an extremely important approach for crop improvement and enhancing crop yield. Such crossing involves pollen transfer from the pollen parent to the stigmatic lobes of the female parent. Nambiar *et al.* (1978) used emasculation, isolating the emasculated spikes in butter paper bags and pollination. Emasculation is carried out by scooping out the anthers from either side of the ovary using a fine pointed needle. The unemasculated portion of the spike is trimmed off and the spike covered with paper bag. Pollen grains are collected by washing the spikes with distilled water and collecting the washings. Pollination is carried out by applying the pollen suspension on the emasculated spike using an ink filler or brush. The setting has been reported to be around 6–12 per cent. Martin and Gregory (1962) described two techniques of pollination in pepper which were also not very successful. In one technique ripe anthers were opened by means of a scalpel and pollen was scooped up and applied on the stigma of selected spikes. In the other technique spikes from male and female parents were brought together and brushed with a camel hair brush. Emasculation was tried by alcohol, hot water and excision. Iljas (1960) suggested emasculation by employing a suction pump.

In Sarawak, De Warrd (1969) developed a method of hand pollination which made use of the extended period of protogyny in the cv. *Kuching*. Here prior to cross pollination all spikes present on the receiving plant (female parent) are removed to prevent geitonogamy. At three or four locations branches were selected, and they were bagged in cheese cloth bags and allowed to develop spikes. As soon as stigmas are receptive in three or four spikes in the selected branch, pollen from a male parent is transferred to the stigma. For this, a portion of spike having freshly opened anthers are cut off and placed on the end of a long pin and the entire pollen cluster is gently brought into contact with the young stigma. This method was reported to give 50–75 per cent success.

Ravindran *et al.* (1981) developed an efficient crossing technique making use of the protogyny. They raised dwarfened pepper plants (bush pepper) of various cultivars by rooting the lateral fruiting, plagiotropic branches. These dwarf plants flowering in pots are used for establishing a crossing block in green house (Fig. 2.21). These plants can be kept isolated either spatially or mechanically using nylon cloth or rain proof bolting cloth or poly bags. In such isolated plants spikes are selected for crossing, and an soon as the stigmas become receptive pollination is carried out. For this, sufficient number of anthers are collected from the male parent the previous afternoon into a small vial and is kept in a desiccator over calcium chloride for dehiscence. The

Figure 2.21 Crossing block established at I.I.S.R. using bush peppers grown from lateral, plagiotropic fruiting branches.

next morning a few drops of distilled water is added to the vial, shaken well and this suspension of pollen is brushed onto the stigma or applied using an ink filler. For successful pollination high concentration of pollen grains in the suspension should be ensured, and this can be checked by observing a drop of suspension under a microscope. The process of pollination is continued for a few days till anther emergence is noticed in the spike, when pollination is stopped and the unfertilized portion of the spike is trimmed off. This method is very successful and upto 82 per cent setting was recorded. Only limitation is that it is not applicable to cultivars having no or only very brief interval between the male and female phases, where emasculation becomes necessary.

Fruit Set, Fruit Development and Fruit Maturity

Under natural conditions the ovules in a spike can either develop into a full grown fruit, or they become under developed fruits or they may become under developed ovules. The full grown fruits are the result of successful pollination, fertilization and development. The undergrown fruits result when the development gets arrested midway, and Martin and Gregory (1962) suspected that insect damage might be a major cause for this. The underdeveloped ovules are probably unfertilized ovules. This may be due to insufficient pollination or due to poor pollen quality, or loss of stigma receptivity before pollination or stigma damage or a combination of these factors. Martin and Gregory (1962) reported that in a sample study, 13.5 per cent of the stigmas was found undamaged, 72.6 per cent moderately damaged and 13.9 per cent severely damaged.

Pepper fruit takes 6–8 months for full maturity from flowering, depending upon variety, the average being 7 months. This is decided both by genetic make up of the plant, and by prevailing climate; the maturity is delayed in cooler climate at high elevation. The fruit ripening is very much uneven. The fruit at the top of the spike turns yellow and then red on full ripening. When a few such spikes appear in a vine, harvesting is done.

Seed Germination

Pepper seed is recalcitrant and viability is retained only for about a week. Storing at 5°C after removing the seed coat prolongs viability. If sown within a few days after harvesting, ripe seeds germinate easily in 20–25 days. Ghawas and Maaraf (1983) showed that seeds stored in poly bags, at 4°C and 42 per cent RH retained viability for 40 days. Removal of pericarp enhanced germination. Keeping seeds in shade for three days after harvest was reported to be beneficial (Ibrahim *et al.* 1993).

Germination is epigeal. Ravindran *et al.* (1985) studied seed germination in 40 cultivars and found that germination starts in 22–45 days after sowing. The time required for completing germination varied from 50 to 77 days, majority of the cultivars completing germination in 50–60 days. Germination varied from 25 per cent in a line of cv. *Kalluvally* to 100 per cent in cv. *Nastnigunda*. Twelve cultivars gave less than 50 per cent germination, while four cultivars gave over 80 per cent germination. It was also noted that seeds of the same cultivar from different sources showed differences in germination percentage. For eg. in cv. *Arakkulammunda* germination varied from 70–84 per cent, in *Balancotta* from 53–92.4 per cent, in *Karimunda* 49.5 to 86 per cent, in *Kuthiravally* 40.7 to 64.8 per cent, in *Narayakodi* 45 to 95 per cent, and in *Panniyur* 1 23.0 to 82.5 per cent.

Yanes and Segoria (1982) studied the process of seed germination in *P. hispidum* and the role of light quality in deciding the dormancy of seeds. They reported that seeds of this species may remain dormant in dark for a long time, and that R/FR ratio does not seem to be responsible for this. Under field condition the seeds falling on the soil germinate normally if they lie on the soil surface, if buried in soil they may lie dormant for sometime. They opined that the R/FR ratio of the light reaching the embryo may well change after being filtered by the seed coat and as the seeds remain dormant it means that phytochrome is inactive when they are at the point of being dispersed. The seeds of *P. auritum,* a species growing in full sunlight, do not germinate in the shade of vegetation (Yanes 1976).

Pepper seeds take a longer time for germination, compared to other recalcitrant seeds, because the embryo is not fully mature when the fruits are shed. The development of the cotyledons takes place later, and the germination process is delayed till the embryo development is complete.

Chaudhury and Chandel (1994) showed that pepper seeds withstood desiccation down to 12 per cent moisture content but viability loss increased with reduction in moisture level below 12 per cent. Seeds desiccated to 12 per cent and 6 per cent moisture contents were successfully cryopreserved with survival rates of 45 per cent and 10.5 per cent respectively.

CYTOLOGY

Cytological studies available are confined mostly to chromosome number determination of various species. Contributions to the cytology of *Piper* were made by Johnson (1902), Johansen (1931), Janaki Ammal (1945), Tjio (1945), Maugini (1950), Mathew (1958, 1972), Sharma and Bhattacharya (1959), Dasgupta and Dutta (1976), Jose and Sharma (1983, 1984, 1988), Rahiman (1981), Stella Bai and Subramanian (1985), Samuel and Bavappa (1981), Samuel (1986), Okada (1986), Samuel and Morawetz (1989) and Nirmal Babu *et al.* (1992 a). Only a few of them attempted to study the chromosome morphology (Mathew 1972, Sharma and Bhattacharya 1959, Dasgupta and Dutta 1976, Jose 1981 and Jose and Sharma 1984, 1985, 1988).

The cultivated pepper is having the somatic chromosome number of 2n=52 (Fig. 2.22). Mathew (1958, 1972) studied eleven cultivated and six wild *P. nigrum* and found that in all the cultivars the chromosome number was 2n=52, while 2n=104 was noted in the wild types. The chromosome length ranged from 1.0 to 3.0 μm. Sharma and Bhattacharya (1959) reported 2n=48 in *P. nigrum*. Dasgupta and Datta (1976) reported 2n=36 for *P. nigrum* collected from North Eastern India and 2n=60 for South Indian types. The chromosome number reports on *Piper* are given in Table 2.10.

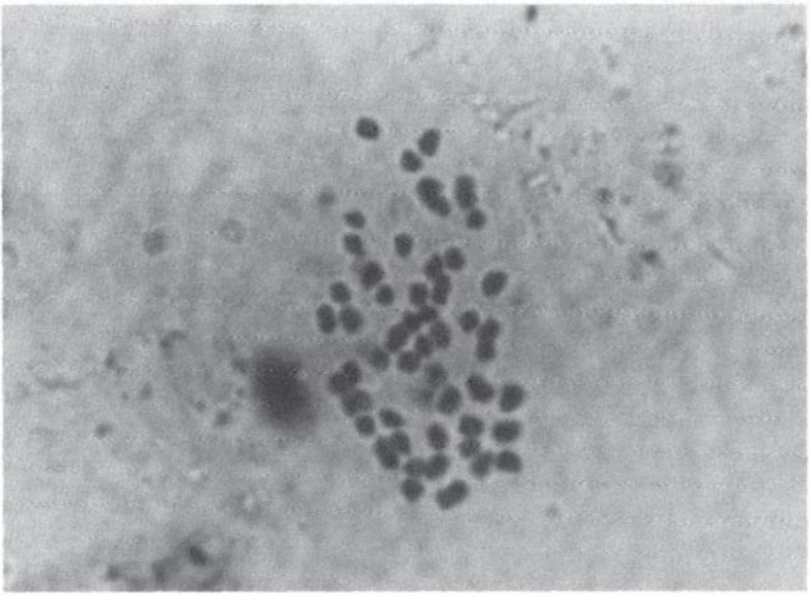


Figure 2.22 Cell showing the somatic chromosome complement of 2n=52.

In *P. longum,* Tjio (1945) observed a heteromorphic bivalent in the somatic cells and interpreted the same as the sex chromosomes. Mathew (1958) reported a heteromorphic bivalent in the male plants of *P. longum,* which he has interpreted as x and y chromosomes. He postulated that the male is xy and female xx.

The studies in general pointed to the existence of a polyploid series in the genus. The chromosome numbers reported include 2n=24, 26, 36, 39, 40, 48, 52, 60, 64, 65, 68, 80, 96, 104, 132 and 156. All the species studied from South India and Sri Lanka could be traced to a common basic number of x=13, while the North Indian species seem to have a basic number of x=12. It has been suggested (Mathew 1958) that x=13 reported consistently for the genus has to be taken as the valid chromosome number of the genus, and that, this might have arisen by hybridization of types with x=6 and x=7. The species with 2n=26 are then diploids, and those with 2n=104 types are octoploids. The highest number so far reported are in *P. mullesua* 2n=132, decaploid. Jose and Sharma (1984) reported 2n=156 in a line of *P. peepuloids* (12-ploid). Stella Bai and Subramanian (1985) are of opinion that *P. galeatum* (2n=40) and *P. betle* (2n=64) are aneuploids, while *P. attenuatum* (2n=36), *P. longum* (2n=60), *P. schmidtii* (2n=96), *P. wightii* (2n=48) and *P. mullesua* (2n=132) are higher polyploids.

Mathew (1972) studied six cultivated *(Karimunda, Narayakodi, Kumbhakodi, Kuthiravally, Kottanadan, Aripadappan)* and six wild varieties of *Piper nigrum*. All the cultivated lines were 2n=52, while two of the wild collections were 2n=104. He also suggested that the 52 chromosome situation in *P. nigrum* was probably of ancient polyploid origin, followed by diploidization during the course of evolution. He concluded that progressive reduction in spike length had accompanied evolution of

Table 2.10 Chromosome number reports on *Piper* species.

Sl. No.	*Species*	*Somatic chromosome number (2n)*	*Reference*
1	*P. attenuatum*	36	Stella Bai & Subramanian (1985)
		52	Rahiman & Nair (1986)
		26, 39	Samuel & Bavappa (1981)
		52	IISR*
		52	Jose and Sharma (1985)
2	*P. argyrophyllum*	36, 39	Samuel & Bavappa (1981)
		52	Rahiman & Nair (1986)
		52	IISR*
3	*P. galeatum*	40	Stella Bai & Subramanian (1985)
		52	Rahiman & Nair (1986)
		52	IISR*
4	*P. hymenophyllum*	104	IISR*
5	*P. hookeri*	60	Stella Bai & Subramanian (1985)
		104	Rahiman & Nair (1986)
6	*P. longum*	60	Stella Bai & Subramanian (1985)
		24, 26, 48, 96	Sharma & Bhattacharya (1959)
		52	Mathew (1958)
		52	Rahiman & Nair (1986)
		52	Jose & Sharma (1985)
7	*P. betle*	32	Janaki Ammal (1945)
		64	Sharma & Bhattacharya (1959),
		78	Stella Bai & Subramanian (1985)
		42, 52, 58, 78, 195	Mathew (1958)
		26, 52	Dasgupta & Dutta (1976), Samuel & Bavappa (1981)
8	*P. colubrinum*	26	IISR*
9	*P. cubeba*	24	Janaki Ammal (1945)
		24	Dasgupta & Dutta (1976)
		24	Jose and Sharma (1985)
10	*P. chaba*	24	Janaki Ammal (1945)
		104	Jose & Sharma (1985)
11	*P. magnificum*	24	Dasgupta & Datta (1976)
12	*P. ornatum*	80	Sharma & Bhattacharya (1959)
13	*P. nigrum*	128	Janaki Ammal (1945)
		48	Sharma & Bhattacharya (1959)
		36, 60	Dasgupta & Datta (1976)
		52	Mathew (1958, 1973)
		52, 65	Samuel & Bavappa (1981)
		52	Rahiman & Nair (1986)
		52	IISR*
		104	Mathew (1958)
		78	Nair *et al.* (1993)
14	*P. schmidtii*	96	Stella Bai & Subramanian (1985)
15	*P. wightii*	(n = 24)	Stella Bai & Subramanian (1985)
16	*P. sugandhi*	52	IISR*

Table 2.10 *continued*

Sl.No.	*Species*	*Somatic chromosome number (2n)*	*Reference*
17	*P. trichostachyon*	52	IISR*
		52	Rahiman & Nair (1986)
18	*P. hapnium*	52	IISR*
19	*P. mullesua* syn.	132	Rahiman & Nair (1986)
	P. brachystachyon	132	Stella Bai & Subramanian (1985)
			IISR*
20	*P. peepuloides*	156	Jose & Sharma (1985)
21	*P. boehmeriaefolium*	52	Jose & Sharma (1985)
22	*P. barberi*	52	Nirmal Babu (1992a), Mathew and Mathew (1992)

* Unpublished data from IISR.

the cultivated pepper varieties. He carried out a karyotypic comparison of the different cultivated and wild varieties based on absolute chromosome size and got a positive correlation between spike length and chromatin content in general. Among the cultivars studied, cv. *Karimunda* had the smallest absolute chromosome size (62 μm) and the shortest spikes (9.1 cm) while cv. *Aripadappan* having higher absolute chromosome size (74 μm) produced the longest spikes (15.5 cm).

Jose and Sharma (1984) distinguished six classes of chromosomes in *Piper*. Type A: Relatively long chromosomes with two constrictions, one median, and the other nearly sub median in position (2.22 μm to 1.48 μm). Type B: Long chromosome with two constrictions, primary and secondary, nearly submedian at the opposite ends of the chromosome dividing it into two, outer short and middle larger segment (3.33 μm to 2.41 μm). Type C: Short chromosomes with nearly median to nearly submedian primary constriction and a satellite at the distal end of shorter arm, joined by a SAT thread (1.88 μm to 1.70 μm). Type D: Relatively long chromosome (2.22 μm to 1.48 μm) with nearly median to nearly submedian primary constrictions. Type E: Short chromosome (1.48 μm to 0.56 μm) with nearly median to nearly submedian primary constriction. These authors suggested that the various *Piper* spp. represent a homogeneous assemblage where gene mutation or imperceptible chromosome changes have affected the evolution both at inter and intra specific levels. *P. cubeba,* according to them, is a notable exception in chromosome number (2n=24), large chromosome size and total chromatin length. This species is generally regarded as primitive, a conclusion supported by anatomical evidences also (Datta and Dasgupta 1977a, b and c). This led to the suggestion that n=12 of *P. cubeba* may represent the original basic number from which the n=13 might have derived, and this number got established in the subsequent speciation in the genus possibly due to selective advantage (Jose and Sharma 1984).

Nair *et al.* (1993) reported a natural triploid among pepper cultivars. They studied the cytology of the progenies of this cultivar and reported considerable chromosome number variations, from 2n=52 to 2n=104. Progenies having 2n= 55, 65, 72, 73, 76, 82, etc. were found to be very abnormal in growth. The triploids could have originated under natural condition by hybridization between 2n=104 and 2n=52 forms, and because of the successful vegetative propagation the triploid have high survival value also.

Samuel *et al.* (1986b) studied the interspecific variation in DNA among nine species of *Piper*. They found that the DNA amount of a wild diploid accession of *Piper nigrum* was approximately double of that of the cultivated tetraploid variety of the same species. The DNA content per basic genome was lower in cultivated species than in wild species.

ORIGIN AND INTERRELATIONSHIPS

Origin of *P. nigrum*

Pepper has originated in the evergreen forests of the Western Ghats of South India. Wild pepper plants are found extensively in the less disturbed forests, more in the moist evergreen forests, even upto elevations around 1200–1500 metres. No study has so far been carried out to find out the origin of *P. nigrum*. Cytological studies led workers like Mathew (1958, 1972) and Jose and Sharma (1984) to suggest that the basic chromosome number of *Piper* is x=13 and that *P. nigrum* with 2n=52 is tetraploid. A study of the species occurring in Western Ghats indicated that *P. nigrum* might have originated through hybridization between species with or without polyploidization of the hybrid. Based on morphological and biosystematic studies, Ravindran (1991) suggested three species namely *P. wightii, P. galeatum* and *P. trichostachyon* as the putative parents of *P. nigrum*. All these are woody climbers, having more or less similar leaf morphology and texture. Their spikes and fruits are more similar to *P. nigrum* than to those of other species. The fruits of all the three have small amount of pungency and flavour. Of the three, *P. wightii* and *P. galeatum* were suggested as the most probable ancestors of *P. nigrum*. The most compelling evidence, according to the above worker, for such a conclusion, comes from the nature of the bracts. In *P. galeatum* the bracts are connate, fleshy and shoe shaped; in *P. wightii* the bracts are fully adnate to the rachis, the shape being more or less oblong. In *P. nigrum* the bracts form a shallow cup like structure, this character being typically intermediate between the first two cases. Ravindran (1991) has suggested the following relationships:
P. wightii is a threatened species now, so also *P. galeatum,* the former occurring only in certain restricted niches around 1500–2000 m, while the latter occupying at the lower elevational levels. In the past, forests were in continuous stretches which might

P. wightii (2n = 52) X *P. galeatum* (2n = 52)
↓
P. nigrum
2n = 52

P. wightii (2n = 52) X *P. trichostachyon* (2n = 52)
↓
P. nigrum var. hirtellosum
2n = 52

have led to the overlapping of these species. Most probably as it happens even today, more than one species might have climbed up the same support trees, thereby providing opportunity for natural crossing. The progenies once formed get effectively isolated from the parents and rest of the progenies, because of the absence of any active pollen transfer mechanism, thereby preventing random mating and subsequent gene flow (Ravindran *et al.* 1990). At the same time the highly successful vegetative propagation ensures their survival and spread. This hypothesis is further supported by the recent discovery of intermediate populations, comprising probably of hybrids between *P. nigrum, P. sugandhi, P. galeatum* and *P. trichostachyon* and their segregants in certain locations in the Western Ghats (IISR unpublished).

Such natural crossings might have happened a great many times at many locations, gradually leading to the building up of large populations of hybrids (Ravindran 1991). Gradually the progenies that co-existed might have undergone sibmatings, back crossings and segregations producing fertile hybrids and also segregants. The successful progenies might have spread both vegetatively and through seeds, gradually becoming successful colonisers in the forest lands. The present day *P. nigrum* are probably the descendents of such segregating populations existed in the past. These populations, isolated from one another due to lack of any mechanism for active gene flow, diverged subsequently, finally leading to the present day wild and cultivated black pepper.

Phylogeny and Interrelationships

Phytogeographical distribution shows that *Piper* and the related genus *Peperomia,* probably have originated in tropical America at a comparatively high altitude and dry conditions. *Peperomia* thrived later in drier and higher Andes zones, *Piper* in comparatively lower and damper Brazil and later spread to parts of Asia and other regions. Datta and Dasgupta (1979) after studying the anatomical features of Piperaceae concluded that the evolution of *Piper* and *Peperomia* are related to adaptation with two different conditions; *Piper* adapted gradually with damper lowlands with elaboration of vascular arrangement, while *Peperomia* evolved in drier and higher lands (Andes zones) which required reduction of bundle surface or surface volume ratios, a xerophytic character. Little is known about the evolutionary trends among Indian *Piper*. Datta and Dasgupta (1977c) after studying anatomical features of *Piper* species from north eastern region of India concluded that there is definite sequence of advancement from *P. cubeba* to *P. longum* to *P. nigrum* and finally to *P. betle*. This sequence of advancement according to them is related to the gradual elaboration of the tracheary plates; the most primitive form is found in *P. cubeba*.

Ravindran (1991) and Ravindran *et al.* (1992a) arrived at certain definite groupings among taxa that are closely related to pepper based on biosystematic studies. These groups are:

1) *P. longum, P. hapnium*
2) *P. galeatum, P. trichostachyon*

3) *P. attenuatum, P. argyrophyllum, P. hymenophyllum*
4) *P. mullesua, P. silentvalleyensis*
5) *P. wightii, P. schmidtii*
6) *P. nigrum, P. sugandhi*

The members of each of these groups are more closely related than members of different groups. Cytological evidence as mentioned earlier, has shown that most of the South Indian species have somatic chromosome number of 2n=52; and that the basic number is x=13. Pepper and all its related taxa are either tetraploids or higher polyploids and that polyploidy seems to have played an important role in the speciation of South Indian *Piper* (Mathew 1958, Rahiman 1981). From the ancestral forms more than one developmental lines can be visualised among the South Indian taxa of *Piper,* one of which leading to *P. longum, P. mullesua,* etc.; a second line leading to *P. galeatum* and *P. trichostachyon* and then to *P. wightii* and *P. nigrum,* a third one leading to *P. attenuatum, P. argyrophyllum* and *P. hymenophyllum*. It is possible that the ancestors as well as the connecting links might have been lost during the course of evolution (Ravindran 1991).

Origin of Black Pepper Cultivars

It was mentioned in the previous section that *P. nigrum* might have originated as a hybrid. The overlapping of the putative parents at many locations could have given rise to hybrids on many occasions, separated in space and time. Much variability might have been accumulated in due course as a result of intercrossing, segregation, back crossing and accumulation of random mutations. Because of the successful vegetative propagation, and the absence of active pollen transfer, random mating and gene flow, an isolation barrier is built up around each individual plant. Chances of crossing is then limited to situations where more than one plant climbs up the same tree. This condition could have led to the establishment of a great many localised small populations, each one isolated from others. The present day cultivars might have originated from such localised populations (Ravindran and Nirmal Babu 1988, Ravindran *et al.* 1990).

Initially black pepper was a forest produce, people were collecting them from the plants growing in the forest. Gradually people started cultivating them. For this the farmers selected vines having good fruit set, pungency, size, spike length etc. As a result of such selection process many cultivars came into existence in many localities. The present day cultivars probably have originated in this way. Because of the selection pressure for better fruit set the bisexual forms might have been selected as they give much better fruit set. This selection would have led to the directional evolution of bisexuality in the cultivated forms.

The New World *Piper* Vs. South Indian *Pipe*—An Evolutionary Dichotomy

When one looks at the New World (South and Central American) and Old World (especially the South Indian) species of *Piper,* one arrives at the inevitable conclusion that the evolutionary development in the genus represents a major case of dichotomy. The South and Central American species of *Piper* and their counterparts in South India seem to have evolved along two distinct evolutionary lines. American *Piper* (with very few exceptions) are bisexual forms and are shrubs or small trees (Yuncker 1958). On the other hand the South Indian *Piper* are mostly dioecious (except the cultivated) and are woody or scandent climbers or creepers, mostly with pendent filiform spikes. Of the eight species of climbing *Piper* described by Tebbs (1989) from the New World, all but one possess erect spikes. These major difference resulted probably due to their evolution through two different lines from two different ancestral forms.

The centre of diversity for the genus is Northern South and Central America, which together account for more than 60 per cent of the species reported (Datta and Dasgupta 1977c). It becomes a moot question how the genus has spread to such diverse geographical areas from the centre of diversity. The genus might have originated in the present day Central and Northern South America during the mid Cretaceous, before the splitting away of the ancient Gondwana land by the plate tectonic activity. The available fossil evidences indicate that the initial major diversification of angiosperms took place during the late Cretaceous (Friis *et al.* 1987). Palynological data suggest that the angiosperm radiation began at low paleolatitudes (Brenner 1976, Hughes 1976), but within a relatively short span of time angiosperms became established world wide, probably during the mid Cretaceous (Upchurch and Wolfe 1987; Crane 1987). The earliest well documented angiosperm fossil includes dispersed monosulcate pollen grains of the form genus *Clavatipollenites,* believed to be closely related to the extant Chloranthaceous genus *Ascarina*. This unequivocally indicates the early appearance of Piperales (Friis *et al.* 1987).

It can be hypothesized that some of the ancestors of the present day *Piper* might have spread to various regions of the ancient Gondwana land. The plate tectonic activity and the opening up of the Atlantic and Indian oceans led to the splitting away of the Gondwana land mass into the present day South America, Africa, India and Australia. Many of the ancestors might have perished as a result of the drastic changes in climate that followed the movement of the continents. The survived ones might have undergone natural crossing, polyploidy etc. that led finally to the present day species.

Thus the present day forms might have originated from the ancestral forms that reached the Indian subcontinent during the mid Cretaceous before the plate tectonic activity shifted India. The South Indian species of *Piper* are all either tetraploids or higher polyploids, while the 2n=26 diploid forms are absent, indicating that these ancestral forms might have become extinct; while in its original home in Central America and Brazil diploid forms have been reported frequently (most of the reported ones are diploids). The descendants of the ancestral forms of South America and South India might have evolved independently in two lines in response to the needs of the habitats. As colonizers of the tropical rain forests, the climbers along with vegetative propagation will have definite selective advantage in getting more sunlight than the undershrubs or small trees. A plant that can reach the forest canopy rapidly gains an advantage, enabling it to utilise the better light availability there (Gentry 1985). This climbing habit has evolved independently several times over in many plant families (Tebbs 1989). The predominance of vegetative propagation combined with the absence of free gene flow among the individuals and populations might have played a role in the evolution of dioecy and the particular growth habit of the black pepper and related South Indian taxa.

PHYSIOLOGY

Root Distribution

Adventitious roots developing on the stem node and from the cut ends, form the root system of pepper, and usually will not have more than 10 main roots. In pepper, 90–98 per cent of feeder roots are distributed between 30–40 cm in two year old plants and 85–90 per cent in four year old plants whereas water absorbing root system penetrate even up to 4 m. The root to shoot ratio increased with age (Terada and Chiba 1971). Irrespective of the age of the plant, most of roots (67–85%) were found in 0–30 cm deep soil layer and 35–70 cm from the base (Ramos *et al.* 1984). Jayasree *et al.* (1988) studied root activity patterns of pepper trailed on *Erythrina* or on teak pole, employing ^{32}P soil injection technique. In both cases 90 per cent of the root activity was found within an area of 30 cm radius around the plant. Vertical distribution of the feeder roots of plants trailed on *Erythrina* was more or less uniform up to a soil depth of 40 cm. On the other hand, the root activity of plants trailed on teak pole was more at 40 cm depth than in upper soil layers. *Erythrina* was found to be more a surface feeder compared to the pepper and its feeder roots extended over 60 cm into the rhizosphere of pepper plants laterally.

Spike Shedding

Shedding of spikes (especially young spikes) is common in pepper. It may be, either due to the fungal *pollu* or black berry disease (*Colletotrichum* sp.), insects or due to prolonged drought after the plants have started flowering. It may also be due to complete absence of pollination of the flowers on the spikes (Anandan 1924). Geetha and Nair (1989) attributed spike shedding to inadequate pollination, low soil moisture and low N and K in shoots. In general, it is seen that soil moisture stress after flower initiation has serious consequences and affects all varieties of pepper more or less equally. Shedding due to non-pollination of flowers is confined to predominantly female cultivars like cv. *Uthirankotta* and they are usually poor yielding. Data on the extent of spike shedding in *Panniyur*-1 at monthly intervals starting from May to December revealed that shedding is lowest in May (1.7%) and highest in June (51.3%). This sharp increase in spike shedding may be due to a combination of reasons such as rapid fall in light intensity and photosynthetic rate in June as a result of the monsoon rains and cloudy weather, sudden spurt in the populations of insect pests such as *pollu* beetle, deficiency of nutrients to support the sudden bursting forth of flushes and flowers etc. No spikes are shed in September. In relation to plant development stages, spike shedding was highest (33.2%) during the first month of fruit set and lowest (1.7%) during fourth month (Menon and Nair 1987). In general, two phases of spike shedding are observed, the first lasting for 2–3 months occurring during early spike development and the second lasting for 1.5–2 months preceding harvest (Geetha and Nair 1989).

Influence of plant growth regulators on spike shedding

Various growth regulators such as NAA, IAA, 2,4-D, GA, planofix, etherel etc., have been tried to prevent spike shedding and also to increase the productivity in pepper (Kandiannan *et al.* 1994). Effect of growth regulators on fruit set, fruit development and yield in pepper was investigated by Ponnuswami *et al.* (1980). Low doses of 2,4-D promoted fruit development in pepper (Hariharan and Unnikrishnan 1985). Application of planofix (90–150 ppm) did not reduce the incidence of spike shedding, but fruit number and weight were increased (Pillai *et al.* 1977). Application of IAA at 50 ppm, planofix at 50 ppm, 0.5 per cent Zn and 2,4-D at 5 ppm reduced spike shedding by 63.6, 52.2, 48.4 and 35.3 per cent respectively in terms of fruit weight relative to the control. The fruit oleoresin content was highest (14.21%) when NAA was applied at 150 ppm (Geetha and Nair 1990). Application of growth regulators had no effect on hastening spike maturity, but increased fruit weight and net returns/ha (Salvi and Desai 1989).

Leaf Area, Photosynthesis and Dry Matter Accumulation

The leaf area per plant in bush pepper (developed from plagiotropic fruiting laterals) depends primarily on the increase in leaf area, while in vine pepper it is primarily dependent on the number of leaves produced. Number of leaves, total leaf area as well as total and aerial biomass production differs significantly between vines and bush pepper and are dependent on nitrogen levels (Geetha and Aravindakshan 1992).

Mathai and Nair (1990) observed excessive vegetative growth in poor yielding pepper cultivars. They obtained positive and significant relationship between biomass production and economic yield in all the cultivars investigated. Leaves accumulated more biomass than stem. Specific leaf weight (mg/m^2) was higher in *Karimunda* than *Panniyur*-1. Shoot growth in *Panniyur*-1 started in late May and continued till mid August with highest growth occurring in June while highest flowering occurred in July (Menon and Nair 1987). Leaves and stem of fruiting branches accumulate highest biomass (Nagarajan and Pillay 1975).

Pepper plants are grown under the shade of supporting trees. It was shown that higher light availability during preflowering (March to April) produced greater leaf area and a more compact canopy structure with shorter lateral shoots. This allowed the plant to accumulate higher levels of metabolites, greater production of lateral shoots during the second flush and more flowers, spikes, and fruit number and higher dry matter (DM) of fruits per plant (Mathai and Sastry 1988). However, photosynthetic rate decreases when illumination exceeds 50,000 lux (900 μ mol s^{-1} m^{-2}) in some pepper cultivars (Mathai 1983).

The normal growth and development of plant depends on the availability of stored and current photosynthates. Hence, better carbon fixation rates and efficient translocation of the synthesized sugars are paramount to attain higher yields. This in turn is dependent on the source area (Aravindakshan and Krishnamurthy 1969). The 45 day old pepper fruiting spikes depend more on stored photosynthates while fruiting spikes older than 45 days depend more on current photosynthates. A drastic reduction in leaf area (62%) of black pepper lateral after 60 days of spike initiation affect the yield attributes severely due to limitation in the availability of current photosynthates (Mathai *et al.* 1988) and spike growth after 45 days of initiation is dependent on current photosynthates for its dry matter accumulation (Mathai *et al.* 1989). However, they noted that the existence of a partial compensatory triggering mechanism in photosynthesis is also possible.

Low yielding cultivars had large canopy surface area and accumulated 80 per cent of dry matter in laterals, whereas high yielding cultivars accumulated only 50 per cent of dry matter in laterals. Dry matter distribution in fruits is low in low yielding cultivars and high in the high yielding cultivar *Panniyur*-1 (Mathai and Nair 1990). *Panniyur*-1 has more laterals, spikes and berries, has higher mean berry weight, higher rate of photosynthesis and translocation and also higher yield compared to four other cultivars (Mathai 1986). The efficient dry matter partitioning capacity of high yielding cultivars was strongly influenced by their total biomass production. For high economic yield biomass production of laterals should be high.

Total Nitrogen and Nitrate Reductase Activity

Pepper leaves and stem contain highest nitrogen during June (Nybe *et al.* 1989). Leaves accumulate highest nitrogen, followed by spikes and shoots, the values varying from 1.9 to 2.1 per cent in stem, 2.7 to 2.9 per cent in leaves and 2.1 to 2.4 per cent in spikes. Similar trends were also noticed by other workers (Nagarajan and Pillay 1975, Pillay and Sasikumaran 1976). Profiles of ten amino acids have been characterized in pepper leaf (Vasantha *et al.* 1991).

The nitrate reductase (NR) activity was found to be optimum at 30° C in the medium with 0.1 M nitrate at pH 7.0 and 0.1 M phosphate concentration (Shaukathali and Ramadasan 1995a). NR activity was induced by nitrate alone in the medium and this induction was enhanced by the addition of ammonium salts (Shaukathali and Ramadasan 1995b). The flag leaf of pepper leaf opposite the spike, irrespective of its own stage of maturity, had higher NR activity during the early stages of fruit development and decreased with fruit maturation (Raju and Rajagopal 1988). They also observed an increase of NR in fruits with maturation and diurnal fluctuation of NR activity in leaf. Varietal differences in NR activity in six pepper cultivars ranged from 0.67 to 1.8 n mol NO_2/gFW/h. Runner shoots exhibited higher enzyme activity than laterals (Thomas 1990).

Productivity

Productivity of a plant depends on its efficiency in harvesting solar energy for the metabolite production and also partitioning efficiency of the metabolites produced. This character of a plant is controlled by its genetical make up to a certain extent. However, the environmental conditions under which a plant grows also influence productivity to a great extent. The growth- light-regime (GLR) is one of the environmental factors that influence the growth and productivity of the plant (Bindra and Brar 1977, Murray 1957, Murray and Nicholas 1966, Alvim 1958, Mathai and Chandy 1988).

Pepper is a shade loving plant. It requires a continuous supply of moisture in the dry period as it has a high evapotranspiration coefficient (Raj 1978). But it develops some physiological disorder when exposed to direct solar radiation even under favourable soil moisture (Vijayakumar *et al.* 1984). The parts of the plant under high GLR produce more fruits per unit surface area and those under low GLR produce less (Montaya *et al.* 1961). Under permanently shaded growth condition, plants generally show poor productivity. In this situation, fruit production shows positive correlation with light availability. In all the cultivars the upper portion of the canopy received on an average 53 per cent more light than the lower portion. Though a comparison among the cultivars receiving varying amount of light is difficult, it could be concluded that low productivity at the lower parts of the canopies is due to low light availability, reducing drastically the production of photosynthates and their partitioning.

Ramadasan (1987) reported that in adult pepper plants under scientific management, generally three canopy shapes are seen. The shaping of the canopy is largely based on the shading provided by the live support and the canopy of the adjoining shading trees. On dead supports, no tapering of the canopy at the top is seen. Trees growing adjoining to dead support lead to tapering of the pepper canopy base due to partial shading. Such tapering at the base is not observed when there are no competing trees. In Sarawak, the wood of Bornean iron wood *(Eusideroxylon zwageri)* is used as support and generally no shade tree is grown. In such dead supports the top of the canopy opens like an umbrella. In intercropping system (pepper, coconut and cocoa) top portion of the pepper plants receive more than 50 per cent of the incident light, which is the light received after interception of about 50 per cent of incoming radiation by coconut canopy. The middle portion receive only 30–40 per cent of the radiation and the base receive only less than 30 per cent. The reduction in incident radiation in the middle and the base portions of the canopy is due to shading by its own canopy besides the support and adjoining trees. There was more than 50 per cent reduction in yield due to shading and yield reduction was found to be directly related to the incident radiation. On the other hand, more than 100 per cent increase in yield in adult plants raised on dead support was recorded in cultivars *Panniyur*-1 and *Karimunda* (Menon *et al.* 1982).

Varietal variation for yield exists in pepper (Ibrahim *et al.* 1986). Yield variation in pepper plants raised from different planting materials is also reported (Pillai 1977).

Fruit yield strongly depends on reproductive as well as vegetative characters. The reduction in source area influence the yield attributes and photosynthates accumulation in pepper (Mathai *et al.* 1989, Koshy *et al.* 1989). Significant positive correlations were observed between yield and reproductive characteristics such as fresh spike yield, fresh fruit yield, number of spikes per vine and number of under developed fruits per spike (Ibrahim 1985 d, Sujatha and Namboodiri 1995) and also vegetative characteristics (Sujatha and Namboodiri 1995). Foliar phosphorus and potassium levels also showed significant positive correlation with yield (Nybe *et al.* 1989). Significant positive correlation between nitrogen content and fresh weight of spikes has also been reported. Investigations on the effect of various micro and macro nutrients on growth and development of spike is also carried out (Stoyan and Drev 1979). The partial or total removal of flag leaf significantly reduced spike length, number of fruits and fruit weight in *Panniyur*-1 (Kumar and Sreedharan 1984).

Vijayakumar *et al.* (1984) observed leaf yellowing leading to development of necrotic patches and eventual loss of vines in post monsoon and summer season which hinders pepper production. Soil water stress was considered to be the major cause for the development of the disorder. Solar radiation of high intensity under well watered condition also cause similar disorder. Application of lime on leaves reduced the incidence which act as reflectant without affecting plant growth. So a concept of Contact Shade Technology (CST) is suggested where reflectants can be used to artificially shade the shade loving crop plants. Spraying reflectant (lime) over the leaf surface enhanced the chlorophyll content also.

Drought Tolerance

Even though Kerala receives good rains, rainfall is not distributed uniformly and the crop suffers due to moisture stress from December to May. So, screening of pepper germplasm for drought tolerance assumes great importance. Stomatal resistance,

Table 2.11 Stomatal resistance (rs), transpiration rate (tr) and leaf water potential (Ψ_L) at critical moisture level (SMC).

	(rs: sec. cm^{-1}; tr: cm sec.$^{-1}$; Ψ_L: bars)					
	Control (SMC: 23.6%)			Treatment (SMC: 16.7%)		
Cultivar	*rs*	*tr*	*ΨL*	*rs*	*tr*	*ΨL*
Karimunda	2.95	7.98	5.80	6.03	4.50	8.20
Kottanadan	4.31	5.45	6.00	10.04	1.89	8.00
Nelamundi	2.15	10.57	5.80	8.06	2.63	8.90
Kuthiravally	3.67	5.69	6.80	6.35	2.48	8.40
Kalluvalli	5.15	4.45	5.60	12.30	2.08	7.20
Arakulammunda	5.95	3.89	5.80	22.05	0.13	16.00
Aimpiriyan	4.47	4.80	5.20	10.26	2.62	9.30
Panniyur-1	4.74	5.38	5.60	8.62	2.50	7.60

Reproduced from Vasantha *et al.* 1990.

Table 2.12 Proline content (F moles/g/f.wt) in black pepper cultivars.

Cultivar	*Proline content*
Karimunda	3.48 ± 0.29
Kottanadan	2.48 ± 0.62
Neelamundi	2.69 ± 0.75
Thommankodi	2.32 ± 0.35
Narayakodi	2.28 ± 0.11
Kuthiravally	2.05 ± 0.17
Kalluvalli	3.46 ± 0.21
Arakulam munda	2.32 ± 0.66
Aimpirian	1.96 ± 0.29
Panniyur-1	2.37 ± 0.14

Reproduced from Vasantha *et al.* 1991.

transpiration rate and leaf water potentials are used to screen drought tolerant types in black pepper (Vasantha *et al.* 1990, Table 2.11). Chlorophyll to carotenoid ratio can also be used as stress index (Vasantha *et al.* 1989). Thomas *et al.* (1990) studied the proline accumulation potential of ten selected cultivars of black pepper under PEG induced stress. Accumulation of proline was higher and earlier in cvs. *Kottanadan* and *Neelamundi* compared to control. Maximum decline in the accumulated proline during recovery from water stress was observed in cvs. *Neelamundi, Kottanadan* and *Aimpiriyan*. Absolute proline content ranged from 1.96–3.48 μ moles (Vasantha *et al.* 1991, Table 2.12). During moisture stress, leaf expansion rate decreased before soil moisture reached critical levels, indicating screening cultivars based on leaf expansion rate may not be useful (Ramadasan and Vasantha 1994). Root to shoot ratio was higher in cv *Kalluvally* compared to other cultivars. Epicuticular wax content ranged from 1.46 to 2.08 mg/cm^2. Nitrate reductase activity declined in all cultivars under moisture stress. Membrane stability tests can be used for screening.

A rain less period extending up to three months together with a frequent day temperatures of 35°C are deleterious to the crop. During the six months from December to May, even the total rainfall received is scanty. The sudden drying of vines in hot summer was found to be due to the intense heat along with low soil temperature, which affected the base of vines (Ramadasan and Vasantha 1994). In any such yellowing and subsequent death of plants, there is also the involvement of root damaging agents such as the burrowing nematode and *Phytophthora capsici*. Extensive damage to the feeder root system by these organisms leads to an induced stress, subsequent yellowing of leaves, leaf shedding and vine death during the severe drought period.

CROP IMPROVEMENT

As in most crop plants the primary objective of pepper breeding is increase in yield.

This primary objective has been broadened towards evolving varieties combining high yield, quality and resistance to biotic and stresses. Thus the important goals in crop improvement in pepper are:

1. Higher yields, greater productivity
2. Resistance to the foot rot disease caused by *Phytophthora capsici* and other diseases, such as little leaf or mosaic (a virus disease)
3. Resistance to nematodes, *Radopholus similis* and *Meloidogyne incognita,* involved in the slow decline of pepper
4. Resistance to insect pests, mainly against the *pollu* beetle *(Longitarsus nigripennis)*, scales shoot borer and mealy bugs
5. Improvement in quality, higher levels of essential oil, piperine and oleoresin
6. Drought tolerance
7. Shade tolerance for evolving cultivars suitable for mixed cropping
8. Evolving high yielding cultivars that respond to low inputs and medium to low level of management (for reducing cost of production)
9. Cultivars suitable for higher elevations.

Present crop improvement programmes are tuned up mainly for achieving high yield and resistance to foot rot, nematode, *pollu* beetle and drought.

Pepper, blessed with the twin advantages of vegetative propagation and viable sexual reproduction, offers much scope for exploitation of hybrid vigour as well as selection breeding. Clonal selection, hybridization, open pollinated progeny selection, mutation and polyploidy have been used in improving pepper. Recently biotechnological approaches are also being developed mainly for developing pathogen resistance. Elite lines of pepper developed through conventional breeding methods and their salient features are given in Tables 2.13 and 2.14.

Existing genetic variability in pepper can be exploited through clonal selection, as there are more than 100 pepper cultivars existing in India, with substantial amount of inter and intracultivar variability.An elite plant once identified can form the basis of a new variety, it can be multiplied vegetatively and subsequently released as a new variety after sufficient yield evaluation trials. Clonal selection can be exercised in (a) existing gene pool, (b) introduced varieties, (c) population created through segregation, hybridization or through other means.

Clonal Selection

Many of the popular pepper cultivars exhibit considerable intracultivar variability. In Kerala—the state having the maximum genetic diversity of black pepper—the most popular cultivar is *Karimunda*. A clonal selection was carried out in this cultivar by the Indian Institute of Spices Research (IISR), (earlier National Research Centre for Spices, NRCS) located at Kozhikode. During the 1980s a survey was conducted to assess the extent of variability in this cultivar (Ratnambal *et al.* 1985). Based on the information gathered in this survey, 216 elite individual plants were selected and their clonal progenies further evaluated. Based on yield and quality two

Table 2.13 Improved varieties of pepper and their salient features.

Name	*Pedigree*	*Average yield (Kg/ha)*	*Remarks*
India			
Panniyur 1	Hybrid – *Uthirankotta* × *Cheriyakaniyakadan*	1242.0	Suited to most pepper regions. Not suited to heavily shaded areas and high elevations
Panniyur 2	Open pollinated progeny of *Balanccotta*	2570.0	Shade tolerant.
Panniyur 3	Hybrid – *Uthirankotta* × *Cheriyakaniyakadan*	1953.0	Late maturing, suited to all pepper growing regions
Panniyur 4	Clonal selection from *Kuthiravally*	1277.0	Reported to perform well under a vareity of conditons, stable yielder
Panniyur 5	Open pollinated progeny of *Perumkodi*	1098.0	Tolerant to nursery diseases and shade
Subhakara	Clonal selection from *Karimunda*	2352.0	Suited to all pepper growing regions, high quality
Sreekara	Clonal selection from *Karimunda*	2677.0	Suited to all pepper growing regions, high quality
Panchami	Selection from germplasm	2828.0	Late maturing type suited to all pepper growing regions.
Pournami	Selection from germplasm	2333.0	Tolerant to root knot nematode
PLD-2	Clonal selection from *Kottanadan*	2475.0	Suited to all pepper growing regions, high quality
Malaysia			
Semongok Perak	Selection from Introduced Cultivars	–	High yielder
Semongok Emas	Back cross progeny of cross between *Balankotta* × *Kuching* (to *Kuching*)	–	Precoccious, high, stable yielder, tolerant to *Phytophthora* foot rot, black berry disease and pepper weevil.
Indonesia			
Natar 1	Selection from germplasm	–	High yielder and tolarant to nematodes and foot rot
Natar 2	Selection from germplasm	–	High yielder and tolarant to nematodes and foot rot
Sri Lanka			
PW 14	–	–	Reported to be resistant to *R. similis*
Madagascar			
Sel. IV. I	Selection from introduced germplasm	–	High yielder
*Sel. IV.*2	Selection from introduced germplasm	–	High yielder

Table 2.14 Improved varieties of pepper from india and their quality features.

Name	*Oleoresin (%)*	*Piperine (%)*	*Essential oil (%)*
Panniyur 1	11.80	5.3	3.5
Panniyur 2	10.90	6.6	3.4
Panniyur 3	12.70	5.2	3.1
Panniyur 4	09.20	4.4	2.1
Panniyur 5	12.33	5.5	3.8
Subhakara	12.40	3.4	6.0
Sreekara	13.00	5.1	7.0
Panchami	12.50	4.7	3.4
Pournami	13.80	4.1	3.4
PLD-2	15.50	3.3	3.4

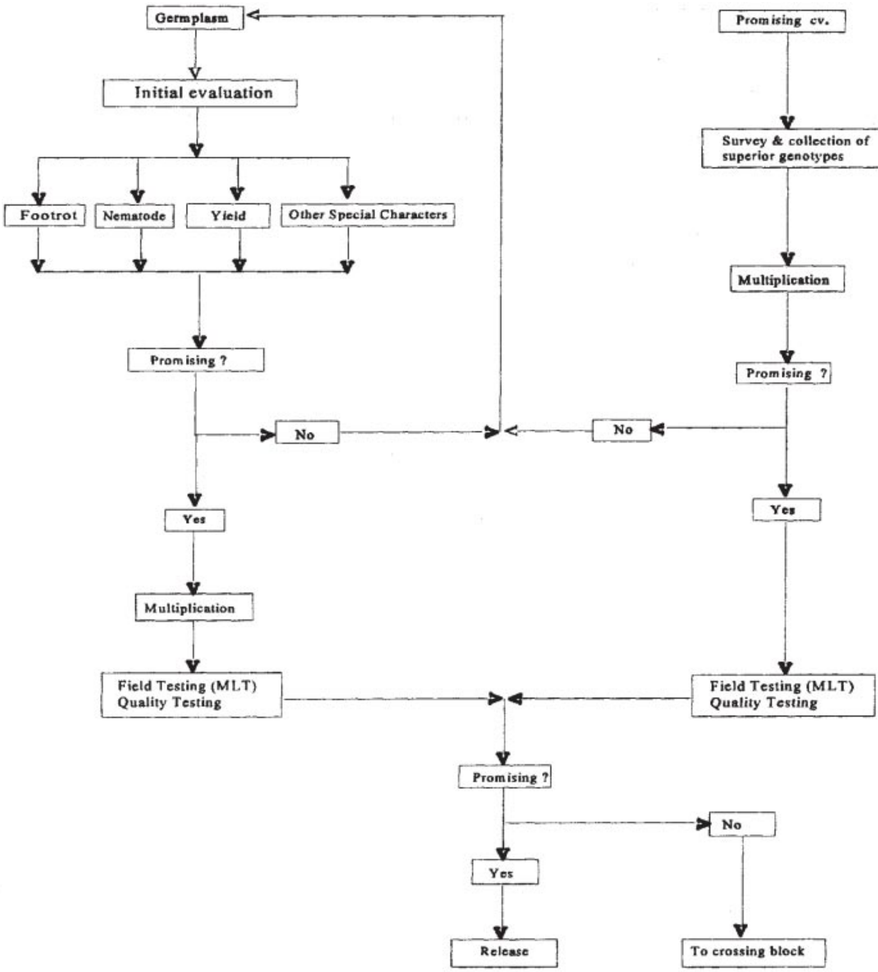
lines were selected for release to farmers. These lines were named *Sreekara* and *Subhakara*. On the fifth year the highest yield (fresh harvest) recorded per plant was 7.5 kg in the case of *Sreekara* and 7.9 kg in the case of *Subhakara*. They have yield potentials of 12,000 kg/ha (4200 kg dry) in the case of *Sreekara* and 12,640 kg/ha (4487 kg dry) in the case of *Subhakara* (at the rate of 1600 plants/ha) on the fifth year after planting (Ratnambal 1990, Nirmal Babu and Ravindran 1992). The yield realized from these two lines were much higher than what obtained from other prevailing cultivars. A generalised procedure for clonal selection in black pepper is given in Scheme 2.1.

In Sarawak, Malaysia, Sim and colleagues (Sim *et al.* 1993) have carried out clonal selection in a few introduced cultivars. These introductions during 1978–79 showed better tolerance to *Phytophthora* foot rot than the Malaysian cultivar *Kuching*. They were tested together in multilocational yield trials. One of the introductions appeared promising, it was precocious and out yielded *Kuching* in yield trials, and moreover was less susceptible to *Phytophthora* foot rot. This clone was released for cultivation under the name *Semongok Perak*.

Clonal selection in cv. *Kuthiravally* carried out by the Pepper Research Station, Panniyur, affiliated to Kerala Agricultural University, has resulted in *Panniyur*-4. PLD-2 is a selection from cv. *Kottanadan* by the Central Plantation Crops Research Institute, Research Centre, Palode.

Selection from Germplasm—*Panchami* and *Pournami*

Panchami and *Pournami* are selections from germplasm. Two promising lines identified in the germplasm collections of the IISR were compared against two promising cultivars, *Panniyur* 1 and *Karimunda* and with introduced *Kuching,* the ruling cultivar in Malaysia. Of the two lines, one was a high yielding line from an elite mother vine of cv. *Aimpiriyan,* and the other was cv. *Ottaplackal* (named after the house of the farmer from where this was collected). The latter was found to be tolerant to root knot nematode—*Meloidogyne incognita*. The performance of these two cultivars was much superior to the prevailing varieties (Ravindran *et al.* 1992b, c).



Scheme 2.1 Flow chart of clonal selection programme in pepper.

Panchami and *Pournami* have good yield contributing characters (Nirmal Babu and Ravindran 1992). *Panchami* has medium long spikes (11.2 cm mean), high spiking intensity (77 spikes/100 nodes), high percentage of hermaphrodite flowers (91.5 %) and high fruit set (82 %). The spikes have the typical 5-rowed arrangement of fruits and the twisted nature of the spike as in the cv. *Aimpiriyan*. It is a late maturing type, fruits coming to harvesting about 8–9 months after flowering (Ravindran *et al.* 1992b). *Pournami* was selected based on its good yield potential and its tolerance to root knot nematodes. Studies showed that *Pournami* supported only a low population of nematodes both in roots and in soil around the plant. The root galling index was also lower (Ravindran *et al.* 1992c).

Selection in OP Progenies

Pepper being heterozygous and propagated mainly through cuttings, segregation of characters can be expected in the open pollinated and selfed progenies. Because of the geitonogamous mode of pollination the open pollinated progenies are comparable to selfed offsprings. There is thus a fair chance to locate useful genotypes in open pollinated progenies. Comparative genetic variability with in open pollinated progenies of a few varieties of black pepper was reported by Ibrahim *et al.* (1986). From the studies carried out at Sarawak (Malaysia), Sim (1993) has identified five promising genotypes. They are the third generation open pollinated progenies from the cvs. *Balancotta, Cheriakanikkadan* and *Kalluvally* (all of them introduced from India). These five lines (14552–14556) were multiplied and tested in replicated trials. Of these, line 14556 was the most promising, having long, well set spikes, and was less susceptible to *Phytophthora* foot rot, and is also less susceptible to black berry disease caused by *Colletotrichum* than the cv. *Kuching*.

Selection in OP progenies was carried out at the Pepper Research Station, Panniyur (Kerala). Two cultivars *Panniyur* 2 and 5 were developed through selection in op progenies of cvs. *Balankotta* and *Perumkodi* respectively. *Panniyur* 2 has an average yield of 2570 kg/ha (dry) and *Panniyur* 5, 1098 kg/ha (dry). They have 35.7 per cent dry recovery. *Panniyur 2* has 6.6 per cent piperine and 10.9 per cent oleoresin and 3.4 per cent oil, while *Panniyur* 5 has 5.5 per cent piperine, 12.3 per cent oleoresin and 3.8 per cent oil. *Panniyur*-2 and 5 have moderately good yield contributing characters such as medium long spike (12.3 and 13.1 cm), high bisexual flowers (97 and 96%), fruit set (74 and 87%), number of fruits/spike (74 and 103), fruit volume (120 and 104 cc/1000 fruits) and higher fruit weight (127 and 110 g/1000 fruits).

Intercultivar Hybridization

Considerable intercultivar variability exists in pepper for yield, quality and morphological features. This aspect coupled with viable sexual reproduction and vegetative multiplication have made hybrid breeding in black pepper very attractive. Genetic improvement through hybridization generally involves three main steps:

(1) Selection of parents (2) Production of progeny and (3) Selection of superior genotypes to be developed into clones (varieties).

Hybridization work in pepper was started by 1959 in India at the Pepper Research Station, Panniyur. Evaluation of F_1 progenies of many crosses led to the hybrid *Panniyur* 1 (Fig. 2.23), a selection from F_1 of a cross between cv. *Uthirancotta*× *Cheriyakanikkadan*. This hybrid was released in 1966. A second hybrid *Panniyur* 3, was also developed from the F_1 population involving the same parents in early 1990s.

No information is available on the breeding value of various varieties used as parents. General or specific combining ability of pepper cultivars are not worked out due to the perennial nature of the vine. In the absence of such information the available gene pool is used at random for inercultivar hybridization. At IISR, cultivars having

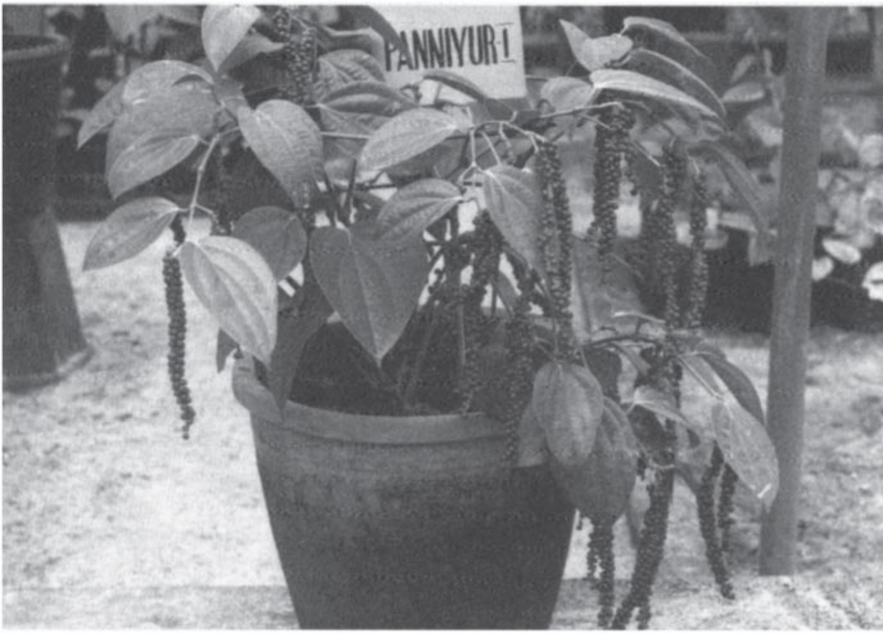


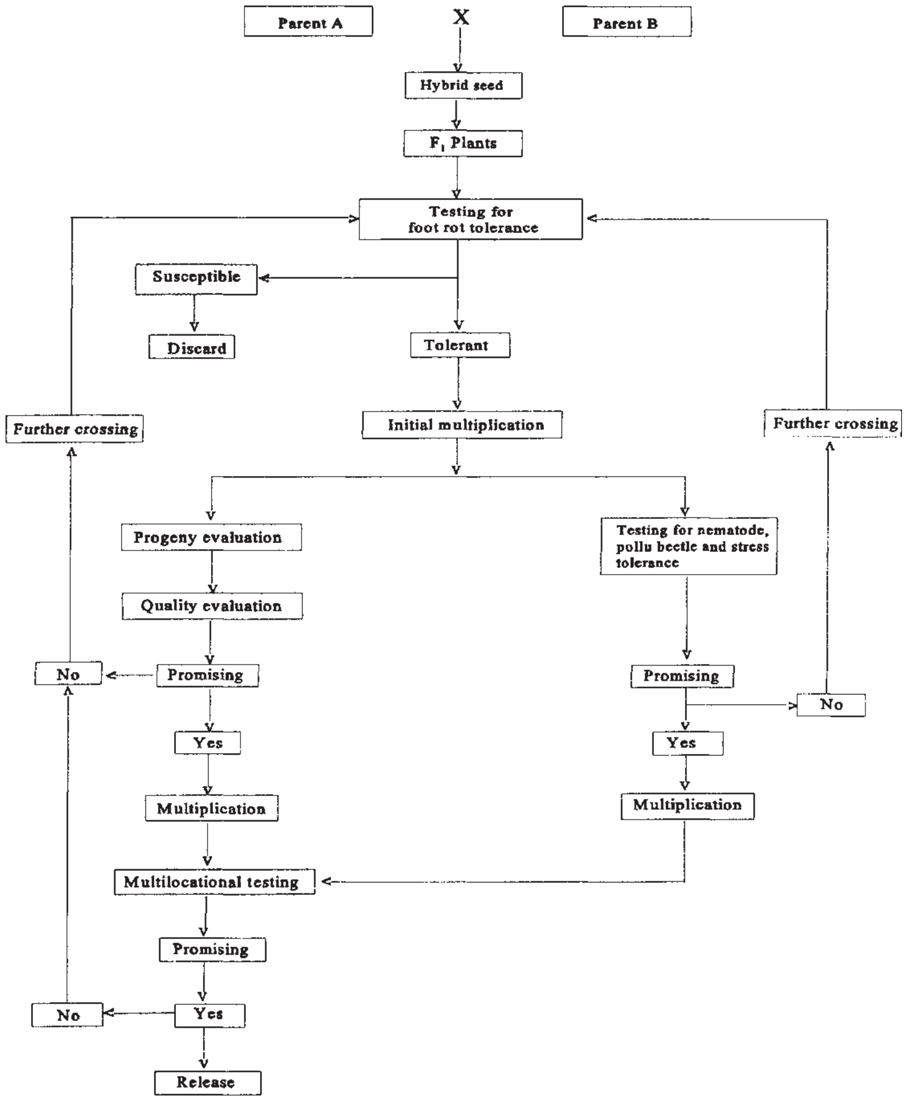
Figure 2.23 Panniyur 1, the first hybrid black pepper growing in a pot as bush pepper.

promising characters are being used as parents. A large number of crosses involving many cultivars were made and the progenies tested for yield in preliminary trials. The promising F_1 plants were multiplied and planted for comparative yield evaluation. A few hybrids having desirable yield attributes have been short listed. Two lines having good yield and adaptability for higher elevation were also identified (NRCS 1992).

Intercultivar hybridization work is in progress in Malaysia from 1963, and in Indonesia from 1989. The genepool in both these countries are quite narrow, and the parents were selected based on their performance as varieties. The F_1 plants were subjected to a preliminary selection in the nursery, eliminating the unhealthy and stunted ones. The others were subjected to screening for *Phytophthora,* and the susceptible ones were further eliminated. The selected progenies were finally field planted for evaluation in progeny plots. The worth of individual plants was assessed visually in terms of vigour in growth, plant architecture, yielding potential and susceptibility to pests and diseases. The promising ones were multiplied and evaluated in replicated and multilocational trials. The general breeding scheme used in cross breeding is given in the Scheme 2.2 (Sim 1993).

Sim (1993) has outlined the following types of crosses that can be used for crop improvement work in pepper:

1. Single crosses between different cultivars and varieties
2. Single crosses between pepper varieties and other *Piper* spp. of economic importance



Scheme 2.2 Flow chart of crossbreeding programme in pepper with special emphasis on foot rot tolerance.

3. Double crosses between promising F_1s of various crosses
4. Three-way crosses between selected varieties and promising progenies of various crosses
5. More complex crosses involving progenies of double and three way crosses
6. Back crosses of promising offsprings to recurrent parent.

Realization of full potential of heterosis from these crosses are limited due to the non-availability of inbred lines. Nevertheless large number of hybrids have been raised and evaluated and many promising lines are under various stages of testing in India and Malaysia.

There is only one variety developed so far from the back cross procedure. In Sarawak, a cross was made between *Balankotta* and *Kuching* in 1966 and one of the progenies (Hybrid 10) that survived the inoculation with *Phytophthora capsici* in the field was selected. It was a poor yielder and hence was back crossed to its high yielding parent *Kuching*. Several back crosses were made and the back cross progenies were subjected to laboratory screening and field testing and one of them (hybrid 359) was found promising. This was planted in 138 localities and evaluated between 1984 and 1991 and released under the name *Semongok emas*. This hybrid has several distinct advantages such as (i) good setting and more uniform spikes than *Kuching,* so that the harvesting can be completed in three rounds compared to five or six rounds in *Kuching,* (ii) foliage is less dense resulting in faster harvesting, (iii) stable yield, (iv) less susceptible to the attack of black berry disease, *Phytophthora* foot rot and pepper weevil. However, *Semongok emas* is more susceptible to root knot nematode, but is also more responsive to nematicides than *Kuching* (Sim 1993).

At the Indian Institute of Spices Research, a large number of intercultivar hybrids are under different stages of testing for yield and resistance to *Phytophthora*. Of the hybrids a few have shown high yield and tolerance to *Phytophthora* and they are under different stages of evaluation.

Interspecific Hybridization

Sasikumar *et al.* (1999) reported the first successful interspecific hybridization between *P. nigrum*×*P. attenuatum* and *P. nigrum*×*P. barberi*. The hybrids exhibited distinct morphological and anatomical features. Isozyme studies have shown hybrid specific as well as male parent specific bands. The hybrids had the same chromosome number (2n=52) as that of the parents.

Polyploidy and its Application

The possibility of using polyploidy in crop improvement was also explored. A natural triploid (2n (3x)=78) was located among the germplasm and this has very bold fruits and low fruit setting. This triploid plant was used for generating a series of cytotypes. But none of these chromosomal variants so far has shown any agronomically useful characters.

An induced tetraploid was developed in *Panniyur*-1 by treating the seeds with colchicine. (Nair and Ravindran 1992). This tetraploid having the somatic chromosome number of 2n (4x)=104, has larger and thicker leaves but the growth was slower than the diploid parents, and is difficult to establish in the field. Ibrahim *et al.* (1987b) reported an extra bold variant of Panniyur 1, which probably is a tetraploid.

Mutation Breeding

Induced mutations were used in pepper mainly for broadening the genetic base, especially in Malaysia, and also for producing mutants tolerant to *P. capsici* and nematodes. In Malaysia, the mutation breeding work was limited to the cultivar *Kuching*. In India, mutation studies were carried out by Irulappan *et al.* (1982) and Ravindran *et al.* (1986). Ravindran *et al.* (1986) used gamma rays for inducing variability in *Karimunda, Panniyur* 1, *Kuthiravally, Kalluvally (Pulpally), Kalluvally (Malabar), Thommankodi* and *Aimpiriyan* and 1–4 kr gamma rays were used for irradiation. Irradiation adversely affected the germination of seeds, as the dose increased, germination was delayed. The Gr_{50} level (50 per cent germination of seeds) was reached in control by 40^{th} day in *Karimunda,* while at 3 kr the Gr_{50} was reached by 65 days and at 4 kr the germination never reached 50 per cent. The difference between control and 3 kr to reach Gr_{50} was three days in *Kalluvaly (Malabar),* six days in *Thommankodi,* 15 days in *Kuthiravally,* 25 days in *Karimunda* and 28 days in *Panniyur*-1. Only in *Kalluvally (Malabar)* all the treatments gave above 50 per cent germination.

The percentage reduction in germination from 0–4 kr was high in *Aimpiriyan* (52%), *Karimunda* (52%), *Kalluvally* (*Malabar* 39%), *Kalluvally (Pulpally* 70.5%) and low in *Kuthiravally* (36%), *Panniyur* 1 (25%) and *Thommankodi* (2.7%). Thus *Kalluvally (Pulpally), Karimunda* and *Aimpiriyan* were most affected by the radiation treatment and *Thommankodi* the least. The M1 population showed certain morphological abnormalities such as chlorophyll changes, twinning of seedlings, rosette leaves etc. The frequency of chlorophyll abnormalities in the M_1 seedling population ranged from 13.0 per cent in cv. *Karimunda* to 0.1 per cent in cultivars *Kuthiravally* and *Kalluvally*. *Panniyur* 1 gave 0.7 per cent, *Thommankodi* 0.8 per cent and *Aimpiriyan* 0.2 per cent chlorophyll abnormalities. *Karimunda* gave the highest number of chlorophyll mutants (13.0%). Incidentally *Karimunda* gave around 3 per cent chlorophyll abnormalities even in the control population. The types of chlorophyll changes noted included albino, xantha (yellow) and variegated. The first two were lethal, whereas variegated ones later developed to normal plants. The variegated seedlings were similar to what Blixt (1961) described in peas as the “chlorotica variomaculata” type (Ravindran *et al.* 1986). Chandy *et al.* (1980) carried out preliminary studies on the effect of EMS on vegetative buds of black pepper but no mutants were noticed in the M_1 and further generations were not studied.

Paulus (1993) reviewed the mutation breeding work carried out in Malaysia. Here mutation breeding was used mainly to create genetic variability especially for developing tolerant or resistant lines against *P. capsici* and *M. incognita*. Cultivars *Kuching* and *Semongok Perak* were used in mutation breeding work. The ripe seeds were irradiated with gamma rays upto 100 Gy. Both M_1 and M_2 were studied, mainly for locating resistance against *Phytophthora*.

In addition to seeds, cuttings were also irradiated and raised. Similar studies using rooted cuttings were carried out in India also. In Malaysia, a method called “cutting back method” was used in irradiation experiments with vegetative cuttings. This technique was originally used by Bauer (1957) for black current *(Ribes nigrum)* and is arrived at for improving the efficiency of mutagen treatment by restricting the disadvantageous formation of chimeras. Chimeras are usually formed during ir radiation of multicellular apical buds. In the cutting back technique the dormant buds are treated and the main shoot is removed at sprouting so that the MV_1 (first vegetative mutation generation) will originate from axillary buds which are present in the treated plant but with a comparatively reduced cell population. Further cutting backs are done in successive vegetative mutation generation (MV_2, MV_3 etc.). This technique has been applied in many vegetatively propagated plants.

Paulus (1993) used two nodal cuttings of *Kuching* with a leaf on the upper node for gamma ray irradiation ranging from 0–50 Gy. The irradiated plants were planted and MV1 and MV_2 generations were studied. The LD_{50} was around 30 Gy. Apart from gamma rays, EMS treatment was also used for inducing mutation, the LD_{50} is around 0.25–0.3 per cent. The progenies were subjected to the leaf screening method (Kueh and Khew 1980) for locating tolerance against *P. capsici*. In this method a culture disc of *P. capsici* is placed together with a drop of distilled water on the abaxial surface of a recently matured leaf. The lesion diameter developed on the leaf is measured four days after inoculation. The reactions were compared with the lesion developed on *Kalluvally, Belantung* and *Kuching* leaves used as checks (representing, tolerant, less susceptible, susceptible respectively). Plants giving reactions similar to *Kalluvally* (lesion diameter equivalent to *Kalluvally*) were selected for further studies (Paulus 1993). Mass screening was also done in the M_2 seedlings using a suspension of *P. capsici* culture. The M_2 seedlings were grown in trays and inoculum at the rate of 250 ml/tray was poured. The surviving seedlings were subjected to another cycle of screening in the same way after two months. The finally survived lines were grown for further studies (Paulus 1993). Eleven lines from the irradiated population were selected for further studies and breeding. In Brazil Ando *et al.* (1980, 1984) carried out mutation studies using gamma radiation for developing *Fusarium* resistance, but could not achieve any resistant genotype.

Because of the inherent limitations, mutation breeding has not been pursued much by pepper workers. It would be a much better idea to use the *in vitro* system for generating variability and perhaps a combination of induced mutation, plus *in vitro* culture technique can provide tremendous amount of variability for eventual selection.

Breeding for Quality

In pepper—as in all spices—quality of the produce is as important as yield itself. Pepper quality is decided mainly by the contents of piperine, essential oil and oleoresin. Piperine is an alkaloid and contributes towards pungency, essential oil is responsible for the flavour, and oleoresin is the solvent extractable portion that contains both piperine and essential oil. The pepper flavour is the combined effect of a large number of chemical compounds present in the essential oil and hence the character is very complex and controlled by a large number of genes.

Evaluation of the germplasm collections has resulted in identifying high piperine, oil and oleoresin types. Variability for quality characters of black pepper is reported (Table 2.15). Gopalam and Ravindran (1987) categorized black pepper cultivars based on quality parameters (Table 2.16). At IISR, most of the cultivars were screened to locate high quality ones. As flavour is the most important factor contributing to the pepper quality and aroma, more emphasis need be given to the improvement in essential oil composition and content. Essential oil is found to vary from 0.4–7 per cent, while piperine varies from 2–7.4 per cent among the cultivars. Two of the improved lines, *Sreekara* and *Subhakara* have high oil contents (>6%) (Tables 2.15 and 2.16). Categorization of cultivars based on quality parameters, indicates the possibility for

Table 2.15 Variability in quality composition of important cultivars (values on dry weight basis).*

Sl. No.	*Cultivar*	*Volatile oil % (v/w)*	*Oleoresin %(w/w)*	*Peperine % (w/w)*	*Starch % (w/w)*
1	*Arikottanadan*	4.75	12.90	4.50	24.66
2	*Arakkulam munda*	4.75	9.84	4.40	36.18
3	*Balankotta*	5.12	9.35	4.26	25.20
4	*Ceylon*	3.75	3.50	7.60	15.66
5	*Cheriyakaniakkadan*	3.75	9.05	3.95	24.84
6	*Chumala*	2.25	5.45	3.30	46.62
7	*Doddigya*	2.50	7.10	2.85	36.00
8	*Kalluvally*	3.25	8.80	4.24	31.50
9	*Kalluvally (PTB)*	0.40	10.90	4.65	29.00
10	*Kalluvally type I*	3.00	8.44	5.40	20.70
11	*Kaniakkadan*	4.75	11.60	6.00	12.42
12	*Kottanadan*	2.50	17.80	6.60	23.40
13	*Karimunda*	4.00	11.00	4.40	39.60
14	*Karuvilanchy*	3.50	9.70	4.30	27.00
15	*Kumbhakodi*	4.50	14.90	7.60	18.20
16	*Kuthiravally*	4.50	14.90	5.97	14.04
17	*Munda*	4.75	7.00	5.60	22.70
18	*Mundi*	3.50	7.50	3.60	23.40
19	*Narayakkodi*	4.00	10.85	5.40	24.50
20	*Nilgiris*	5.50	15.50	6.05	23.60
21	*Palulauta*	3.00	7.60	3.60	19.26
22	*Panniyur 1*	3.50	9.52	3.60	35.10
23	*Perumkodi*	3.00	8.60	4.00	28.80
24	*Perumunda*	4.00	8.00	7.40	26.64
25	*Shimoga*	2.50	7.20	4.56	17.64
26	*Sullia*	4.00	6.80	3.60	20.70
27	*TMB II*	2.50	10.80	5.80	32.60
28	*Uthirankotta*	4.75	8.55	3.92	28.80
29	*Vally*	2.50	6.53	4.90	16.02
30	*Aimpiriyan*	2.63	15.70	4.69	–
31	*Udhakare*	3.82	8.61	2.36	–
32	*Thommankodi*	5.98	13.77	2.77	–
33	*Srikara***	7.00	13.00	5.10	–
34	*Subhakara***	6.00	12.40	3.40	–
35	*Panchami***	3.40	12.50	4.70	–
36	*Pournami***	3.35	13.80	4.10	–

* Raju *et al.* (1983).
** High yielding selections; Ratnambal *et al.* (1990), Ravindran *et al.* (1992b, c).

Table 2.16 Categorisation of pepper cultivars on the basis of piperine, oleoresin and essential oil contents.*

Constituent	*Name of the cultivar*	*Category and level of the constituent*	
Piperine	*Ceylon, Kaniyakkadan, Kottanadan, Kumbhakkodi, Kuthiravally, Munda, Nilgiris, Perumunda, Taliparamaba Local, Karimunda.*	High	> 5.45
	Arikottanadan, Arakulammunda, Balankotta, Cheriyakaniakkadan, Chumala, Doddigae, Kalluvally (1), *Kalluvally* (II), *Kalluvally* (III), *Karimunda* (I), *Karuvilanchy, Mundi, Narayakodi, Palulauta, Panniyur*-1, *Perumkodi, Shimoga, Sullia, Uthirankotta, Vally, Local* (*Sagar*), *Kuthiravally* (I), *Thommankodi* (I), *Kalluvally* (IV), *Kurimalai, Aimpirian* (I), *Karimunda* (II), *Balankotta, Aryanmundi, Padappan, Thirthahally, Karimunda* (III), *Karimalligeswara, Thommankodi* (II), *Aimpirian* (II), *Karimunda* (IV), *Aimpirian* (III), *Perambramunda, Kuthiravally* (II).	Medium	5.5–2.6
	Vokkalu, Narayakodi, Kalluvally (V), *Udhakere, Doddale, Kuthiravally* (II), *Udhakere* (II), *Local* (*Pulpally*).	Low	< 2.6
Oleoresin	*Kottanadan, Kumbhakkodi, Kuthiravally* (I), *Nilgiris, Aimpirian, Kuthiravally* (II), *Udhakere, Pulpally, Malabar.*	High	> 14.6
	Arikottanadan, Arakulammunda, Balankotta, Ceylon, Cheriyakaniakkadan, Kalluvally (1), *Kalluvally* (II), *Kaniyakkadan, Kalluvally* (III), *Karimunda* (I), *Narayakodi, Panniyur*-1, *Perumkodi, TMB-II, Uthirankotta, Thirthahally, Kurimalai, Karimunda* (II), *Karimalligeswara, Thommankodi, Doddale, Karimunda* (III), *Arayanmundi, Aimpirian, Perambramunda, Vokkalu, Local* (*Sagar*), *Narayakodi, Kuthriravally* (I), *Kalluvally* (IV), *Udhakkere, Karimunda* (IV), *Karimunda* (V), *Padappan.*	Medium	14.6–8.4
	Doddigae, Chumala, Munda, Mundi, Palulauta, Perumunda, Shimoga, Sullia, Vally, Karimunda (V).	Low	< 8.4

Table 2.16 *continued*

Constituent	*Name of the cultivar*	*Category and level of the constituent*	
Essential oil	*Arikottanadan*, *Arakulammunda*, *Balankotta*, *Kaniakkadan*, *Kumbhakodi*, *Kuthiravally* (I).	High	> 4.4
	Munda, *Nilgiris*, *Perambramunda*, *Kalluvally* (I), *Thommankodi*, *Karimunda* (I), *Ceylon*, *Cheriakaniyakadan*, *Doddigae*, *Kalluvally* (II), *Kalluvally* (III), *Kottanadan*, *Karimunda* (II), *Karuvilanchi*, *Mundi*, *Narayakodi*, *Palulauta*, *Panniyur*-1, *Perumkodi*, *Perumunda*, *Shimoga*, *Sullia*, *TMB*, *Uthirankota*, *Vally*, *Karimunda* (III), *Kurimalai*, *Karimunda* (IV), *Karimalligeswara*, *Thommankodi*, *Karimunda* (IV), *Aimpirian*, *Kuthiravally* (I), *Kuthiravally* (II), *Vokkalu*, *Local* (*Sagar*), *Narayakodi*, *Kuthiravally* (III), *Kalluvally* (IV), *Udhakere*, *Kurimalai*, *Aimpirian*, *Karimunda* (IV), *Malabar*, *Aryanmundi*, *Padappan*.	Medium	4.4–2.4
	Chumala, *Kalluvally* (V), *Thirthahalli*, *Vokkalu*, *Doddale*, *Arayanmundi*, *Udhakhere*, *Pulpally* (*Local*)	Low	< 2.4

* Gopalam and Ravindran (1987).

evolving cultivars having higher quality through cross breeding among the high quality ones.

Among the cultivars, *Kottanadan* has the highest oleoresin content, but is lower in essential oil. This is a high yielding cultivar and there is a need to upgrade its quality by improving the essential oil content. Exploitation of the intracultivar variability in *Thommankodi, Kuthiravally, Karimunda* and *Kottanadan* can further increase their essential oil contents. Little efforts have been made in this area of quality upgradation. But because of the inherent variability already available, both selective breeding and cross breeding strategies may be fruitful in developing high quality lines.

Genetical and Biometrical Studies

Ibrahim *et al.* (1985a, b, c, e 1987a, 1988a) studied genotypic and phenotypic variability, heritability and genetic advance using 28 lines of hybrids and open pollinated progenies. Spike yield, followed by spike number, showed the highest phenotypic coefficient of variation. The lowest variability was shown by fruit weight. Based on the results, above authors came to the conclusion that spike yield and spike number were the characters more amenable for improvement, as these had high genotypic coefficient of variation. Heritability values varied from 28 to 81 per cent, the highest for fruit weight followed by spike length. Spike yield and spike number had low heritability indicating that these characters are highly influenced by environmental fluctuations. Genetic advance was highest with respect to spike yield, indicating that selection will be advantageous in this character. On the other hand fruit weight showed the lowest value suggesting that this character will produce only marginal improvement on selection.

Pillai *et al.* (1987) reported that *Panniyur*-1 showed positive heterosis for length of spike, developed fruits, bisexual flowers per spike and for yield, but the fruit characters were found to be intermediate. Internode length in the hybrid was greater than the parental values and showed significant difference compared to mid parental value. Expression and association of spike character was also studied by Ibrahim *et al.* (1988a). They found that the expression of character was markedly influenced by season. Fruits per spike was more prone to seasonal variation (cv=22.73%) than spike length (cv=16.3%). The cv. *Arakkuluam munda* showed high stability of expression over seasons for spike length.

Ravindran *et al.* (1992d) studied the genetics of shoot tip colour in pepper. They concluded that shoot tip colour is controlled by two pairs of genes having complementary action. Thus *Panniyur* 1 having greenish white shoot tip colour is having genotype constitution $A_1\ a_1\ a_2\ a_2$ or $A_1\ A_1\ a_2\ a_2$. *Karimunda* with purple shoot tips is $A_1\ a_1\ A_2\ a_2$, *Cheriyakanikkadan* $A_1\ A_1\ A_2\ a_2$, *Valiakannikkadan* $A_1\ A_1\ A_2\ a_2$, *Cholamundi* $A_1\ A_1\ A_2\ A_2$, *Neelamundi* $A_1\ A_1\ A_2\ A_2$, *Aimpiriyan* $A_1\ a_1\ A_2\ A_2$, etc. Ibrahim *et al.* (1985f) reported the inheritance of anthocyanin pigmentation on “stipules” in pepper (here the term stipule is wrongly used). Sasikumar (IISR 1997) has studied the genetics of leaf shapes in cultivars. He concluded that leaf shape in pepper is controlled by multiple alleles. Three basic leaf shapes have been recognized: cordate ($c^+ c^+$), ovate ($c^0 c^0$) and oblong-elliptical (cc).

Grafting

An effective method to prevent foot rot caused by *Phytophthora capsici* is grafting pepper on a resistant root stock such as *Piper colubrinum* Link. Studies on grafting was carried out mainly at Sarawak in Malaysia. Recently some studies are being carried out in India also. One of the earliest studies in this field was that of Albuquerque (1969) in Brazil. He found that among the various *Piper* spp. resistant to *Phytophthora* only *P. colubrinum* showed success in grafting and is reported to be upto 95 per cent. Fork method was the most successful grafting method, and the grafting was done at the third or fourth internode. The grafted plants showed good initial growth. Performances of these plants in later years were not known. Alconero *et al.* (1972) reported that grafts on *P. colubrinum* deteriorated after fourth year. Gaskins and Almeyda (1969) failed to get any resistance in grafts using root stock of *P. aduncum, P. scabrum, P. treleaseanum,* though all the three showed resistant reaction on inoculation.

Interspecific grafting using *P. colubrinum* as the root stock was investigated by workers in Sarawak (Malaysia), Brazil and India. In Sarawak, this species, introduced from Puerto Rico in 1969, showed two distinct types. One type is having more vigorous growth, flowers freely and the petioles are pink. The other type is less vigorous, rarely branch, seldom flower and the petioles are almost green. Preliminary chromosome counts indicated 2n=26 in the pink genotype and 2n=39 in the green genotype (Anon. 1977). Both genotypes exhibited complete resistance to *Phytophthora capsici*. The results of grafting work carried out at Sarawak, gave following information (Anon. 1977, 1978).

1. Single stocked graft—cv. *Kuching* (Ku) as scion and *P. colubrinum* (Col.) pink genotype seedling as root stock.
2. Double stocked graft—cv. *Kuching* as scion and Col. pink genotype seedling as root stock.
3. Double stocked graft—cv. *Kuching* as scion and Col. pink genotype cutting as root stock.

Various grafting techniques such as bud, saddle, splice and wedge grafting were used. In 1974 a trial was initiated in farmers' fields where there were wide spread occurrence of foot rot disease. After five years all the ungrafted cv. *Kuching* plants succumbed to the disease while, none of the grafted plants were affected. The casualties in the grafted plants were due to graft incompatibility. The graft compatibility of pink and green genotypes to *Kuching* differed. Irrespective of the method of grafting used, most of *Kuching*+green *colubrinum* graft declined within four years of field planting. Break down of *Kuching*+*P. cubeb*a grafts was slower when compared to green *colubrinum,* but the yield of *cubeba* grafts was extremely low. The grafts involving

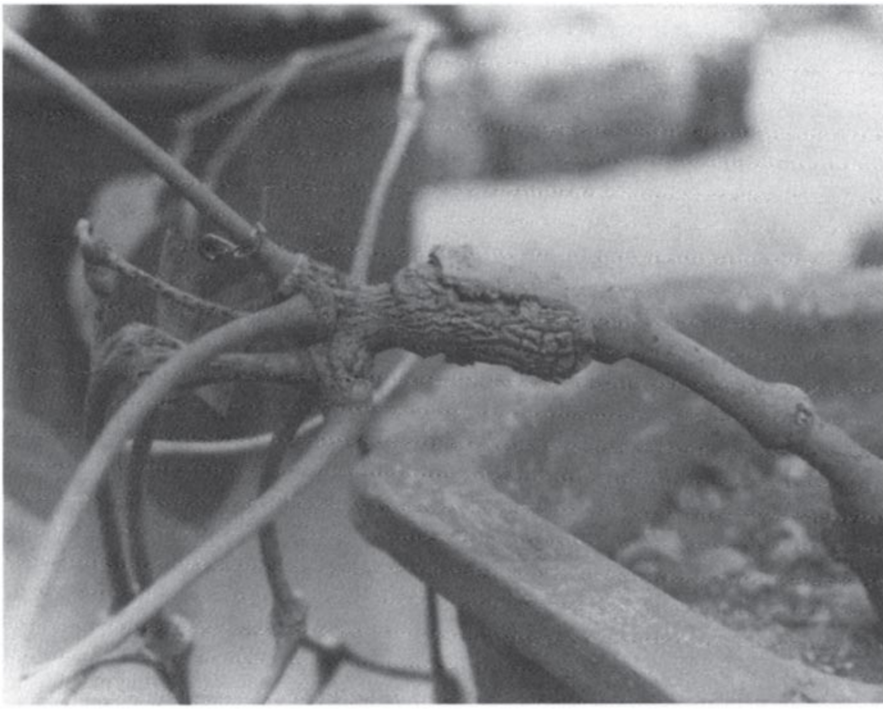


Figure 2.24 A graft union showing breakdown, note the development of cracks at the point of union.

pink *colubrinum* served better and yield was comparable to ungrafted *Kuching* (Anon. 1977, 1978, 1981).

Both intra and inter-specific grafting have been carried out, and in both cases cv. *Kuching* was used as scion. In intraspecific grafting cv. *Balankotta, Belantung, Cheriakaniakkadan, Djambi, Kalluvally* and *Uthirancotta* were used as root stock (Anon. 1979). Trials have shown that Indonesian cultivars were more compatible with cv. *Kuching* than those of Indian cultivars.

Complete to partial incompatibility was not detected while under nursery stage. There was gradual decline of grafted plants as they grow, subsequently the plant become stunted with only a few lateral branches and yellowish foliage. Stem above the graft union swelled up and the bark developed longitudinal cracks (Fig. 2.24). Presumably the graft union might have been from the union of only the parenchyma cells and not between, vascular tissues. Absence of a united, continuous cambium limits further growth of the grafted plant (Anon. 1977).

Anatomical studies carried out by the Sarawak group (Anon. 1979) disclosed the presence of a brown layer at the point of union, believed to be the remains of the necrotic cells on the cut surface of the scion and rootstock which did not degenerate during the course of the union development, or it could be the oxidized substances secreted from the mucilage canals to the cut surface of the scion and the root stock. This layer might be an obstruction to the flow of assimilates, minerals and water between the grafted plants. There was also indication of break down of phloem. The longitudinal cracks developing at the graft union is an indication of the graft incompatibility. Such cracks develop two or three years after field planting.

CONSERVATION OF PEPPER GENETIC RESOURCES

The Western Ghats of South India is one of the eighteen biodiversity hot spot areas on earth and is unique in its vegetation, comprising of various forest types such as tropical wet evergreen, moist deciduous, tropical dry deciduous, montane sub tropical and montane temperate. The population and diversity of *Piper* is most in the tropical wet evergreen forests that occur on the western side of Western Ghats. Unfortunately the Western Ghats is also one of the most ecologically threatened areas due to large scale encroachments and human settlements that have taken place during the past hundred years. The Western Ghats is very high in endemic species. Out of the 17 species of *Piper* occurring here 11 are endemic (Ravindran and Peter 1995).

There were more than a hundred pepper cultivars known to be under cultivation once, but during the past 25 years most of them have disappeared from the growers' gardens. Such fast gene erosion might have happened because of two major reasons: (i) the impact of diseases such as *Phytophthora* foot rot and slow decline that led to large scale devastation in many production centres, (ii) replacement of old and unproductive cultivars by a few high yielding elite ones. As in any other crop, human interference and human activities are destroying in a few years what nature has developed over many millennia.

To save the pepper genetic resources, the Indian Institute of Spices Research has established a National Conservatory for the *ex situ* conservation. Due to the serious disease problems facing this crop a multi-pronged conservation approach has been evolved by the IISR. Pepper germplasm is conserved at four stages (Ravindran and Nirmal Babu 1994a).

1. In the nursery gene bank, where each accession is trailed in bamboo splits in serial order and are under continuous multiplication and maintenance. (Fig. 2.25)
2. In the clonal repository where 10 rooted cuttings of each accession is maintained.
3. In the field genebank where the accessions are planted for preliminary yield evaluation and characterization.
4. In the *in vitro* and cryogenebanks.

The present status of the conservatory is given in Table 2.17.

The type of diversity conserved include pepper cultivars in vogue, old land races, elite cultivars, breeding lines, various cytotypes, morphotypes, wild pepper

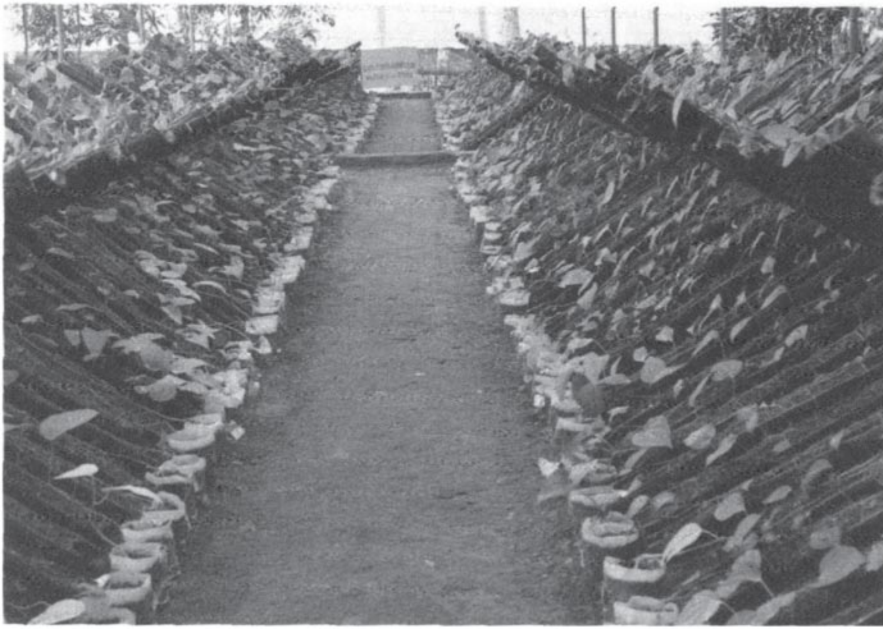


Figure 2.25 A view of the germplasm conservatory showing the method of maintaining nursery gene bank.

collections and related taxa. The germplasm collection also contains sources of pest and disease resistance (Table 2.18).

In addition to the IISR, smaller collections are being conserved in the centres of the All India Coordinated Research Project on Spices (AICRPS) and the current holdings are given below:

Pepper Research Station, Panniyur (Kerala)	65
Pepper Research Station, Sirsi (Karnataka)	90
Horticultural Research Station, Chintappalli (Andhra Pradesh)	37
Horticultural Research Station, Yercaud (Tamil Nadu)	106

Small germplasm collections exist in other growing countries, especially in Indonesia and Malaysia. De Waard (1984) reported that the Sarawak (Malaysia) gene pool included 18 cultivars of *Piper nigrum,* 18 identified *Piper* spp. and 98 unidentified accessions and that the Indonesian gene pool included 40 cultivars and seven *Piper* species.

But no attempts were made to collect, study and conserve the vast number of *Piper* spp. occurring in the Central and Northern South America, Malaysia, North Eastern India and Indonesia, though they are not closely related to the cultivated black pepper. Yet they may be sources for useful genes especially against pest and disease resistance. This in fact calls for an international effort.

Table 2.17 Genetic resources of black pepper at the national conservatory, IISR, Calicut.

Species name			*Number of holdings*
Piper nigrum			
a) Cultivated Pepper			
Cultivars			727
Karimunda lines			213
Kottanadan lines			75
Hybrids, OP lines, Cytotypes etc			1136
b) Wild Relatives 651			
P. argyrophyllum	*P. attenuautum*	*P. arboreum**	
P. betle	*P. barberi*	*P. chaba**	
*P. crocatum**	*P. colubrinum**	*P. galeatum*	
P. hapnium	*P. hymenophyllum*	*P. longum*	
P. mullesua	*P. magnificum**	*P. nigrum*	
P. silentvalleyensis	*P. sugandhi*	*P. schmidtii*	
P. wightii			
c) Related Genera			
Pothomorphe subpeltata			
Peperomia spp.			
Undetermined types			
		Total	2802

* Exotic.

BIOTECHNOLOGY

The past few years have witnessed a dramatic increase in our ability to manipulate and study plant tissues and cells *in vitro*. Techniques of plant cell and tissue culture have permitted investigations at molecular, cellular and organismal levels leading to better understanding of genetics, biochemistry, physiology and cell biology and also resulted in developing novel organisms that otherwise could not have been derived from sexual reproduction. The growing realisation of the potential of plant tissue and cell culture for plant propagation and breeding has resulted in its commercial exploitation in many ornamentals and other plants through shoot tip cultures, somaclonal variation to get new varieties and breeding lines, anther culture and protoplast fusion. The increasing competence to manipulate DNA (Recombinant DNA technology) and its use in developing transgenics has led to the appreciation that plant tissue and cell culture is the key to progress in plant biotechnology (Evans *et al.* 1983). Plant biotechnology is a rapidly growing field and the extent of information available in plant cell and tissue culture is vast and enormous. Biotechnology will be of immense use in solving many constraints facing pepper production. “Foot rot” caused by *Phytophthora capsici* is the major disease affecting pepper plantations. None of the existing genotypes have resistance to this disease. *Piper colubrinum,* a distantly related species from South America, is resistant to *Phytophthora*. Development of resistant varieties and transfer of resistance from *P. colubrinum* to *P. nigrum* are the major thrust areas in black pepper crop improvement programme. This could be achieved more easily through biotechnological means.

Table 2.18 Genetic resources of pepper—accessions having specific attributes.

IISR, India	
Cvs. having *Phytophthora* tolerance	*Balankotta*, *Kalluvally*, *Narayakkodi*, *Neelamundi*, *Uthirancotta*
Cvs. having nematode resistance/tolerance	*Pournami*
Accessions having insect pest tolerance (Pollu)	Acc. No. 816, 841, 1084, 1114, 2070*
Hybrids and cultivars with high elevation adapatability	HP 34, HP 105, HP 812, HP 728, Coll. 1041
Drought tolerant lines	KS 51, KS 69, KS 114**
Higher polyploids and aneuploids	*Vadakkan* triploid (2n = 78), *Panniyur* 1 tetraploid (2n = 104), OP progenies of *Vadakkan* (2n = 53, 2n = 55, 2n = 63, 2n = 73, 2n = 77 etc.)
Related taxa having disease/pest resistance	*P. colubrinum*, *P. arboreum*, *P. barberi*, *P. attenuatum*
Species having ornamental value	*P. crocatum*, *P. magnificum*
Species having medicinal value	*P. longum*, *P. mullesua*, *P. betle*, *P. chaba*
Indonesia ***	
Tolerance to *Phytophthora*	*Natar* 1, 2
Species having medicinal value	*P. cubeba*, *P. chaba*
Malaysia	
Tolerance to *Phytophthora*, high yielding hybrid	*Semongok Emas*
Sri Lanka	
Tolerance to *R. similis*	PW 14

* S.Devasahayam (NRCS Ann. Rep. 1993, 94; IISR Ann. Rep. 1996, 97).
** Vasantha *et al.* (1990).
*** Sitepu and Mustika (this volume).

Broome and Zimmerman (1978), were the first to micropropagate pepper. Since then many reports are available on micropropagation, plant regeneration, production of somatic embryos, protoplast isolation and culture, synthetic seeds, screening of somaclones against infection of *P. capsici,* molecular characterisation of somaclones of *Piper* using RAPDs, kanamycin sensitivity, genetic transformation using *Agrobacterium* Ti plasmid based vectors and medium term *in vitro* conservation of germplasm (Ravindran *et al.* 1996).

Micropropagation

In vitro culture methods for cloning of pepper have been reported (Table 2.19) using explants such as shoot tips, nodal segments and apical meristems from both juvenile and mature plants (Mathews and Rao 1984; Agarwal 1988; Philip *et al.* 1992; Nazeem *et al.* 1993; Nirmal Babu *et al.* 1993a, b; Joseph *et al.* 1996; Lissamma *et al.* 1996). Micropropagation of pepper is seriously hindered by bacterial contamination

Table 2.19 *In vitro* responses of black pepper and related species.

Crop & explant	*Media composition*	*Morphological response*	*Reference*
Black pepper			
Shoot tip	MS + 1 mgl^{-1} IAA, 1 mgl^{-1} BA	Multiple shoots	Agarwal (1998)
Shoot tip	MS + 0.2 mgl^{-1} NAA	*In vitro* rooting	Mathews and Rao (1984)
Shoot tip	MS + 1 mgl^{-1} NAA	*In vitro* rooting	Nirmal Babu *et al.* (1993a,b)*
Hypocotyl, lateral bud, stem segments	MS + 1 mgl^{-1} BA	Callus	Mathews and Rao (1984)
Leaf discs	MS + 2 mgl^{-1} 2,4-D	Callus	
Shoot tip, node	$\frac{1}{2}$ WPM + 3 mgl^{-1} BA + 1 mgl^{-1} Kin	Multiple shoots	Nirmal Babu *et al.* (1993a,b)*
Leaf		Protoplast isolation	
Shoot tip, node, leaf, callus derived from buds, leaf	MS + Kinetin + NAA	Callus, organogenesis and plant regeneration	Nirmal Babu *et al.* (1993a,b) Shaji *et al.* (1995, 1996) Geetha *et al.* (1990), Nirmal Babu *et al.* (1993a,b), Nazeem *et al.* (1993)
Piper species *P. betle, P. longum, P. colubrinum, P. attenuatum*			
Shoot tip	$\frac{1}{2}$ WPM + 3 mgl^{-1} BA + 1 mgl^{-1} Kin	Multiple shoots, Callus	Nirmal Babu *et al.* (1992b,c, 1993b), Rema *et al.* (1995)
Root tip		Conversion to shoot meristem and multiple shoot formation	Madhusoodanan *et al.* (1996)
Leaf		Callus	
Callus derived from leaf, buds		Organogenesis and plantlet formation	
Leaf tissue (*P. colubrinum*)		Isolation of protoplast and plant regeneration	Shaji *et al.* (1996)

Table 2.19 *continued*

Crop & explant	*Media composition*	*Morphological response*	*Reference*
P. attenuatum			
Stem, leaf, petiole	MS + 200 mgl^{-1} AC	Plant regeneration	Madhosudhanan and Rahiman (1996)
P. barberi			
Shoot, leaf	$\frac{1}{2}$ WPM + 3 mgl^{-1} BA + 1 mgl^{-1} Kin	Multiple shoots	Nirmal Babu *et al.* (1991c, 1992c, 1993b, 1996), Rema *et al.* (1995)
P. chaba			
Shoot	$\frac{1}{2}$ WPM + 3 mgl^{-1} BA + 1 mgl^{-1} Kin	Multiple shoots	Nirmal Babu *et al.* (1992c, 1993b), Rema *et al.* (1995)

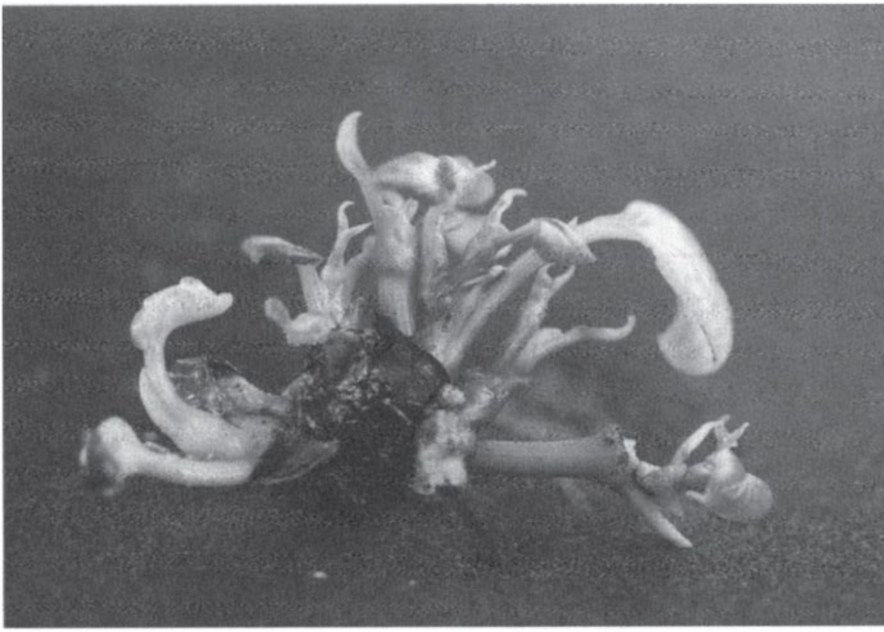


Figure 2.26 Micropropagation—multiple shoots from nodal explant.

(Kelkar and Krishnamurthy 1996). However, contamination is minimal in seedling explants. Multiple shoots can be induced using BA (N_6-benzyl adenine) in the culture medium either alone or in combination with auxins. *In vitro* developed shoots could be easily rooted using growth regulator free basal medium (Rema *et al.* 1995). This may be due to natural ability of the pepper shoots to develop roots at every node. The multiplication rate is around 6 shoots per culture in about 90 days (Fig. 2.26). The tissue cultured plantlets are easy to harden, by transferring the well rooted plantlets into polybags containing garden soil, perlite and sand in equal proportions after thoroughly washing away the culture medium from the root zone. The plantlets should be kept in humid chamber for 20–30 days for hardening. Micropropagated pepper plants can be successfully established in field. Though there were earlier reports on micropropagation of pepper (Chua 1981, Fitchet 1988a, b), phenolic exudates from the cut surface and endogenous bacterial contamination (Raj Mohan 1985, Fitchet 1988a, b) severely hampered the establishment phase. Treating the explants with fungicides prior to routine sterilisation followed by frequent transfer to fresh medium was suggested in reducing contamination and phenolic interference. Systemic contamination in the *in vitro* cultures has been reported (Fitchet 1988a, b, Nazeem *et al.* 1993). Madhusudhanan and Rahiman (1996) reported that use of activated charcoal at 200 mgl^{-1} resulted in reduction in browning of the explants and culture medium in pepper *(P. nigrum), P. longum, P. attenuatum* and *P. betle*. Incorporation of antibiotics in the culture media was suggested by Kelkar and Krishnamoorthy (1996) to control endogenous bacterial contamination in *in vitro* cultures of pepper.

The culture media used are mostly based on Murashige and Skoog's (1962), Schenk and Hildebrandt's (1972) and Woody Plant Medium (McCown & Amos 1979). The most common growth regulators and other additives used are IAA (Indole-3-acetic acid), NAA (*a*-naphthlaene acetic acid), IBA (Indole-3-butryic acid), 2,4-D (2,4-dicholorophenoxy acetic acid), 2iP (2-isopentenyl adenine), Kinetin, BA (N_6-benzyl adenine), Phloroglucinol, coconut water and Palmyrah endosperm extract. Of these, NAA, IBA, BA and phloroglucinol seems to give better *in vitro* responses.

Plant Regeneration from Callus Cultures

Protocols for plant regeneration were standardised and plants were regenerated from leaf and shoot derived callus cultures (Nirmal Babu *et al.* 1993a, b, Nazeem *et al.* 1993, Bhat *et al.* 1995) (Fig. 2.27). Plants could be regenerated from leaf tissues

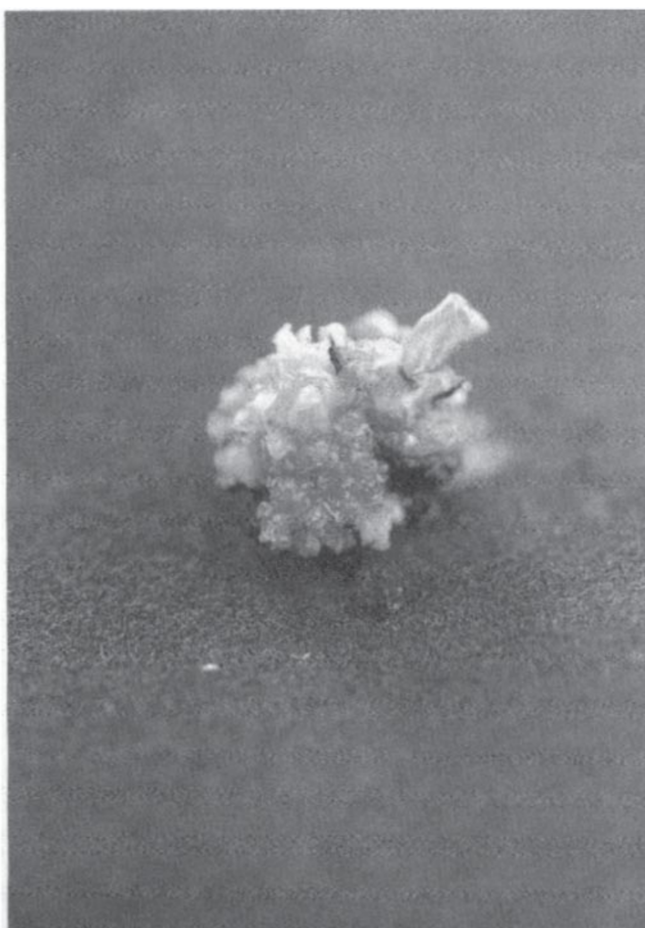


Figure 2.27 Regeneration of plants from callus.

directly without intervening callus phase (Nirrnal Babu *et al.* 1993a). Joseph *et al.* (1996) have reported *in vitro* somatic embryogenesis from zygotic embryos. They induced development of embryogenic callus from zygotic embryos which later produced somatic embryos on SH basal medium on both solid media as well as in liquid suspension cultures. They reported the highest number (over 1500) of somatic embryos and plantlets in suspension cultures containing half strength medium without growth regulators and reduced (1.5%) sucrose. The regenerated plantlets were established in soil. They suggested that exogenous growth regulators are not essential for autonomous proliferation and development of somatic embryos in pepper. These plant regeneration systems are useful for transfer of *Phytophthora* resistance from *P. colubrinum* to pepper.

Related species of Piper

Micropropagation reports are also available in many other economically important and related species of *Piper* viz., *P. longum, P. chaba, P. betle, P. colubrinum, P. attenuatum* and *P. barberi*. Protocols for rapid clonal multiplication of *P. longum* from shoot tip explants are available (Sarasan *et al.* 1993, Nirmal Babu *et al.* 1993b, Rema *et al.* 1995). Micropropagation of *P. chaba* (Nirmal Babu *et al.* 1993b, Rema *et al.* 1995), *P. betle* (Nirmal Babu *et al.* 1992b), *P. colubrinum* (Nirmal Babu *et al.* 1996a) and *P. barberi* (Rema *et al.* 1995, Nirmal Babu *et al.* 1996c), *P. attenuatum* (Madhusudhanan *et al.* 1996) has been standardised. Conversion of root meristem into shoot meristem and its subsequent development to plantlets were reported in *P. longum* and *P. colubrinum* (Nirmal Babu *et al.* 1993b). Micropropagated plantlets of these species are being evaluated for their field performance at the Indian Institute of Spices Research, Calicut.

Plants were regenerated from leaf and stem explants of *P. longum, P. betle, P. chaba, P. attenuatum* and *P. colubrinum* through direct and indirect organogenesis (Bhat *et al.* 1992, Bhat *et al.* 1995, Rema *et al.* 1995, Madhusudhanan *et al.* 1996). In *P. betle* and *P. longum,* different explants from shoot, leaf and root developed multiple shoots and regenerated into plantlets either directly or through intervening callus phase (Nirmal Babu *et al.* 1993b, Rema *et al.* 1995). Regeneration of betel vine through somatic embryogenesis was reported by Johri *et al.* (1996).

Somaclonal variation and in vitro selection for Phytophthora foot rot tolerance

Attempts on induction of variability on somaclones for tolerance to *Phytophthora* foot rot resistance were reported (Shylaja *et al.* 1994, Nazeem *et al.* 1997). They reported *in vitro* selection of calli as well as somaclones using crude culture filtrate and toxic metabolites isolated from *P. capsici* cultures resulted in identification of tolerant somaclones among the regenerated plantlets.

Protoplast Culture and Development of Protoclones

The "protoplast" is a naked cell, without cell wall, surrounded by plasma membrane, but is potentially capable of cell wall regeneration (in case of plants), growth and division. The absence of cell wall makes the protoplast suitable for a variety of manipulations, that are not normally possible with intact cells, such as uptake of cell organelles, microorganisms, foreign genetic material to form genetically modified cell and also for production of somatic hybrid cells by fusion of two protoplasts. Thus protoplast is an important tool for parasexual modification of genetic content of cells (Vasil and Vasil 1980). Successful isolation of protoplast is a prerequisite for many genetic transformation experiments for developing transgenics.

Successful isolation and culture of protoplasts were reported in *P. colubrinum* and *P. aduncum* (Anon, 1995). Shaji *et al.* (1995, 1996) reported isolation of viable protoplasts at high frequency from *in vitro* derived leaves of both *P. nigrum* and *P. colubrinum* using the method described by Sankara Rao and Gunasekari (1991). The protoplast yield was 5×10^3 per ml in *P. nigrum* and 2×10^3 per ml in *P. colubrinum*. The isolated protoplasts developed a cell wall in three days after isolation in *P. nigrum* and in 24 hours in *P. colubrinum*. First cell division was noticed after 13 days in *P. nigrum* and five days in *P. colubrinum*. Microcallus formation was observed after two months in *P. nigrum* and one month in *P. colubrinum*. Regeneration and development of protoclones were observed only in *P. colubrinum* protoplast cultures.

Genetic Transformation

Recent advances in techniques of foreign DNA transfer into plant cells have aroused much interest in the possibility of utilizing recombinant DNA technology in crop improvement (Walder 1988). Among the more important and frequently used techniques of gene transfer are *Agrobacterium* or viral vector based transformation and the transformation by direct uptake of naked DNA. Of these, the *Agrobacterium* mediated gene transfer is the most successful in plants, especially in dicots. For many plant species methods have been standardized for obtaining transgenic plants using *Agrobacterium* mediated transformation. Leaves, roots, hypocotyls, petioles, cotyledons or seeds are used as targets for transformation (Kado 1991, Hooykaas and Schilperoort 1992, Zambryski 1992).

Agrobacterium mediated gene transfer

Preliminary studies have been carried out on *Agrobacterium* transfer system in pepper (Sasikumar and Veluthambi 1993). Sasikumar and Veluthambi (1994) studied the kanamycin sensitivity of tissues and suggested that kanamycin at 50 μg ml^{-1} completely inhibited callus formation and growth and hence it is the minimum concentration needed to select transformed tissues of pepper. They have also obtained primary transformants for kanamycin resistance in the cotyledons using *Agrobacterium tumefaciens* binary vector strains LBA 4404 and EHA 105

(Sasikumar and Veluthambi, 1996a, b). Sim *et al.* (1995) reported *Agrobacterium* mediated transfer of GUS to pepper. Transformation system can be used for the transfer of disease resistance against *Phytophthora* foot rot from *P. colubrinum* to *P. nigrum*. In Sarawak, programmes are in progress to develop transgenic pepper with delayed ripening. This is to induce uniform maturity and thus to reduce labour input needs for several rounds of harvesting (Anon. 1995).

Isolation of DNA and studies on biochemical/molecular markers

Recent advances in the mapping of the genome of important crop species through RFLP analysis and the use of PCR technology will be useful in genetic fingerprinting, in identification and cloning of important genes and in understanding of inter relationships at molecular level.

DNA was isolated from three species of *Piper* and RAPD profiles of pepper and long pepper were recorded using 15 random primers. Most of them gave positive differences between these two species (IISR 1996). Marker aided studies for screening genetic stability in micropropagated plants of *Piper* was reported by Ajith (1997).

Isolation of RNA and construction of cDNA library

In an effort to build complementary DNA (cDNA) library, total RNA was extracted and purified from pericarps of berries at various developmental stages (Anon. 1995).

In Vitro Conservation of Germplasm

IISR holds the world's largest collection of pepper germplasm which is at present conserved in clonal field repositories, where they are threatened by serious diseases. Storage of germplasm in seed banks is not practical as they are vegetatively propagated and seeds are recalcitrant and heterozygous. Hence storage of germplasm *in vitro* is a safe alternative.

Protocols for *in vitro* conservation by slow growth of pepper and its related species *viz., P. barberi, P. colubrinum, P. betle* and *P. longum* were standardised (Geetha *et al.* 1995, Nirmal Babu *et al.* 1996b) by maintaining cultures at reduced temperatures, in the presence of osmotic inhibitors, at reduced nutrient levels and by minimising evaporation loss by using closed containers. Pepper cultures could be maintained in half strength WPM supplemented with 15 gl^{-1} each of sucrose and mannitol for one year with 85 per cent survival. In *P. barberi* full strength WPM with 25 gl^{-1} sucrose and 5 gl^{-1} mannitol was suitable for storage of cultures upto one year with 80 per cent survival. Shoot tips of *P. longum* and *P. colubrinum* could be stored upto one year in full strength WPM with 20 gl^{-1} sucrose and 10 gl^{-1} mannitol with 75 per cent and 70 per cent survival respectively. *P. betle* cultures could be stored in half strength WPM supplemented with 20 gl^{-1} sucrose for one year.

The conserved materials of all the species showed normal rate of multiplication when transferred to multiplication medium after storage. The normal sized plantlets when transferred to soil established with over 80 per cent success. They developed into normal plants without any deformities and were morphologically similar to mother plants.

Pepper seeds are recalcitrant and the seed viability decreases with reduction in moisture content. Seeds desiccated to 12 per cent and 6 per cent moisture contents were successfully cryopreserved in liquid nitrogen at -196°C, with a survival rate of 45 per cent and 10.5 per cent respectively (Chaudhury and Chandel 1994).

Production of Synthetic Seeds

Production of artificial seeds or "synthetic seeds", consisting of somatic embryos or shoot buds enclosed in a biodegradable protective coating can be an ideal system for low cost plant movement, propagation, conservation and exchange of germplasm. Since it is important to produce disease free plantlets, encapsulation of disease free buds utilising tissue culture technique serves as an easy and safe delivery system.

Pepper shoot buds of 0.5 cm were used for production of synthetic seeds and could be stored up to 5 months and 9 months in sterile water with 80 per cent and 65 per cent viability respectively. The shoot buds emerged out of the matrix and regenerated into plantlets on transfer to multiplication medium containing WPM basal salts supplemented with 3 mgl^{-1} BA and 1 mgl^{-1} Kin. (Sajina *et al.* 1996).

CONCLUSION

Black pepper is the best known and the most intensively researched spice. In spite of the fact that it is the most widely used spice by human kind from very ancient times, there are still many gaps existing in our understanding of this crop. How has it originated and what are its interrelationships with other species in the region? We have no definite answer. There are gaps in our understanding on developmental anatomy, embryology, cytology and reproductive biology. Genetical studies have not been initiated, and we are totally ignorant of the genetics of resistance against such devastating pathogens like *Phytophthora* and *Fusarium*. Pepper physiology is little understood and very little is known about the metabolic pathways leading to the production of pepper quality components. Stress physiology is another area where our knowledge is scanty. In the realm of crop improvement the achievements are limited to the release of a few high yielding lines. Heterosis breeding is hampered by the lack of homozygous lines. Biotechnology of pepper is still in its infancy. In this chapter an effort is made to collect and collate the available knowledge on botany, crop improvement and biotechnology of pepper, to provide a springboard for the future pepper workers.

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3. CHEMISTRY OF BLACK PEPPER

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The chemistry of black pepper has intrigued chemists from early nineteenth century and is still continuing to the present. In the intervening period many interesting compounds contributing to the pungency and aroma have been characterised. The chemistry of pepper can be broadly classified into: i) compounds contributing to its pungency and ii) compounds imparting its characteristic aroma.

The aroma of pepper is contributed by the essential oil present in the fruits, while the pungency is due to the alkaloid piperine. The commercial product oleoresin, solvent extracted from pepper powder, contains both pungency and aroma contributing compounds, the chemistry of pepper is the chemistry of its essential oil and piperine, the history of which spans more than a century.

The early investigations on the chemistry of pepper are recorded in Guenther (1952) and Wealth of India (1969) and later work by Govindarajan (1977), Purseglove (1981) and Lawrence (1979–80). Parmar *et al.* (1997) has listed the compounds occurring in *Piper*.

PEPPER ESSENTIAL OIL

Earlier Investigations on Essential Oil of Pepper

The first reported investigations on pepper essential oil were by Dumas and then by Subeiran and Capitaine in the early nineteenth century (Guenther 1952). They came to the conclusion that pepper oil is almost free of oxygenated constituents. Eberhardt obtained terpin hydrate by treating a fraction of the oil boiling at 176°C with alcohol and acid. The presence of l-phellendrene, caryophyllene and tentatively dipentene were reported by Schimmel & Co and by Schreiner and Kremers (Guenther 1952).

In 1951 Hasselstrom and coworkers established the presence of α-pinene, β-pinene, l-α-phellandrene, dl-limonene, piperonal, dihydrocarveol, a compound melting at 161°C, β-caryophyllene and a piperidine complex from the essential oil obtained by steam distillation of ground Malabar pepper. The above compounds were identified by classical methods of derivatization and degradation. They also reported the presence of epoxydihydrocaryophyllene, cryptone and possibly citroneliol and an azulene.

By the use of infrared spectroscopy, Jennings and Wrolstadt (1961) confirmed the presence of α and β-pinenes, limonene and caryophyllene in the hydrocarbon portion of black pepper oil.

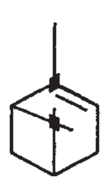
An impetus to the characterisation of constituents of essential oils started with the advent of Gas Chromatography. A combination of vacuum distillation, column chromatography, thin layer chromatography and gas chromatography to separate the constituents and identification using U.V, I.R., N.M.R. and M.S. were employed by later investigators. Hyphenated techniques like GC-IR, GC-MS etc. speeded up the identification process. High resolution capillary column GC coupled to MS or IR along with the availability of IR and MS spectral libraries made identification of known compounds easier. The compilation of data on relative retention indices or Kovats indices on methyl silicone and carbowax capillary columns of 50 metres in length was of tremendous utility. The contributions of the following research groups resulted in the identification of about 135 compounds consisting of monoterpenoids, sesquiterpenoids, aliphatic, aromatic and miscellaneous nature: Ikeda *et al.* (1962); Sharma *et al.* (1962); Nigam and Handa (1964); Wrolstadt and Jennings (1965); Chopra (1965); Muller and Jennings (1967); Muller *et al.* (1968); Russel and Else (1973); Richard and Jennings (1971); Debrauwere and Verzele (1975a,b 1976); Muller (1976); Lawrence (1979–80); Gopalakrishnan *et al.* (1993).

The constituents of pepper oil identified by the above researchers are listed in different classes given below.

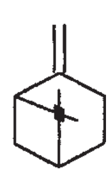
Monoterpene hydrocarbons and oxygenated compounds

There are 15 monoterpene hydrocarbons identified so far and they are camphene, d^3-carene, p-cymene, limonene, myrcene, *cis*-ocimene, α-phellandrene, β-phellandrene, α and β-pinenes, sabinene, α- and γ-terpinenes, terpinolene and α-thujene.

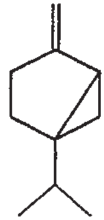
The major monoterpene hydrocarbons present in pepper oil are α and β-pinenes (1,2), sabinene (3) and limonene (4).

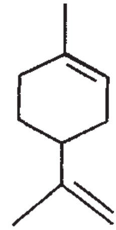
1 

α-Pinene

2 

β-Pinene

3

Sabinene

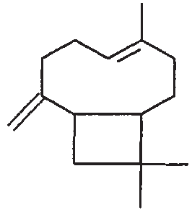
4

Limonene

About 43 oxygenated compounds of monoterpenoid nature have been characterised and they are borneol, camphor, carvacrol, *cis*-carveol, *trans*-carveol, carvone, carvetanacetone, 1,8-cineole, cryptone, p-cymene-8-ol, p-cymene-8-methyl ether, dihydrocarveol, dihydrocarvone, linalool, cis-2-menthadien-2-ol, 3,8 (9)-p-menthadien-1-ol, 1 (7)-p-menthadien-6-ol, 1 (7)-p-menthadien-4-ol, 1,8 (9)-p-menthadien-5-ol, 1,8 (9) p-menthadien-4-ol, *cis*-p-2-menthen-1-ol, myrtenal, myrtenol, methyl carvacrol, trans-pinocarveol, pinocamphone, *cis*-sabinene hydrate, *trans*-sabinene hydrate, 1-terpinen-4-ol, 1-terpinen-5-ol, α-terpeneol, 1,1,4,trimethylcyclohepta-2,4-dien-6-ol, phellandral, piperitone, citronellal, nerol, geraniol, isopinocamphone, methyl citronellate, methyl geranate, α-terpenyl acetate, terpenolene epoxide and *trans*-limonene epoxide.

Sesquiterpene hydrocarbons and oxygenated compounds

β-carophyllene (5) is the major sesquiterpene hydrocarbon present in pepper oil. Another 24 more sesquiterpene hydrocarbons are also identified. They are α-*cis*-bergamotene, α-trans-bergamotene, β-bisabolene, δ and γ-cadinenes, calamenene, α-copaene, α- and β-cubebenes, ar-curcumene, β- and δ-elemenes, β-farnesene, α-guaiene, α- and γ-humulenes, isocaryophyllene, γ-muurolene, α-santalene, α- and β-selinenes, ledene, sesquisabinene and zingiberene.

About 20 oxygenated sesquiterpenes have been identified from pepper oil. They are 5,10 (15)-cadinen-4-ol, caryophylla-3 (12), 7 (15)-dien-4-β-ol, caryophylla-2,7(15)-dien-4-β-ol, caryophylla-2,7(15)-dien-4-ol, β-caryophyllene alcohol, caryo-


5. β-Caryophyllene

phyllene ketone, caryophyllene oxide, epoxy-dihydrocaryophyllene, *cis*-nerolidol, 4,10,10-trimethyl-7-methylene bicyclo-(6.2.0) decane-4-carboxaldehyde, cubenol, *epi*-cubenol, viridiflorol, α- and β-bisabolols, cubebol, elemol and γ-eudesmol.

Miscellaneous compounds

Eugenol, methyl eugenol, myristicin, safrole, benzaldehyde, *trans*-anethole, piperonal, m-methyl acetophenone, p-methyl acetophenone, n-butyrophenone, benzoic acid, phenyl acetic acid, cinnamic acid and piperonic acid are some of the aromatic compounds characterised in pepper oil. Methyl heptenone, pinol, butyric acid, 3-methyl butyric acid, hexanoic acid, 2-methyl pentanoic acid, methyl heptanoate, methyl octanoate, 2-undecanone, n-nonane, n-tridecane, n-nonadecane and piperidine are the other compounds identified.

Gas Chromatographic Analysis of Essential Oil Constituents of Different Cultivars

There is wide variation in the chemical composition of pepper oil analysed by different research groups. These are due to use of oils from different varieties and geographic regions, variation in maturity of raw material, differences in the method of obtaining the oil, nonresolution of constituents in early gas chromatographic analyses using packed columns. The general composition of pepper oils is dependent to some extent upon the method of preparation. Steam distilled pepper oils usually contain about 70–80 per cent monoterpene hydrocarbons, 20–30 per cent sesquiterpene hydrocarbons and less than 4 per cent oxygenated constituents. Oils prepared by vacuum distillation of oleoresin extracts differ in containing less monoterpene hydrocarbons and more sesquiterpene hydrocarbons and oxygenated constituents. The low abundance of sesquiterpene hydrocarbons and oxygenated constituents in the steam distilled oils is probably a result of incomplete distillation and poor recovery of these high boiling constituents. Comparison between the oils obtained by these two methods should be judicious and confined to comparison of individual constituents in groups of mono- and sesquiterpene hydrocarbons.

Lewis *et al.* (1969) reported the composition of 17 cultivars of Kerala, India. The oil was isolated by steam distillation and the yield of the oil ranged from 2.4 to 3.8 per cent. The oil was analysed by packed column chromatography and compounds identified by retention time of authentic samples. In the oils, monoterpene hydrocarbons ranged from 69.4–85 per cent; sesquiterpene hydrocarbons 15–27.6 per cent and the rest oxygenated constituents. The major monoterpene hydrocarbons viz *a*-pinene ranged from 5.9–12.8 per cent, β-pinene 10.6–35.5 per cent, limonene 22–31.1 per cent. The major sesquiterpene hydrocarbon, β-caryophyllene ranged from 10.3–22.4 per cent. A Sri Lankan variety was also analysed by Lewis *et al.* and found that the oil contained α-pinene to the extent of 22.1 per cent, β-pinene 11.1 per cent,sabinene 21.3 per cent, limonene 11.1 per cent and β-caryophyllene 16.6 per cent.

Richard *et al.* (1971) also analysed the same 17 cultivars from Kerala, India. The volatile components were extracted with pentane-ether and injected into a packed column to separate the solvent and the aroma effluents introduced into a second connected capillary column through a Carle micro volume valve to separate the constituents. They found that in the pepper oil samples, the monoterpene hydrocarbons ranged from 49.5–73.3 per cent, the sesquiterpene hydrocarbons ranged from 19.8–45.1 per cent and oxygenated constituents ranged from 2–15.7 per cent.

Russel and Else (1973) analysed 12 samples of Lampong and 16 samples of Sarawak pepper grown in different regions of the two areas following the same procedure utilised by Richard *et al.* and carried out a statistical analysis. Significant differences could be established between the varieties.

Gopalakrishnan *et al.* (1993) analysed four new genotypes of pepper by a combination of GC-MS and Kovats indices on a methyl silicone capillary column. The four genotypes viz *Panniyur*-1, *Panniyur*-2, *Panniyur*-3 and *Panniyur*-4 (Culture-239) were developed at the Pepper Research Station of Kerala Agricultural University, Panniyur, Kerala State, India. The oils from the three *Panniyur* genotypes contained α-pinene in the range of 5.07–6.18, β-pinene 9.16–11.08, sabinene 8.50–17.16 per cent, limonene 21.06–22.71 per cent and β-caryophyllene 21.57–27.70. The oil from *Panniyur*-4 (culture 239) contained α-pinene 5.32 per cent, β-pinene 6.40 per cent, sabinene 1.94 per cent, myrcene 8.40 per cent, p-cymene 9.70 per cent, limonene 16.74 per cent and caryophyllene 21.19 per cent. The capillary GC chromatogram is given in Fig. 3.1 and the composition of the oils in Table 3.1.

Sensory Evaluation of Pepper Essential Oil

Arctander (Purseglove 1981) has described the odour of pepper oil as fresh, dry-woody, warm-spicy and similar to that of the black peppercorn. The flavour is rather dry-woody and lacks the pungency of the spice since the alkaloids are not extracted by steam distillation. Few studies are reported in the literature on correlation of oil composition to odour characteristics. Hasselstrom *et al.* (1951) attribute the characteristic odour of pepper oil to the small amounts of oxygenated constituents present. Lewis *et al.* (1969) consider that a number of monoterpenes present in the oil are necessary for strong peppery top notes. Lewis also reports that caryophyllene rich oils possess sweet floral odours where as oils with high pinene content give turpentine like off-odours. Pangburn *et al.* (1970) carried out a systematic sensory evaluation of Malabar pepper oil using column chromatographic fractions and mixtures of fractions of the oil. The early fraction was considered pepper like and floral, the late fraction pepper like, fresh and woody and the middle fraction fell in between. Binary combinations of fractions were all termed pepper like, floral and woody and spicy, but the total original oil was judged to be more pepper like. By direct sniffing at the eluting port of the gaschromatographic column the distinct odour of black pepper was ascribed to three areas of the late fractions. In earlier studies these were identified as *trans*- and *cis*-bergamotenes and santalene. Descriptive odour analysis developed by Harper *et al.* and Sydow *et al.* was utilised by Govindarajan *et al.* (1977) and developed an odour description of pepper to evaluate horticultural varieties and trade types of pepper. Gopalakrishnan *et al.*

Table 3.1 Comparative chemical composition of four pepper varieties.

Peak No.	*Compound*	*Kovats index*		*Percent composition*			
		Exp	*Ref*	*1*	*2*	*3*	*4*
1.	α-thujene	931	938	0.73	1.26	1.59	0.91
2.	α-pinene	943	942	5.28	6.18	5.07	5.32
3.	camphene	954	954	0.14	0.18	0.14	0.13
4.	sabinene	975	976	8.50	13.54	17.16	1.94
5.	β-pinene	981	981	11.08	10.88	9.16	6.40
6.	myrcene	986	986	2.23	2.30	2.20	8.40
7.	α-phellandrene	990	1002	0.68	0.20	–	2.32
8.	δ-3-carene	1005	1009	2.82	0.18	–	1.03
9.	α-terpinene	1008	1010	–	–	0.39	1.13
10.	p-cymene	1018	1020	–	0.18	0.07	9.70
11.	(Z)-β-ocimene + β-phellandrene	1022	1025	–	0.15	0.23	0.37
12.	limonene	1039	1030	21.06	21.26	22.71	16.74
13.	(E)-β-ocimene	1045	1038	0.18	2.84	0.30	0.17
14.	γ-terpinene	1055	1057	0.01	0.49	–	0.03
15.	trans-sabinene hydrate	1057	1060	0.14	–	0.30	0.19
16.	terpinolene	1066	1074	0.10	0.20	0.22	0.08
17.	trans-linalool oxide (furanoid)[ti]	1082	1082	0.03	0.18	–	0.08
18.	unidentified	1085	1087	0.24	0.22	0.26	0.60
19.	linalool	1092	1092	0.22	0.22	0.46	0.28
20.	cis-p-menth-2-en-1-ol + cis-p-menth-2,8-diene-1-ol	1117	1111/ 1120	0.04	0.04	0.05	0.02
21.	trans-p-menth-2-en-1-ol	1128	1128	0.01	0.01	0.01	0.01
22.	citronellal	1134	1137	0.02	0.03	0.03	0.01
23.	p-menth-8-en-l -ol	1154	1156	0.03	t	–	t
24.	borneol	1159	1164	t	t	t	t
25.	terpinen-4-ol	1170	1175	0.19	0.32	0.52	0.18
26.	α-terpineol	1183	1185	0.10	0.17	0.12	0.07
27.	dihydrocarveol	1187	1188	0.01	–	0.02	0.02
28.	p-menth-8-en-2 -ol	1199	1208	–	0.01	0.02	0.02
29.	trans-carveol	1206	1209	0.01	0.01	–	0.02
30.	cis-carveol + carvone	1224	1222/ 1228	0.01	0.03	0.03	0.03
31.	piperitone	1245	1247	0.04	t	0.03	t
32.	carvone oxide*	1261	1261	0.01	0.01	–	0.01
33.	myrtenol	1277	1281	0.20	0.04	0.11	0.04
	(a) unidentified	1287	–	0.02	–	–	–
	(b) unidentified	1299	–	0.02	t	t	–
34.	α-terpinyl acetate	1334	1333	0.86	1.22	1.33	1.05
35.	neryl acetate	1346	1345	0.20	0.07	0.05	0.13
36.	geranyl acetate	1364	1363	0.12	0.01	0.07	0.11
37.	α-cubebene/–δ-elemene	1376	1381	3.25	0.26	0.16	2.56
38.	α-copaene	1384	1398	0.82	0.49	0.44	0.71
39.	β-elemene	1403	1400	0.09	0.09	0.06	0.05
40.	β-caryophyllene	1429	1428	21.59	27.70	23.2	21.19
41.	trans-α-bergamotene	1431	1436	0.31	–	9	0.28
42.	α-humulene	1435	1437	0.21	0.20	–	0.29
43.	(E)-β-farnesene	1445	1448	0.08	0.22	0.11	0.13
44.	α-amorphene	1451	1451	1.51	1.53	0.03	1.28

Table 3.1 *continued*

Peak No.	*Compound*	*Kovats index*		*Percent composition*			
		Exp	*Ref*	*1*	*2*	*3*	*4*
45.	α-guaiene	1455	1454	0.11	0.07	1.54	0.10
46.	clovene[ti]	1460	–	0.14	0.07	0.07	0.13
47.	germacrene-D[ti]	1469	1469	0.04	0.03	0.04	0.26
48.	ar-curcumene	1474	1475	0.26	0.12	0.04	0.29
49.	β-selinene	1480	1477	0.64	0.87	1.37	0.63
50.	α-selinene	1483	1484	0.07	0.12	0.48	0.14
51.	γ-muurolene	1489	1486	0.73	0.93	0.16	0.58
52.	(E,E)-α-farnesene	1492	1494	0.72	–	0.47	0.72
53.	β-bisabolene[ti] + α-bisabolene[ti]	1498	1496	4.25	2.15	3.10	0.49
54.	δ-guaiene[ti]	1515	1502	0.82	0.17	0.09	1.85
55.	cuparene[ti]	1520	1518	1.38	0.09	0.14	0.04
56.	δ-cadinene	1523	1524	0.12	–	0.07	0.13
57.	(Z)-nerolidol	1530	1524	0.20	0.05	0.11	0.05
58.	elemol	1540	1540	0.11	0.06	0.07	0.08
59.	unidentified	1548	–	0.04	0.02	0.07	0.03
60.	(E)-nerolidol	1551	1553	0.12	0.04	0.07	0.03
61.	caryophyllene alcohol	1557	1559	0.07	0.02	0.04	0.02
62.	unidentified	1566	–	0.03	0.11	0.07	0.07
63.	caryophyllene oxide	1570	1576	0.90	0.35	0.38	0.25
64.	unidentified	1582	–	0.06	0.04	0.05	0.05
65.	unidentified	1592	–	0.10	0.07	0.14	0.07
66.	unidentified	1598	–	0.10	0.03	0.05	0.07
67.	unidentified	1604	–	0.04	0.24	0.02	0.02
68.	cedrol[ti]	1608	1609	0.07	–	0.05	0.05
69.	unidentified	1614	–	0.38	0.24	0.22	0.27
70.	α-cadinol[ti]	1632	–	1.51	0.29	0.12	1.27
71.	α-cadinol[ti]	1639	–	0.26	0.12	0.15	0.25
72.	unidentified	1649	–	–	0.05	0.02	0.04
73.	unidentified	1651	–	–	0.05	0.05	0.12
74.	β-bisabolol	1666	1666	0.20	0.09	0.17	0.14
75.	unidentified	1687	–	0.06	0.02	0.02	0.04
76.	unidentified	1692	–	0.06	0.11	0.03	0.94
77.	unidentified	1712	–	0.02	0.07	0.06	0.02
78.	unidentified	1715	–	–	–	0.04	0.01
79.	unidentified	1778	–	0.09	–	t	0.16
80.	unidentified	1787	–	0.01	–	t	0.01
81.	unidentified	1823	–	–	–	0.04	–
82.	unidentified	1832	–	t	t	t	t
83.	unidentified	1858	–	–	t	t	0.05
84.	unidentified	1872	–	t	t	t	t
85.	unidentified	1876	–	t	t	t	t
86.	unidentified	1886	–	t	t	t	0.05
87.	unidentified	1900	–	t	t	t	0.03

Exp = experimental; Ref = reference; t = trace (<0.01%); * correct isomer not given; ti = tentative identification; 1 = Pannniyur-1; 2 = Panniyur-2; 3 = Panniyur-3; 4 = panniyur-4.

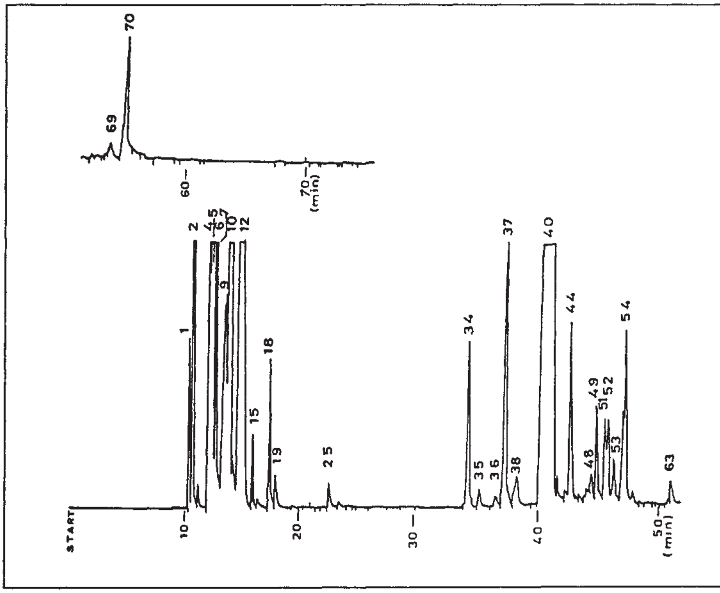


Figure 3.1 Capillary G.C. chromatogram of the oil of *Panniyur-4* (Culture 239) in 50 m methyl silicone column.

(1993) has described the odour evaluation of four new genotypes of Indian pepper by descriptive odour profile based on a four point category scale and also subjecting the oils to ranking test. The descriptive odour profile has been diagrammatically represented in Fig. 3.2. The mean of the scores for each odour characteristic was plotted on radiating lines representing odour characteristic in the sequential order, from left to right. The desirable odours are represented in the upper quadrants, the lower quadrants depict undesirable notes

PUNGENT COMPOUNDS OF PEPPER

Earlier Investigations on Pungent Compounds of Pepper

The pungency of black pepper has been the subject of chemical investigations since the early nineteenth century. In 1819 Oersted (Guenther 1952) isolated piperine, the most abundant alkaloid in pepper, as a yellow crystalline substance, and its structure was later identified as the *trans* form of piperoyl piperidine. Later workers

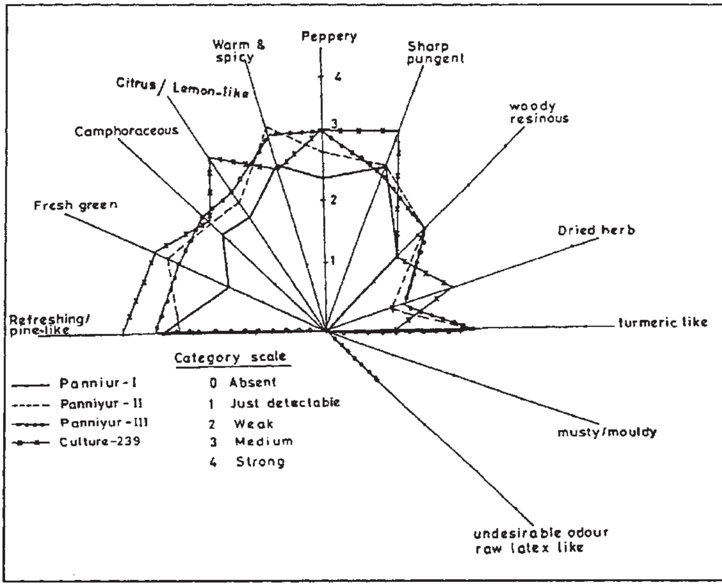


Figure 3.2 Descriptive odour profile of four pepper genotypes.

recognising that piperine is not the only pungent principle of pepper continued the isolation work. Bucheim (Govindarajan 1977) obtained a pungent dark oily resin which he named as chavicine after removal of piperine from the oleoresin. This oily substance was claimed to possess a far greater bite on the toungue than crystalline piperine,but later workers demonstrated that piperine in solution is very pungent. The controversey over which compound viz. piperine, its *cis-cis* isomer chavicine or other possible isomers-isopiperine *(cis-trans)* and isochavicine *(trans-cis)*—is more pungent lasted almost a century. Recent investigations have demonstrated, however, that piperine is the major pungent principle and chavicine of the older literature is a mixture of piperine and several minor alkaloids. The presence of chavicine and isopiperine has not been confirmed in pepper extracts while isochavicine is shown to occur as an artefact of photolytic transformation of piperine. Five new minor alkaloids possessing a degree of pungency have been identified in pepper extracts. They are piperettine, piperylin, piperolein A and B and piperanine. Three trace constituents viz peepuloidin, guineesine and pipericide showing insecticidal properties have recently been identified.

Piperine: Structure Determination and Synthesis

Oersted (1820) isolated piperine from the extract of pepper as a yellow crystalline substance having a melting point of 128–130°C. Piperine, $C_{17} H_{19} O_3 N$, was shown to be a weak base which on hydrolysis with aqueous alkali or nitric acid yielded a volatile base, $C_5 H_{11} N$, later identified as piperidine. The acidic product of hydrolysis, piperinic acid ($C_{12} H_{19} O_4$, m.p. 216–217°C), was shown to be 5-(3,4-methylene dioxy phenyl)-2,4, pentadienoic acid by establishing two double bonds by the tetrabromo derivative as well as by oxidation to oxalic acid and piperonal.

The partial synthesis of piperine was achieved by Rugheimer in 1882 by condensing piperinic acid chloride with piperidine. Ladenberg and Scholtz (1894) established the structure of piperine by total synthesis of piperinic acid. By condensation of piperonal with acetaldehyde, followed by treatment with sodium acetate and acetic anhydride, piperinic acid was obtained. Thus the structure of piperine was established as piperinic acid piperidide.

Ott and Eichler (1922) postulated the presence of four geometric isomers from the formula of piperinic acid: 2 *trans,* 4 *trans;* 2 as, 4 *trans;* 2 *trans,* 4 *cis* and 2 *cis,* 4 *cis.* By the formation of oxalic acid and tartaric acid by careful oxidation of piperinic acid and its synthesis from 3,4 methylenedioxy-cinnamaldehyde, known to have a stable *trans* configuration, they assign *trans-trans* configuration to piperinic acid.

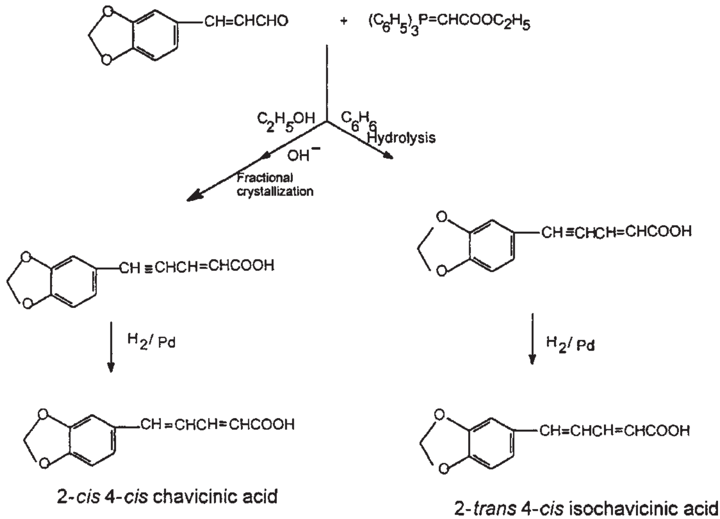
Due to controversey over the pungency of piperine and chavicine, a great amount of work was carried out to synthesise all the four isomers. Isopiperinic acid was synthesised by Ott and Eichler (1922) from piperonylidene malonic acid, the structure of which was known, by elimination of carbon dioxide and they assigned the *cis-trans* configuration to this acid.

Grewe *et al.* (1970) carried out an unequivocal synthesis of all the three isomers of piperinic acid and recorded the physicochemical properties of the isomeric acids. They utilised triphenyl ethoxycarbonyl methylene phosphorane for preparing the isomers and it is shown in Scheme 1.

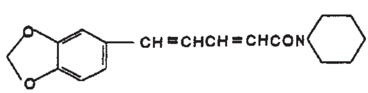
All the three isomers of piperinic acid were sensitive to light and convert almost completely to the *trans-trans* isomer in a short period of time. The corresponding piperidides of the isomers were prepared and they undergo conversion to *trans-trans* form by irradiation with U.V. light.

Upon alkaline hydrolysis, the *trans-trans* and *cis-trans* isomeric piperidides yielded only the *trans-trans* acid, while the *trans-cis* and *cis-cis* piperidides gave almost exclusively the *trans-cis* isomer. By simple taste tests, the three isomers of piperine were found to have very weak pungency. The structure of piperine along with the isomers are given in (6).

Yamamoto *et al.* (1974) investigated the photochemical changes of piperine. Irradiation of piperine in alcoholic solution under a high pressure mercury lamp gave a mixture of *cis-trans* (isopiperine) and *trans-cis* (isochavicine) as determined by U.V., I.R. and N.M.R. spectra. Isopiperine was synthesised following the method of Ott and Eichler (1922). The 1,2 *trans* 3,4 *cis* isomer, isochavicine was prepared by debromination of brominated piperic acid to yield trans 2-en-4 yn carboxylic acid.



Scheme 1 Synthesis of isomers of piperinic acid.



6.

5 (3,4-methylene dioxyphenyl) penta 2,4-dienoic acid piperidide

2-trans,4-trans	**Piperine**
2-cis,4-trans	**Isopiperine**
2-trans,4-cis	**Isochavicine**
2-cis,4-cis	**Chavicine**

This was converted to the piperidide and partially hydrogenated to yield isochavicine. The *trans*-2-en-4-yn carboxylic acid piperidide was irradiated under high pressure mercury lamp for conversion to the *cis* form and then hydrogenated to yield the *cis-cis* isomer chavicine. The piperine isomers were found to be considerably less pungent and could not be detected in black pepper.

The structure of piperine and its isomers have been confirmed by NMR by Del Clyn and Verzele (1975). Single crystal diffractometry study also proved the conjugated double bond system of piperine to be all *trans*. (Sumathikutty *et al.* 1981).

Estimation of Piperine

The alkaloid piperine is generally accepted as the active “bite” component in black pepper. The homologues and analogues of piperine are minor or trace compounds and their contribution to pungency is small. Despite the controversey over the nature of pungent compounds in pepper, piperine content has been taken as a measure of the total pungency.

Methods for estimation of piperine may well be explained on the basis of its structural characteristics.

i) Total nitrogen estimated by Kjeldahl’s method, though recommended by standards for estimation of piperine, would be an overestimate because all nitrogenous compounds do not contribute to the pungency. In extracts and powdered spices, adulteration with suitable organic nitrogen compounds could not be ruled out and Kjeldahl’s method would give exaggerated values of piperine content for the product.

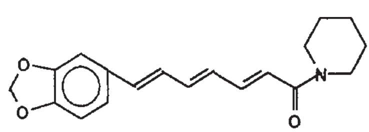
ii) When it was found that piperine gives an absorption in the UV region with a maximum at 345 nm, a simple and rapid method for the quantitative estimation of piperine became available. The absorption maximum is due to the extended conjugated double bonds in the structure of piperine. Necessary precautions should be taken to avoid exposure to direct light as piperine is photosensitive in dilute solutions. Piperine solutions in chloroform and to a lesser degree in benzene showed a loss of absorption when exposed to light and hence benzene is recommended as the suitable solvent and experimental solutions should be stored in darkness for accuracy and reproducibility. The recent report in which piperine is extracted into ethylene dichloride and measured at maximal absorbance 342–345 nm has been adopted as an official method of the American Spice Trade Association and as an official first action method by AOAC.

iii) Colorimetric methods proposed for estimation of piperine use reagents that react with different parts of the piperine molecule. The earliest method is based on hydrolysing the methylenedioxy group to formaldehyde which is estimated by the distinct colour developed with chromotropic acid. Methylene dioxy groups in the breakdown products of piperine as well as carbohydrates yield formaldehyde under acid conditions to react with chromotropic acid thus giving higher values. The disadvantage with colorimetric methods using nitric acid and sulfuric acid and an aromatic aldehyde are that all compounds with a benzene nucleus can be nitrated and all unsaturated compounds formed by conc. H_2SO_4 interfere and vitiate the usefulness of the method. Though the colour produced by piperine with phosphoric acid is rather specific for piperine and its isomers several critical experimental variables limit the general use of the procedure for quantitative estimation. According to reports all colorimetric methods give values higher than those given by UV method.

iv) The hydrolytic distillation method in which the pepper extractive is subjected to alkaline hydrolysis and the liberated piperidine distilled out is converted to colori metric methods. The distilled piperidine with CS_2 yields piperidinium pentamethylene dithiocarbamates which reacts with $CuSO_4$ to give yellow compound with absorption maximum at 435 nm. In another method piperidine is reacted with nitrophenyl diazonium fluoroborate to give a red colour with an absorption maximum of 530 nm. There are some reports on the gas chromatographic analysis of pungent constituents of pepper, and also there are a few reports on the estimation of piperine by high pressure liquid chromatography.

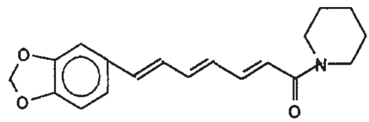
Piperine and its Analogues

From the mother liquor after removal of piperine by crystallisation, Spring and Stark (1950) obtained an amorphous powder which on crystallisation from ethyl acetate gave two different types of crystalline aggregates, leaf like clusters and opaque wart like deposits. They were mechanically separated and further purified by crystallisation from ethyl acetate. The leaf shaped material yielded piperine and the opaque solid gave highly refractive yellow rods with green sheen. It had a melting point of 146–149°C and analysed for $C_{19}H_{21}O_3N$ and it was named piperettine. On hydrolysis with alcoholic potash piperettine gave piperidine and an acid piperettic acid as yellow needles having a m.p. 223–224°C. The acid gave a positive Labat test for a methylene dioxy group and an absorption maximum at 360 nm indicating it could be an analogue of piperic acid and that piperettine is the corresponding piperidide. The structure of piperettine was confirmed as 7-(3,4-methylenedioxy phenyl) hepta 2,4,6-trienoic acid piperidide by synthesis (7). They also analysed black pepper samples from different sources and found piperettine in all the samples ranging from 0.23 per cent in an Indian sample to 1.56 per cent in a sample from Sri Lanka.



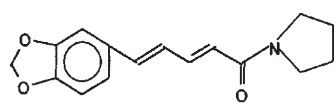
7 Piperettine

By elaborate column chromatography of the residue after removal of piperine by repeated crystallisation, Traxler *et al.* (1971) obtained a viscous colourless liquid having pungency. It was named piperanine. Based on UV, IR and NMR spectra, its structure was proposed as 5-(3,4-Methylenedioxy phenyl)-2-trans pentenoic acid (8). The structure was confirmed by synthesis. The natural concentrate which could not be crystallised earlier, was crystallised by seeding with the synthetic product. The identity of synthetic piperanine with the natural isolate was established by mixed m.p., UV, IR and NMR spectra.



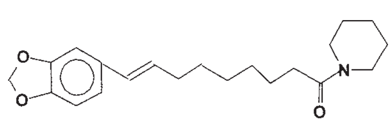
7 Piperettine

Grewe *et al.* (1970) on repeated column chromatography of a methylene chloride extract of black pepper, isolated a new alkaloid named as piperylin, crystallising as colourless needles melting at 142°C. UV and IR spectra resembled that of piperine. The mass spectral fragments were same as those produced in the acid part of piperine, but had a molecular ion at m/z 271. It showed an ion fragment at m/z 70 instead of m/z 84 for piperidine. The base was suspected to be pyrrolidine and was confirmed by NMR. The structure was confirmed by synthesis of piperylin from piperic acid chloride and pyrrolidine. Piperylin (9) was found to be same as trichostachine isolated from *Piper trichostachyon* by Singh *et al.* (1969) Mori *et al.* (1974) also isolated by preparative thin layer chromatography a compound identified as 1-piperoyl pyrollidide and named it pyrroperine. This compound appears to be same as piperylin isolated by Grewe *et al.* (1970).



9 Piperylin

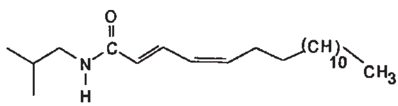
They could also isolate three other alkaloids, oily in nature and highly sensitive to light, by repeated preparative thin layer chromatography and named them piperoleins A, B and C. Piperolein B was obtained almost pure by this method. Based on UV, IR and NMR spectra it was proposed as the piperidide of 9-(3,4-methylene dioxy phenyl) non 8-enoic acid (10). Mass spectrum of the compound confirmed this structure. This was further confirmed by synthesis of piperolein B. Piperolein A and C could not be purified completely. Based on mass spectra, piperolein A appeared to have shorter aliphatic side chain while piperolein C appeared to have a longer aliphatic side chain compared to piperolein B.



10 Piperolein B

Su and Horvat (1981) isolated three insecticidally active compounds present in trace amounts from black pepper. They have been identified as (E,E)-N-(2-methyl propyl)-2,4-decadienamide, (E,E,E)-13-(1,3-benzodioxol-5-yl)-N-(2 methyl propyl)-2,4,12-trideca trienamide and (E,E,E)-11-(1,3-benzodioxol-5-yl)-N-(2-methyl propyl)-2,4,10-undecatrienamide. These compounds have earlier been isolated from various other species of *Piper* and named as peepuloidin, guineesine and pipericide. Atal *et al.* (1975) has reported isolation of minor amounts of highly pungent dihydro and tetrahydro piperine from black pepper.

Siddiqui *et al.* (1997) has recently isolated a new amide named pipericine, and based on spectral data it was identified as the N-butylamide of octadeca-*trans*-2-*cis*-4 dienoic acid (11).

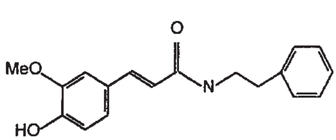


11 Pipericine

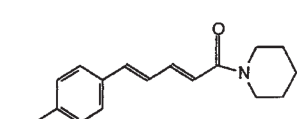
Parmar *et al.* (1997) listed the following alkaloids in addition to those discussed above: brachymide B, guineesine, retrofractamide A, sarmentine, sarmentosine and tricholein.

Phenolic Compounds of Pepper

Nakatani *et al.* (1980), on chromatographing the weakly acidic fraction of a methylene chloride extract of pepper, isolated a compound which crystallised as white needles with a m.p. of 144–144.5°C. It was identified as N-feruloyl tyramine (12) by spectral data. The synthesis of the compound by condensation of acetyl feruloy-lacid chloride with tyramine followed by hydrolysis yielded a product identical with the isolated compound. Another fraction on chromatography and crystallisation afforded pure crystals melting at 199.5–200.5°C and named coumaperine. It was identified based on spectral data as N–5-(4-hydroxy phenyl)-2E, 4E-pentadienoyl piperidine (13). The structure was confirmed by synthesis achieved by a modified Wittig reaction of p-benzyloxy benzaldehyde and 4-bromocrotonyl piperidine. The product was obtained as a mixture of 2E, 4E and 2E, 4Z isomers of the pentadienyl moiety in 19:1 ratio and separated by column chromatography (Inatani 1980).



12 N-Feruloyl tyramine



13 Coumaperine

The phenolics in black pepper are a mixture of phenolic acid glycosides and flavanol glycosides. On hydrolysis nine phenolic acids comprising hydroxy benzoic acids and hydroxy cinnamic acids along with significant quantities of quercetin and kaempferol were obtained (Bandyopadhyay 1990). Farmer *et al.* (1997) has listed the following flavones from pepper: isoquercetin, isorhamnetin, 3-0-ß-D-rutinoside, kaempferol 3-0-arabinoside-7-rhamnoside, kaempferol-3-0-ß-glucoside, quercetin 3-0-ß-D-rutinoside. Pepper also contains sitosterol.

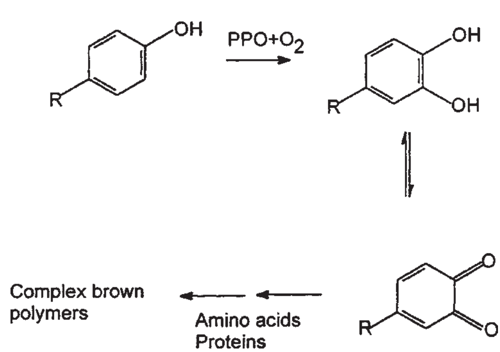
Grewe *et al.* (1970) found several lignans: one of the lignans was identified as cubebin, which had already been isolated from tailed pepper, *P. cubeba*.

Blackening of Pepper

A preliminary report on the blackening of pepper by Lewis *et al.* (1976) suggested that it was due to enzymatic oxidation of polyphenolic substrates present in the skin of green pepper. Based on this, Lewis *et al.* developed a process for dehydrated green pepper in which green pepper was blanched to arrest the enzyme action and subsequently dried in a cross flow drier. The green pepper could also be preserved in brine containing acetic acid or citric acid (Pruthi 1976).

Browning of raw fruits,vegetables and beverages is a major problem in food industry and is believed to be one of the main cause of quality loss during post harvest handling and processing. The pathway of browning in food is well characterised and can be enzymatic or non enzymatic in origin. The formation of pigments via enzymatic browning is initiated by the enzyme polyphenol oxidase (PPO) also known as tyrosinase, phenol oxidase or cresolase. Endogenous PPO activity is present in foods like potato, apples, mushrooms, banana, peaches, fruit juices and wines.

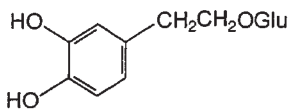
Enzymatic browning is the result of PPO catalysed oxidation of phenols or diphenols to o-quinones. PPO is a mixed function oxidase that catalyses both the



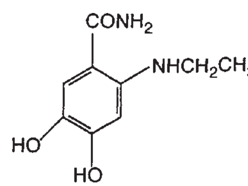
Scheme 2 Action of PPO on phenolie substrates.

hydroxylation of monophenols to diphenols and the subsequent oxidation to o-quinones. The o-quinones are highly reactive and can polymerise to form high molecular weight compounds or brown pigments (melanin) or react with amino acids and proteins that enhance the brown colour produced (Scheme 2).

Variyar *et al.* (1988) isolated the crude enzyme from green pepper and used it to pinpoint the active phenolic substrates of the enzyme. They isolated 2,4-dihydroxy phenyl ethanol glycoside (14) and its aglycone and found to be the active substrates for this o-diphenol oxidase enzyme. They also isolated another efficient substrate for polyphenol oxidase and characterised as a 3,4-dihydroxy-6-(n-ethyl amino) benzamide (15) (Bandyopadhyay 1990).



14 2,4-dihydroxy phenyl ethanol glycoside



15 3,4-dihydroxy -6-(n-ethyl amino) benzamide

Other Constituents of Black Pepper

Starch is a predominant constituent of black pepper ranging from 35–40 per cent of its weight. There are no reports on the characterisation of the nature of starch present in pepper. The protein of pepper has not been investigated in any detail because pepper is used in only small amounts to flavour foods and hence not expected to contribute to nutritive value. Pepper contains fat ranging from 1.9–9.0 per cent. Bedi *et al.* (1971) and Salzer (1975) have determined the fatty acid composition. The major fatty acids are palmitic (16–30%), oleic (18–29%), linoleic (25–35%) and linolenic acid (8–19%). Recently Parmer *et al.* (1997) listed the following miscellaneous constituents from pepper: acetylcholine, caffeic acid, capric acid, choline, p-coumaric acid, p-and m-cresol, 2(3,4-dihydroxyphenyl) ethanol, henriacontane, henriacontane-16-ol, henriacontane-16-one, lauric acid, melvalic acid, 3,4-methyleredioxy cinnamaldelyde, myristic acid, oleic acid, palmitic acid, phenyl acetic acid, piperonal, stearic acid, sterculic acid and vernolic acid.

CONCLUSIONS

Chemical investigations spanning over a century have contributed immensely to the understanding of this wonderful spice. But a last word has not been written. Further studies may in future reveal novel compounds. An area relatively neglected by the pepper chemists is that of the chemical diversity among cultivars. Detailed study of the flavour profiles and chemical composition will be helpful in locating lines having high flavour quality. Such lines can then be incorporated in breeding programmes to develop high yielding, high quality varieties. Such an approach calls for a close collaboration between the breeders and chemists.

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Jagella, T. and Grosch, W. (1999) flavour and off flavour compounds of black and white pepper (*Piper nigrum* L.).

1. Evaluation of potent odorants of black pepper by dilution and concentration techniques. *European Food Res. Tech.,* **209,** 16–21.
2. Odour activity values of desirable and undesirable odorants of black pepper. Ibid, 26–26.
3. Desirable and undesirable odorants of white pepper. Ibid, 27–31.

The following paper deals with the chemical composition of four related species.

Sumathykutty, M.A., Rao, J.M., Padmakumari, K.P. and Narayan, C.S. (1999) Essential oil constituents of some *Piper* species. *Flavour and Fragrance J.,* **14,** 279–282.

4.1. AGRONOMY AND NUTRITION OF BLACK PEPPER[1]

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INTRODUCTION

Black pepper has originated in the tropical evergreen forests of Western Ghats of South India. From ancient times, the Malabar coast of South India (consisting of the state of Kerala and parts of Karnataka), was the major producer and exporter of pepper. The state of Kerala, accounts for around 95 per cent of the area under cultivation and production. Major pepper growing districts of Kerala are Idukki, Wynad, Cannanore, Kasaragod and Calicut. The adjoining states of Kerala *viz.,* Karnataka on the west coast and Tamil Nadu on the east coast together accounted around 5 per cent of the area and production of pepper (Table 4.1.1).

In Karnataka state, pepper is grown in Kodagu, Dakshina Kannada, Uttara Kannada, Chikmagalur, Shimoga and Hassan districts, mostly as intercrop in coffee or arecanut gardens. In Tamil Nadu, pepper is grown in Nilgiris, Coimbatore and Kanyakumari districts. Pepper cultivation is further spread from the states of Kerala and Karnataka to adjoining states *viz.,* Maharashtra and Goa on a very limited extent. The area under pepper in the North Eastern region of India is minimal, contributed by West Bengal as well as North Eastern States of India *viz.,* Assam, Tripura, Meghalaya and Arunachal Pradesh.

Table 4.1.1 Area and production of pepper in India (1994–95)*.

States	*Area (ha)*	*Production (mt)*
Kerala	188,690	52,010
Karnataka[1]	2,980	740
Tamil Nadu	2,960	280
Pondicherry	10	10
Andaman & Nicobar	410	80
Total	195,050	53,120

* Source: IPC 1997. Pepper Statistical Year Book 1995/1996, IPC, Jakarta.

[1] See PS on page 223.

[1] See annexure to this chapter for additional information on some topics.

Pepper cultivation started in Malaysia following the European colonization during the 17th century. In Malaysia, as in India, pepper is a smallholders' crop and is confined mainly to Sarawak, with holdings ranging from 0.1 to 0.4 ha per family. In view of the high density planting and more intensive cultivation, productivity of pepper in Malaysia is one of the highest in the world, with around 3000 kg ha^{-1}. In Indonesia, cultivation of pepper dates back to many centuries, and was a leading producer and exporter for centuries. Here also it is mainly a smallholders' crop, concentrated in the Islands of Bangka, Lampung, Kalimantan, Sulawesi, etc. The productivity is higher than that in India, ranging from 800 kg ha^{-1} in certain areas to 2500 kg ha^{-1} in certain other locations (for details see Wahid, this volume). In Brazil, pepper is cultivated in about 21,000 ha with an annual production of 19,500 mt. In Thailand 80 per cent of the pepper cultivation is confined to the eastern parts and the rest in the southern region. It is grown under irrigation in Thailand, the net area under cultivation is around 2390 ha with an annual production of 9773 mt. However, the productivity is the highest (4000–4500 kg ha^{-1}) in Thailand. In Vietnam, pepper is cultivated in 17,000 ha with an annual production of 20,000 mt. In Sri Lanka, pepper cultivation is confined to around 12,000 ha, out of which 35–40 per cent are of mixed home gardens and 60 per cent of the crops are confined to Kandy, Matale and Kagalle districts. The productivity is around 248 kg ha^{-1}. In total, pepper is cultivated in twenty six countries located in the tropical belt of the globe (See Chapter 1, Table 1.1).

Climatic Requirements

Pepper is grown in the humid tropics, its cultivation confined to the tropical zones of the Asia Pacific Region—mainly India, Indonesia, Malaysia, Sri Lanka, Thailand and Vietnam. Outside of the Asia Pacific region, this is grown in Brazil and Madagascar. Even in tropics, the cultivation is concentrated in tracts having hot, humid climate. The characteristic climatic requirements for pepper are high rainfall, uniform temperature, high relative humidity which is typical of the hot and humid tropical region with little significant variation in day length and humidity throughout the year (Cobley 1956, Rutgars 1949). Though the original home of pepper is Western Ghats and adjoining plains of India (Kerala state), no effort is made so far to study critically the effects of components of climate and then to classify the areas according to their suitability. Such efforts have been done in countries like Indonesia (See Wahid, this volume).

Rainfall

Well distributed heavy rainfall ranging from 1000 to 3000 mm is required for proper growth and development of pepper plant, though the crop comes up even in low rainfall areas with uniform distribution of precipitation. The distribution of rainfall, drainage status and moisture holding capacity of the soil, are more important than the quantum of total rainfall. A higher precipitation will be an advantage if the soil is well drained; if not, the plants will be prone to diseases. Long spells of dry periods are always harmful. In India, during the drought period of 1973, 1977, 1983, 1987 and

1989 thousands of pepper plants dried up in the Cannanore district of Kerala (Sadanandan 1993). In such situations life saving irrigation together with mulching the basin of pepper plants have to be resorted to conserve the soil moisture. In a study at Indian Institute of Spices Research (IISR), Calicut, India, it was found that pepper yield was significantly correlated with the rainfall received during the first half of May and the cumulative total rainfall in second half of June. About 70 to 100 mm, depending upon the soil type, received within a period of 20 days, is adequate for triggering the flushing and flowering mechanism of the plant. Once the flowering process sets in, there need to be continuous, though not heavy rainfall for proper fruit set. Dry spell if any for a few days during this critical period, will result in spike shedding and substantial reduction in pepper yield. At IISR, Calicut, a few promising drought tolerant lines, such as KS-69, KS-51 and KS-144 have been identified and are being field evaluated (IISR 1997).

The pepper growing tracts in India receive rain in the south-west (SW) monsoon period (June to September) and north-east (NE) monsoon (October to November), the peak being in July and the pattern of rain fall is bimodal. The total rainfall received during the year is around 3500 to 4000 mm in 120 to 135 rainy days. Summer months are practically dry.

In the pepper growing tracts of Malaysia, most of the precipitation is received from October to March, April to August receive less rainfall, but in no month does the average falls below 175 mm $month^{-1}$. The pepper growing tracts of Sarawak fall well within the continuous wet belt with an average rainfall of at least 100 mm in one month (DeWaard 1969). It may be summed up that the effective rainfall received during different periods of the year is more vital than the total rainfall received during any particular period of the year, and the effectiveness or otherwise of the rainfall received during any particular period is determined by the texture and depth of the soil, atmospheric temperature and humidity.

Temperature

Pepper plants prefer an equable climate and does not tolerate extremes of temperature; minimum is around 10°C, the optimum being 20–30°C. The temperature during the monsoon months is lower than the drier part of the year. Soil temperature at 30 cm below the surface ranges from 25 to 28°C depending upon the weather condition. As the elevation increases the temperature decreases.

Humidity

A hot humid climate, though good for growth and development of pepper, continuous high humidity interferes with normal growth and also encourages incidence of diseases and pests. A dry and slightly windy atmosphere is advantageous, provided soil moisture availability is adequate. It is imperative to take these factors into consideration while new areas are taken up for cultivation. The relative humidity varies from 63 per cent (March) to 98 per cent during rainy season in July.

Sunshine

The daily mean sunshine reflects the rainfall distribution pattern. In India, during June to July, the mean sunshine hours per day is the minimum (three) due to continuous rain and tend to increase in summer to 10 hrs per day. The standards used to trail pepper are pruned and vines are exposed to sun during April–May, immediately after the receipt of one or two summer showers, and is primarily to expose the plants to sun during the preflowering period. In Malaysia, DeWaard (1969) reported that sunshine hours rise from 2.8 hours in December to the peak of seven hours in May with an annual mean of 4.9 hours.

Soils

Pepper plantations are established on a wide variety of soils, their texture varying from sandy loam to clayey loam. In Malaysia, most of the plantations are in soils which have been developed on slate, sandstone and on areas of alluvial origin having poor nutrient status (DeWaard 1969). The clay is of kaolinite type and of poor buffering capacity. The soil pH ranges between 4.5 to 5.5. In Indonesia, pepper plantations are raised in all types of soils, ranging from rich loose volcanic to clayey loam. In Sri Lanka, red clay loam and sandy loam are favoured by planters. In India, pepper is grown on a wide range of soils under the following situations:

i. Coastal and midland areas where pepper is grown as a backyard crop along with coconut/arecanut and/or other support trees
ii. In the uphills, hill slopes and valleys where pepper is extensively cultivated
iii. Hills at an elevation ranging from 750–1200 m, where it is grown on shade trees in coffee, cardamom and tea plantations
iv. Valleys as a mixed crop in arecanut gardens.

Pepper requires a porous, friable soil, with good drainage, adequate water holding capacity, rich in humus and essential plant nutrients. The major pepper growing soils of India can be broadly classified into four major orders *viz.,* Oxisols (6%), Alfisols (70%), Mollisol (10%), and Entisols (4%) (Sadanandan 1993) (Table 4.1.2).

Table 4.1.2 Distribution and classification of major pepper growing soils*.

Soil type	*Order*	*Sub-order*	*States in India*
Forest loam	Mollisols	Udolls Ustolls	Kerala, Karnataka and Tamil Nadu
Laterite	Alfisols Oxisols	Ustalfs	Kerala, Karnataka and Tamil Nadu
Alluvium	Entisol	Ustorthcut	Kerala and Karnataka
Red loam	Alfisols	Ustalfs Ustults	Kerala and Karnataka

* Sadanandan, A.K. 1994.

Red loam (Alfisol)

This soil is acidic in reaction (pH 5.3–6.3), highly porous and friable, low in organic matter and essential nutrients, including potash, low in cation exchange capacity, high Fe and Al, prone to P fixation and having low water retention capacity. In this soil, pepper is grown as mixed crop in coconut/arecanut groves, using them as standards to trail pepper or mixed with other trees, both perennial and annual.

Forest loam (Mollisol)

This soil is acidic (pH 5.0–5.5), restricted to high lands of the Western Ghats, shallow in depth, but well drained, having dark brown to black colour on the surface due to the presence of organic matter. The soil is rich in organic matter, N and K, but organic carbon decreases irregularly at depths. The phosphorus and base status are medium, highly valued soil for pepper, because of the inherent fertility. Pepper is grown mainly as a monocrop in this soil.

Laterites (Oxisol)

The soil is acidic (pH 5.0–6.2), generally having low level of plant nutrients, including potash, low cation exchange capacity (CEC) with weak retention capacity of bases applied as fertilizers or as amendments. The soils are low in P status and having high P fixing capacity because of the abundance of Fe and Al; deficient in S, and N loss through leaching is substantial in high rainfall area. The high exchangeable aluminium, can become toxic to plants, low Ca content limit root volume and increases moisture stress. The micro nutrient deficiencies are also frequent in this soil. Pepper is grown mainly as a mixed crop in the coconut/arecanut gardens and as a homestead crop.

Alluvium (Entisols)

The soil is acidic (pH 5.0–6.5) and mostly occurring along the banks of rivers and its tributaries, moderately rich in plant nutrients including potash and bases, shows wide variation in the physico-chemical properties, depending upon the nature of aluminium deposit. The soils are deep with sandy or loamy in texture and respond well to management. Pepper is grown as a mixed crop on arecanut which is used as standards to trail pepper.

Though pepper is grown on a wide range of soils, moisture availability is one of the major factors that governs the suitability or otherwise of a particular soil type. In heavy rainfall tracts, well-drained soil types are ideal. Even though adequate supply of soil moisture is desirable, inadequate drainage is harmful for the plant. The pepper roots are very sensitive to shortage of oxygen and to high partial pressure of carbon dioxide which results in diminishing root activity, root growth and nutrient uptake. Soil conditions ideal for plant growth and development are, adequate drainage, good water holding capacity of soil, and absence of rock or hard substratum within one meter of the soil surface.

Planting Material

Pepper plants under good management, continues to yield up to 30 years and full bearing commences from 4–5 years after planting under the condition existing in India. In Sarawak (Malaysia), Thailand, Brazil, etc. pepper is retained only for a period of 10–15 years as they are trailed on non-living standard of limited height, and regular replanting is practiced after this effective productive period. Development of pepper plantations involves substantial investment during prebearing period, and much emphasis should be given for proper planting material selection.

In India, ten high yielding varieties are available for the growers to choose from; in fact it is always advisable to grow a mixture of varieties than to go for a single one as a safeguard from diseases and insect pests. At the same time a highly heterogeneous population is a disadvantage on a harvesting-post harvest technology point of view and in the maintenance of high quality and uniformity of the product. A farmer has to judiciously select the planting material, striking a balance between these two requirements. In addition, there are a few high yielding cultivars, such as, *Karimunda, Kottanadan, Aimpiriyan, Kuthiravally,* etc. that can be grown. Certain lines that are tolerant to drought and suitable for high elevation are also available with IISR, Calicut. In Malaysia most pepper areas are covered by a single cultivar, *Kuching*. *Semongok perak* and *Semongok emas* are the two high yielding varieties developed there, the latter one is also tolerant to *Phytophthora* foot rot. In Brazil also cv. *Kuching* is mostly grown.

In most pepper growing countries, the orthotropic, climbing shoot is used as the planting material, except in India. They are not popular in India due to their non-availability, because most plantations are on living standards and the pepper vines grow unrestricted. The orthotropic climbing shoots are the best for planting as they give vigorous plants, develop fruiting laterals from the base itself and start yielding early. Earlier, the growers used to plant either the runner shoots or the climbing orthotropic shoots with the onset of the south-west monsoon. Now only pre-rooted cuttings from runner shoots are used for planting by most growers in India. The hanging shoots are not good as planting material as they give weak, lanky growing plants. In many pepper growing countries, the pepper plants are pruned 5–6 months after planting and again after one year. These stem cuttings obtained through pruning are also used as planting material.

Rooted Cuttings Production

The annual requirements of pepper planting material is very large in India, running to millions. Such heavy demands led to large scale production of pre-rooted cuttings in polybags. Many studies have been carried out in various pepper growing countries for developing an efficient propagation technique for pepper. Such a technique is required for large scale production of the new breeding lines also.

Use of 3-node cuttings

When the large scale production of pepper cuttings started in India (in Kerala), three node cuttings from runner shoots were used. The success rates were often very low. The runner shoots from high yielding and healthy plants are kept coiled on wooden pegs fixed at the base of the vine to prevent the shoots from coming in contact with soil and striking roots. The runner shoots can be separated from the mother plant in Jan-Feb., dip in a fungicide like copper oxychloride or Bordeaux mixture for 1 minute, surface dry in the shade and after trimming the leaves, cut into 2–3 nodes and plant either in nursery beds or polythene bags filled with fertile soil mixture with sand and farmyard manure. Studies by various workers indicated that application of IBA 200 ppm improved the rooting percentage of cuttings, and it was the best for defoliated single node cuttings (Suparman and Zaubin 1988). Two node cuttings dipped in IBA at 1000 ppm for 45 seconds produced highest root numbers (Pillai *et al.* 1982). Application of 25 per cent cattle urine gave the same effect as 2000 ppm IBA in terms of fresh and dry weight of roots and the number of roots per cutting (Suparman *et al.* 1990). The growth of single node cuttings in general was significantly better in the soil at 80 per cent or 100 per cent of field capacity. Ernawati and Yufdy (1990) found that single and double node plus a part of climbing shoot were better than single and double node cuttings. Adequate shade and frequent irrigation are necessary. The cuttings strike roots and become ready for planting in June. Problem of rotting of the cuttings in nurseries by fungi like *Rhizactonia solani, Pythium* sp., *Colletotrichum* sp. and *Sclerotium rolfsi* can be effectively managed by regulating shade with coconut leaves or other locally available materials to regulate the light intensity to 11,338 lux (Mammootty *et al.* 1993) and by occasional fungicide application (See Annexure for additional details).

Rapid multiplication technique

An efficient propagation technique (commonly called as bamboo method) has been developed in Sri Lanka and it is becoming increasingly popular in India (Bavappa and Gurusinghe 1978). In this method, a trench of 60 cm deep and 40 cm wide, having convenient length is made. The trench is filled with rooting medium (preferably forest soil, sand, farmyard manure mixture, 1:1:1). Split halves of bamboo with septa or split halves of PVC pipes having 1.25–1.5 m length and 8–10 cm diameter provided with plastic septa are fixed at 45° angle on a strong support. The bamboo/PVC pipes can be arranged touching one another. Rooted cuttings, one each per bamboo, are planted. The lower portions of the bamboo or PVC pipe splits, are filled with a rooting medium (preferably weathered coir dust-farm yard manure mixture, 1:1) and the growing vine is tied to the bamboo or PVC split pipes in such a way as to keep the nodes pressed to the rooting medium. The tying could be done with degradable jute or other vegetable fibres. The vines are irrigated daily. As the vines grow up, filling up the bamboo with rooting medium are to be continued regularly. For rapid growth, the following nutrient solution may be applied every

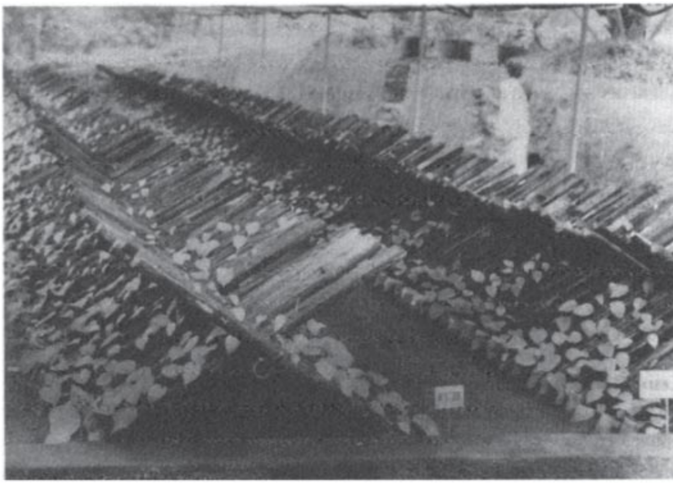

Figure 4.1.1a A view of the rapid multiplication system established at IISR. Split bamboo pieces of 1.5 m length are used.

Figure 4.1.1b A rooted vine after removing from the bamboo. Each rooted node is separated and planted.

fortnight: urea (1 kg), super phosphate (0.75 kg), muriate of potash (0.5 kg), magnesium sulphate (0.25 kg) in 250 litres of water. The solution is applied at the rate of 0.25 litre vine^{-1} two to three times a month (Fig. 4.1.1a).

When the vine reaches the top (the initially planted vine takes 3–4 months for this) the terminal bud is nipped off and the stem is crushed at about three nodes above the base, in order to activate the axillary buds. After about 10 days, each vine is cut at the crushed point and removed from the rooting medium and each node is separated (Fig. 4.1.1b). The nodal cutting with the bunch of roots intact is planted in polybags filled with pot mixture. Care should be taken to keep the axil above the soil. The polybags should be kept in a cool humid place, or should be covered with thin polythene (200 gauge) sheet to retain high humidity. The buds start developing in about three weeks and then the polybags can be shifted to partial shade. The stumps regenerate giving out one or two shoots each and they also can be trained as in the earlier case. Thus continuous regeneration and harvesting of rooted cuttings can be possible. About four harvests can be taken in an year, giving a multiplication rate of about 1:40 in a year. The advantages of this method are: multiplication is rapid (1:40), the root system is well developed and better field establishment and more vigorous growth as a result of better root system and the propagation is a continuous process. In Malaysia, Ghawas and Miswan (1984) could get on an average 54 rooted cuttings using the above method where top soil plus coconut husk was used as the rooting medium.

Nutrition of Nursery Plants

The exact requirement of the nutrients for proper growth and development of pepper plants in nursery has not been worked out. Studies on nutrients removed (Table 4.1.3) showed that rooted pepper plants of about three months with four to five leaves removed 64.8, 3.3, 54.8, 24.5, 11.2, 8.1 mg of N, P, K, Ca, Mg and S respectively. Among the major nutrients studied, consumption of N was highest followed by K and Ca. The micro nutrients utilized were 0.978, 0.191, 0.128 and 0.451 mg of Fe, Mn, Zn and Cu respectively. Among these, iron utilization was more followed by copper.

Significant differences exist among cultivars with regard to utilization of nutrients. *Aimpiriyan* utilized more of N and K than the other cultivars. The studies conducted at IISR showed that proper nutrient management of pepper nursery is essential to get healthy plants that can give high establishment rate and vigorous growth in the field.

Planting and After Care

Site selection

The land proposed for planting pepper should be cleared of weeds and undergrowths. In level lands proper drainage channels should be provided. Hill slopes are also suitable for raising pepper. When plantations are raised on sloppy land, the slopes

Table 4.1.3 Uptake of nutrients by rooted cuttings of some black pepper cultivars (mg kg^{-1}).

Variety	*Dry matter (g)*	*N*	*P*	*K*	*Ca*	*Mg*	*S*	*Fe*	*Mn*	*Zn*	*Cu*	*Mo (µg $plant^{-1}$)*
Panniyur-I	1.724	53.33	3.55	51.30	15.86	5.56	6.05	1.54	0.185	0.098	0.207	5.24
Kottanadan	2.470	58.65	3.00	59.25	30.11	12.84	8.88	0.75	0.195	0.184	0.832	3.38
Karimunda	1.657	59.13	3.36	40.51	16.05	6.85	6.08	0.75	0.140	0.074	0.241	3.63
Aimpiriyan	2.834	88.13	3.47	68.08	35.77	19.62	11.57	0.87	0.243	0.157	0.524	4.70
Mean	21.7	64.81	3.35	54.79	24.45	11.22	8.15	0.978	0.191	0.128	0.451	4.24
CD 5 %	0.590	6.73	0.99	15.09	10.46	4.94	3.77	0.18	0.061	0.040	0.189	1.17

facing south should be avoided. The lower half of north and north-eastern slopes are better suited for raising plantations so that the plants are not subjected to scorching effect during summer months. If the land is sloppy it is necessary to adopt soil and moisture conservation measures such as contour terracing. The site should be fenced to prevent trespassing of animals, which is essential as a phytosanitary measure.

Land preparation and standard establishment

With the receipt of first rain in May-June the primary stem cuttings of *Erythrina indica, Garuga pinnata,* seedlings of *Ailantbus* spp. or *Grevillea robusta* are planted. However, when *Erythrina indica* is used as standard, application of Carbofuran 3 g at the rate of 30 g may be given once in a year to control nematode and root grubs. When *Erythrina indica* and *Garuga pinnata* are used, the primary stems/stem cuttings of about two metre are cut in March-April and stacked in shade in groups. The stacked stems start sprouting in May. The stems are planted at the edge of the pits dug for pepper vines.

In India, pepper is invariably trailed on live standards, the most commonly used ones are dadap (*Erythrina indica* and *E. lithosperma*) (Fig. 4.1.2), silky oak *(Grevillea robusta), Glyricidia, Garuga pinnata, Ailanthus* spp., etc. The less common support trees include *Mesopsis eminii, Leucaena glauca (=L. leucocephala), Pajanalia rheedii, Macaranga peltata, Salmalia malabarica,* mango and jack trees. Both coconut and arecanut palms are used for trailing pepper when pepper is planted as a

Figure 4.1.2 A monocrop of pepper on *Erythrina indica* standard. The pepper is maintained at 5–6 m in height.

Figure 4.1.3 Long columns of pepper 12–15 m high are found when pepper is trained on tall trees. Pepper on *Grevillea robusta* intercropped with coffee.

mixed crop. When interplanted in cardamom and coffee plantations pepper is trailed on all forest trees in the area. Dead standards are not used in India, though trials at IISR have shown that pepper trailed on dead standards gives higher yield (Menon *et al.* 1982). Tall columns of pepper can be established on tall trees such as *Grevillea robusta* (Fig. 4.1.3).

Sadanandan *et al.* (1992) reported that pepper plants trailed on *Erythrina indica* yield better than those trailed on other standards. But this is highly susceptible to stem and root borer and often they do not last long. The timber is also valueless. At higher elevations, silky oak is the most widely used standard and is found to be an ideal tree for trailing pepper. This is also a valuable hard wood. In plains *Ailanthus* sp. (mainly *A.malabarica*) are very good standards and they are valuable soft woods.

Both in Sri Lanka and Philippines only live standards are used. In Sri Lanka *Glyricidia* is the most common standard. In Phillipines *Glyricidia,* ipil-ipil *(Leucaena),* dadap *(Erythrina indica)* and *Acacia* are used. It has been shown that *Glyricidia* has strong allelopathic effect on pepper growth (Murni 1989). In other pepper growing countries dead standards are preferred though in recent times many small farmers started using live standards, mainly because of the high capital investment required for establishing dead standards and also due to their relative non-availablity. In Malaysia and Indonesia, the preferred support material is wooden pole of the Belian

Figure 4.1.4 The Sarawak system, when pepper is grown over Belian poles. Note the bushy growth of plants resulting from pruning.

tree (*Eusideroxylon zwageri,* Lauraceae, otherwise called Borneo Ironwood, is a high density, heavy construction timber resistant to white ants—ed.). The Ironwood poles are very durable and can remain for many years without getting damaged (Fig. 4.1.4). In India, teak poles *(Tectona grandis)* and reinforced cement concrete poles were tried for trailing pepper (Menon *et al.* 1982). The trials conducted at IISR indicated that both are useful, but teak poles are not long lasting and they are highly expensive and difficult to get. RCC poles are also very expensive. Reports from Indonesia indicated that RCC poles are not good for trailing pepper. But in Thailand, RCC poles are extensively used. Earthern pipes erected vertically and filled with sand or mud are also used in Thailand, Vietnam and also in Malaysia. (See annexure for more details).

Planting

With the onset of monsoon, 2–3 rooted cuttings of pepper are planted individually in the pits on the northern side of each standard. (In the case of unrooted cuttings, about 4–5 cuttings per pit are to be planted and the number of nodes in this case may be 4–5). At least, one node of the cutting should go below the soil for proper rooting. To boost rapid growth during initial years, pits can be filled with a mixture of top soil, five kg well rotten cattle manure, one kg neem cake and 150g rock phosphate. In case of large pits alternate layers of coconut husk and the above mixture can be filled to help the young plants to withstand hot summer (Pillai 1992). Ten to twelve cuttings may be planted around the large trees except on southern side. At a spacing of 2.5×2.5 m, there will be about 1600 standards ha^{-1}. Karimunda yielded highest (6160 kg ha^{-1} green) under 2×1 m spacing followed by Panniyur-1 (4278 kg ha^{-1}) when trailed on RCC standards (Menon *et al.* 1982). The build-up of soil nutrients increased substantially under wider spacings. As plant density increased from 1100 to 5000 ha^{-1} depletion of organic matter, K, Ca, Mg and micro nutrients like Zn, Fe, Cu and Mn were more conspicuous (Reddy *et al.* 1992). The young plants in the first one or two years are shaded loosely with twigs of trees or coconut leaves, and should be removed at the onset of rain.

In Sarawak, usually only one top shoot cutting (5–7 nodes) is planted on mounds, and is then tied to a wooden stake. Young plants are shaded usually with fern leaves or straw. In 3–4 weeks the vines get established and start growing. Wooden supports—4 to 5 m poles of the Borneo Iron wood, are planted after 2–3 months. The recommended spacing is 1.8 m×2.4 m, accommodating about 2300 plants/ha. However, the average plant density is only 1970–2000/ha (George 1982). The first fertilizer application also starts with the planting of the support (See annexure for more details).

Cultural Practices

As a pepper plant grows it should be tied to the standard as often as required so that the stem gets firmly attached to the support. The young plant should be protected from hot sun during summer months by artificial shade. Pruning the terminal portion of the plant can also be practiced to encourage the development of lateral shoots and hence the higher production of spikes. Kurien and Nair (1988) showed that pruning of terminal shoot increased the number of spikes produced and the number of bearing laterals. Pruning is not a regular practice in India, but is a routine operation in most other pepper growing countries. Regulation of shade by lopping the branches of standards is necessary not only for providing optimum light to the vines but also for enabling the standards to grow straight. Adequate mulch with green leaf or organic matter should be given towards the end of north-east monsoon. The base of the vines should not be disturbed to avoid root damage.

During the second year, practically the same cultural practices are repeated (Table 4.1.4). However, lopping of the standards should be done in every year, not only to regulate the height of the standards, but also to shade the pepper vines optimally. Excessive shading during the flowering and fruiting period encourages pest infestation and result in poor flowering and yield.

From the fourth year, usually two diggings are given in the interspaces (leaving the basins intact), one during May-June and the other in October–November. Growing cover crops like *Calopogonium mucunoides, Mimosa invisa* are also recommended under west coast conditions to provide an effective soil cover to prevent soil erosion during rainy season. Further they dry up during summer, leaving

Table 4.1.4 Calender of operations and inputs for pepper (for India).

January–February	Harvesting pepper. Cutting and removing hanging shoots, tying vines, mulching pepper basins.
March–April	Phytosanitation. Uprooting diseased vines with roots and by burning. Taking pits 0.5 m cube, filling with top soil + 1 kg lime + 5 kg FYM/compost.
May–June	With the receipt of 100 mm rain, apply farmyard manure 5 kg $vine^{-1}$ + rock phosphate 250 g + neem cake 1 kg and mulch pepper basins. Shade regulation.
June–July	Spray 1 per cent Bordeaux mixture, drench copper oxychloride 0.2 per cent. Spray the plant with endosulfan (1.5 ml/litre) to control pollu beetle infestation (only in plains). Apply urea 50 g + muriate of potash 120 g and mix with soil.
September–October	Apply urea 50 g + MOP 120 g + magnesium sulphate 50 g and mix with soil. Shade regulation. Spray 1 per cent Bordeaux mixture all around diseased vines only. Vine tying should continue as and when required.
November–December	Remove diseased plants; drench the site with copper oxychloride. Remove hanging shoots. Mulch basins. Shade young vines.

a thick organic mulch. In Malaysia and Indonesia, cover crops have not shown to be useful, rather they are disadvantageous. Clean cultivation is recommended in these countries. Combined application of dolomite with nematicide and mulching significantly increased the growth and yield components (Nuryani *et al.* 1990). (See annexure 4.1). (There is no information on the long term allelopathic effect of cover crops on pepper—ed.).

Care should be given for proper management of pepper basin. Maintaining a grass cover is helpful in conditioning the soil due to its root effect and improvement of soil structure besides checking soil splashing and reducing soil temperature. The prunings from the standards can be used as mulch for pepper vine, which after decomposition enhances the organic matter and retains higher soil moisture. Ramachandran *et al.* (1988) reported the beneficial effect of grass/legume cover in reducing foot rot disease incidence. Yaacob and Sulaiman (1992) reported that covering the soil and terracing will conserve soil moisture and fertility, reduces soil losses as much as by 150 per cent. Mounding of pepper basin is found to be advantageous and is a regular practice in most pepper growing countries. Mounding is shown to increase root density and better growth. But mounding is not a popular practice in India.

Multiple Cropping

Multiple cropping in pepper garden is an age-old practice followed in India. Multiple cropping is a system in which two or more crops are grown in the same field in a year, at the same time, or one after the other, or a combination of both. The average size of holdings, in majority of the pepper growing countries, is not adequate enough to sustain an average family. The pepper crop is very much prone to the vagaries of monsoon, incidence of pests and diseases, drought etc. The price fluctuation is so much, that the returns from monoculture of pepper do not compare favourably with those from other commercial crops like coffee, tea etc. Such observations emphasize the urgent necessity for optimum utilization of pepper holdings to enhance the level of income per unit cropped area. In this context, it is important to utilize effectively the available space of the pepper holdings for raising additional crops to augment the income from unit area.

A systematically planted pepper garden would provide adequate interspace for cultivation of annual crops especially during the pre-bearing period because of the negligible shade effect. The factors that assume significance in inter/multiple cropping are the probable competition for nutrients, moisture and sunlight between pepper and inter or multiple crops and its effect on pepper yield.

Pepper roots extend only up to about 90 cm from the base and so ample space will be available for the intercrop without affecting the pepper. In pepper gardens receiving well distributed mean rainfall of not less than 1500 mm^{-1} per year, the competition for soil moisture is unlikely and in such areas, cultivation of annual crops like ginger, turmeric, elephant foot yam and perennial crops like fodder grass, banana, coffee, etc. can be very well accommodated as intercrops.

In any multiple or inter-cropping programme, competition for soil nutrients is a potential danger and inter-cropping without adequate manuring will adversely affect the yield of pepper and the competition is usually for N, K, Ca and Mg. Studies conducted at the Indian Institute of Spices Research (IISR), showed that growing Congo-signal grass *(Brachiaria muziziensis)* and manuring with NPK fertilizers at the rate of 50 kg ha^{-1} in the interspace in pepper garden, where plants are spaced at 2.7 m, increased the physical, physico-chemical properties and soil fertility besides increased yield of pepper. Growing Congo signal grass in pepper garden, increased the organic matter status and nutrient status of soil, reduced soil erosion, bulk density, soil temperature and aluminium toxicity (Sadanandan 1992) and also reduced nematode population of soil. In yet another study in India at IISR, Sadanandan (1994) showed that growing banana cv. *Mysore Poovan,* as an intercrop during the initial three years, in between rows of pepper spaced at 2.7×2.7 m, and fertilizing at the recommended dose of NPK increased the growth and establishment of pepper, enhanced soil productivity, reduced ambient temperature in the plantation, besides fetching an additional return of Rs. 23,000 ha^{-1}. In similar studies conducted at the Pepper Research Station at Panniyur in India, Pillai *et al.* (1987) showed that banana can be grown very profitably as an intercrop in pepper garden in the initial three years. In India, inter-crop, multiple crop, multi-storeyed cropping utilizing an array of crops of different growth habits, were under trial at different Research Institutions. In these trials, pepper was trained on adult coconut or arecanut trees and the results are encouraging (Fig. 4.1.5).

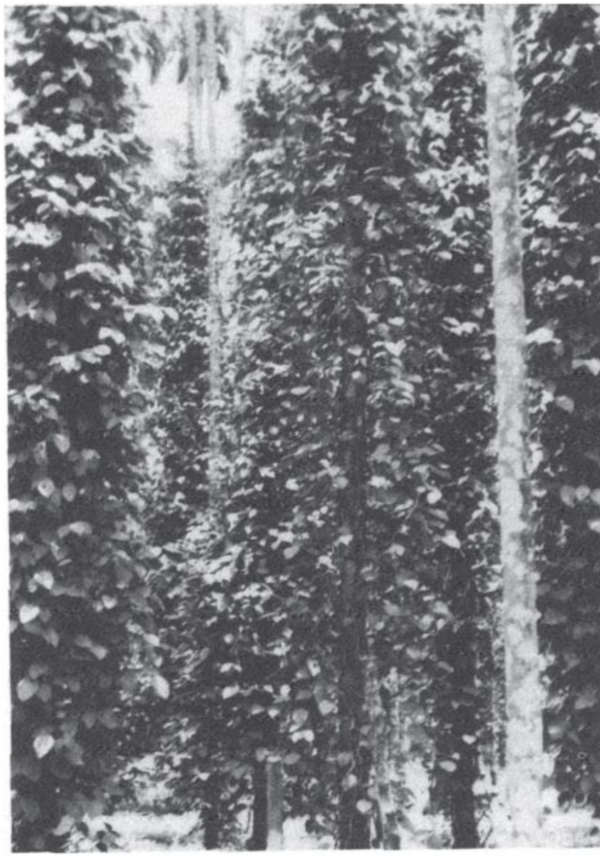

Figure 4.1.5 Pepper arecanut system, where pepper is grown on arecanut palms, the main crop. Here also pepper grows to heights of 8–10 m.

Inter or mixed cropping in pepper garden is a routine practice in Kerala. A variety of crops are grown mixed in most areas, but often without any logic or scientific basis and as a result, the pepper yield becomes negligible. The most important intercrops are elephant foot yam, colacasia and ginger. Studies carried out at CPCRI, Kasaragod (CPCRI 1977), India, showed that ginger is one of the most profitable inter-crops in pepper garden. Sadanandan (1974) on the basis of inter-cropping experiment in a bearing arecanut garden observed that there was no adverse effect on the yield of pepper when grown as a mixed crop and raising elephant foot yam as an inter-crop. The results of inter-cropping experiment at Hirehalli in Karnataka showed more or less similar results. Mixed cropping studies in coconut gardens with pepper as one of the crops was undertaken at CPCRI, Kasaragod. Pepper is usually trailed on old coconut palm trunk as a standard. In this case rooted pepper plants are planted away from the coconut base. As and when the vines grow, they are trailed along the ground and taken on to the trunk of the coconut.

As the vines climb up the trunk, the pepper canopy is restricted to about 4–5 m height from the ground so that climbing on the palm for harvesting may not be hindered. At CPCRI, Kasaragod (1977), pepper plants of the hybrid *Panniyur*-1 planted in 1971–72 and trailed on coconut palms of 60 years old in one ha plot gave a mean yield of 2 kg dry pepper vine^{-1}. All pepper cultivars are not suitable for inter or mixed cropping. For example, the hybrid *Panniyur*-1 requires bright sunlight for proper flowering and fruiting. Varieties like *Sreekara* or *Subhakara* (selections from cv. *Karimunda*) are more tolerant to shade and hence are useful for mixed cropping. Ibrahim *et al.* (1996) reported that *Panniyur*-5 (culture 239) gave the highest yield in a mixed cropping trial with arecanut, followed by *Karimunda*. Unfortunately improved *Karimunda* lines were not included in this trial.

Sadanandan *et al.* (1991) in a study in the laterite soil in farmers' fields for four years in 162 locations reported an increase in almost all the nutrients and yield (Table 4.1.5) due to the adoption of integrated nutrient management, where in farmers' recycled FYM obtained from the animals into the soil. Nair and Gopalasundaram (1993) in a review on high density multi cropping system practiced with arecanut as a base crop with pepper as one of the components, reported that the arecanut-pepper system gave 3832 kg of arecanut *chali* (dried dehusked arecanut) and 1418 kg dry pepper ha^{-1}, from a population of 1000 vines ha^{-1}.

Mixed cropping is also practiced in Brazil, where in the Para State pepper-rubber mixed cropping is common, in Bahia state pepper-clove mixed cropping is extensive. Other crops inter-cropped are cocoa, papaya, orange, lemon, guarana (*Paullinia cupana* var. *sorbilis*). It has been reported that inter cropping has reduced *Fusarium* disease incidence in pepper (Duarte and Albuquerque 1991).

(***Note:*** Published results are not available on the impact of inter and mixed cropping on disease incidence and development. In a mixed/inter cropping system, the possibility of pest and disease development is more and so is the possibility of the longer survival of the pathogens. The long term benefits of such cropping

Table 4.1.5 Nutrient status of soils of major pepper growing tracts*.

Nutrient	*Minimum*	*Maximum*	*Mean*	*CV (%)*
Soil pH	4.5	7	5.5	8.8
O.C g 100 g^{-1}	0.3	4	1.7	43.7
Bray-P mg kg^{-1}	1.0	94	31.6	45.5
Exch K "	40.0	550	180.0	51.8
Exch Ca "	216.0	986	454.5	30.9
Exch Mg "	19.0	92	42.4	35.3
DTPA Fe "	9.3	74	16.2	17.9
Mn "	2.0	23	14.1	41.9
Zn "	0.6	8	0.9	38.9
Cu "	0.4	27	5.2	76.3

* 196 locations.

systems need critical study. Even the usefulness of maintaining grass cover or growing grasses like congosignal grass has not been analysed critically. *Mimosa invisa,* a commonly used cover crop, is known to produce root exudates that show strong suppressive effect on other plants—Ed.)

Management of Diseased Garden

The foot rot pathogen *(Phytophthora capsici)* can survive in soil for many months, especially in the presence of cover crops. The time lapse needed for gap filling and replanting of diseased plants have not been worked out under the West Coast condition in India. In Sarawak, Malaysia, a trial carried out to determine the time lapse period for replanting of diseased plants indicated that disease always reoccurred when the replanting was done immediately after the removal of diseased plants, inspite of fungicide treatment (Anon. 1979). The reoccurrence of foot rot was negligible when the replanting was done at least after a period of three months. But the same result may not be applicable to Indian situation because of the shade effects, cover crops and companion crops present in the field. Under such situations a gap of at least one year seems to be essential. Kueh and Sim (1992) recommend a gap of eighteen months before replanting.

Malnutrition often results in incidence of disease in pepper plants. Deficiencies of nutrients like P and K have been indicated as the reason for diseases (Harper 1974, DeWaard 1969). DeWaard stated that a fertilizer mixture having 400 kg N, 180 kg P, 480 kg K, 425 kg Ca and 112 kg Mg applied to one hectare with appropriate mulching will control the disease and yield 2.0–2.5 kg dry pepper vine^{-1}. Slow decline of pepper was first reported by Menon (1949) in Wynad, Kerala and a crop loss of 10 per cent was recorded. Nambiar *et al.* (1965) worked out tentative ratios of K_2O (total)/N, K_2O (available)/N and $CaO+K_2O+MgO/N$ in soil, and found that slow decline of pepper occurred when these ratios were below 14.1, 0.05 and 3.8 respectively. Slow decline is attributed to fungal infection, soil moisture stress and deficiency of K and P (Nambiar and Sarma 1977) and nematode (Ramana and Mohandas 1987). Wahid and Kamalam (1982) found that K levels of the leaves of healthy vines were considerably higher than those of diseased ones and arrived at the conclusion that K deficiency as a cause for the slow decline of pepper vines.

Sadanandan and Hamza (1992) surveyed major pepper growing areas of Kerala and Karnataka states to study the relationship of nutrients with yield and slow decline of pepper. The study showed that the pepper yield was correlated with DTPA extractable Fe (r=0.55*) and Cu (r=0.41**) in healthy gardens (Table 4.1.6). The yield was also correlated with leaf iron (r=0.56**) in a healthy and also diseased gardens (r=0.62**), with leaf manganese (r=0.27*) and leaf Cu (r=0.37**) in diseased gardens. This indicated the importance of these elements in pepper nutrition. Thus, micro nutrients like Fe, Zn and Cu play a vital role in predisposing the plants to disease incidence. Wahid and Kamalam (1982) reported that foliar yellowing and necrosis of distal ends of lamina in slow wilt affected gardens were due to N and K deficiencies respectively. The adoption of integrated nutrient management together with adoption of disease and pest

Table 4.1.6 Build-up of soil nutrients due to integrated nutrient management in farmers' fields (1986–90)*.

Nutrients	*Farmers' practice*	*Exp. plots*	*Increase over farmers' practice (%)*
Organic matter (%)	1.8	2.7	50
Bray-P mg kg^{-1}	17.0	32.0	88
Exch. K "	108.0	154.0	43
" Ca "	454.0	691.0	52
" Mg "	42.0	62.0	48
DTPA extr. Fe "	16.2	18.7	15
" Mn "	3.9	6.0	54
" Zn "	0.9	1.4	52
" Cu "	2.2	4.1	86

* Sadanandan, A.K. 1994.

management brought down the incidence of *Phytophthora* foot rot from 6.1 to 1.9 per cent and slow decline from 6.4 to 2.2 per cent.

In Brazil the *Fusarium* wilt caused by *Fusarium solani* f. sp. *piperis* is the most serious disease problem and it has been hypothesized that deficiencies in minor nutrients such as Zn, Fe and Bo and the lack of equilibrium between potash and phosphorous in relation to calcium and magnesium might be predisposing the plants to infection (Durate and Albuquerque 1991).

(***Note:*** The epidemiology of slow decline of pepper (or pepper yellows) has been thoroughly worked out and is definitely shown to be due to the infection by *Radhopholus similis* (burrowing nematode) along with the root damage caused by *Phytophthora capsici*. These organisams destroy the root system, thereby preventing the absorption of water and nutrients, eventually upsetting the nutrient balance in the plant system. See the chapter on Nematode Induced Diseases for a full discussion—Ed.).

Water Management

Among the different constraints limiting pepper production, moisture stress is one of the most serious. Irrigation during summer months (December to May) in India have been reported beneficial. A field experiment conducted to study the effect of irrigation (on *Karimunda* and *Panniyur*-1) during 1988–96 at the Pepper Research Station, Panniyur, Kerala has shown that irrigation at IW/CPE ratio of 0.25 significantly increased the productivity of pepper by over 90 per cent, the effect was more significant in *Karimunda* than in *Panniyur*-1 (Satheesan *et al.* 1997a). A study at IISR, has shown that irrigating pepper vines at the rate of seven to ten litres water day^{-1} $vine^{-1}$ during summer months recorded higher yield of green pepper (4.07 kg $vine^{-1}$ $year^{-1}$) compared to control (1.33 kg $vine^{-1}$ $year^{-1}$) (IISR 1997).

Yet another study on the water requirement of pepper in a multiple cropping system was carried out in India during 1994–96 by using the Bowen ratio-energy balance

(BREB) method and Vapour diffusion model (VDM) for estimating the water consumption of three multiple cropping systems with pepper. By adopting the vapour diffusion model, it is possible to partition the stand transpiration rate of pepper plantation with *Erythrina indica* as standard, among different layers of black pepper canopy and *Erythrina* canopy. The maximum transpiration rate was in the middle region of the pepper canopy, mainly due to the large γ leaf area index (LAI) of this region. Due to the low LAI values, the transpiration rate of *Erythrina* was remarkably less compared to that of pepper. The black pepper constitute 71–86 per cent of the stand transpiration rate. The evapotranspiration coefficient (ET_C) of pepper plantation achievable using BREB method ranged from 2.5–3.2 mm day^{-1}, while those obtained by VDM ranged from 2.9–3.4 mm day^{-1}. The crop coefficient values for crop stand ranged from 0.53–0.78 mm day^{-1}. There was good agreement between VDM and BREB methods for precisely estimating the evapotranspiration of pepper plantation with *Erythrina* as standard. In the multiple cropping system of pepper trailed on coconut and arecanut, ET_C value of pepper ranged from 0.31–0.42 mm day^{-1}, while those of coconut and arecanut ranged from 3.25–3.60 mm day^{-1} and from 1.45–1.78 mm day^{-1} respectively. The crop coefficient of pepper in multiple cropping system ranged from 0.07–0.10 mm day^{-1}, while those of coconut and arecanut ranged from 0.74–0.82 and from 0.33–0.38 mm day^{-1} (Satheesan *et al.* 1997b). While developing irrigation scheduling programmes for the above cropping systems, the crop coefficient values of component crops are more appropriate than those of the pure crops of individual species.

Moisture stress is a serious problem only in India. Most other pepper growing countries receive well distributed rainfall. In Thailand pepper is grown as an irrigated crop.

Mineral Nutrition

General features

The nutritional requirements of pepper are to be considered in the light of agroecological conditions, soil nutrient status and incidence of diseases that affect yield to a great extent. In Kerala, India, pepper is grown predominantly as an intercrop in laterite soils, generally poor in fertility and nutrient retention capacity. The clay is of kaolinitic in nature. Forest loam is found in Western Ghats which are shallow in depth, well-drained and having high organic matter. These are low to medium in P and K status. They receive high rainfall and are highly valued for growing pepper, either as a pure crop or as an intercrop in coffee, cardamom or tea plantations. Pepper prefers well-drained alluvium rich in organic matter and will not thrive in waterlogged soils. Low bulk density of the soil also seems to be an important factor in pepper growth though systematic studies have not been made regarding this.

Sources of fertilizer

Earlier days in India, the growers were using only small quantities of organic manures and the use of chemical fertilizers become prevalent only during the past few decades. Even now only the affluent growers fertilize the pepper crop adequately, though the awareness on proper fertilizer management is improving. Slow release fertilizers are useful to minimize fertilizer losses by leaching, erosion, etc., and they will supply the nutrient as and when needed for long duration crops. Organic matter increases the soil buffering capacity, maintains good soil texture and soil health.

Slow release formulations such as *Nimin* coated urea followed by cyclo-diurea and urea formaldehyde are significantly superior as evidenced by the utilization efficiency, increased availability of various fractions of N in the soil, tissue concentration of N and yield response. Sadanandan *et al.* (1991) reported that ammonium polyphosphate at 50 kg P_2O_5 ha^{-1} was as efficient as diammonium phosphate with regard to nutrient availability, yield response and uptake of P (Table 4.1.7, 4.1.8) and that mussoorie phos at 80 kg P_2O_5 $vine^{-1}$ $year^{-1}$ was as efficient as superphosphate for both var. *Panniyur*-1 and *Karimunda* with respect to soil availability of P, yield response, relative agronomic efficiency (RAE) and economics (Fig. 4.1.6). The growers use mostly complex fertilizers in other major growing countries. In Malaysia the two common fertilizer formulations are Nitrophoska 15–15–15 and Nitrosphoska special 12–12–17–2+T.E. (N-P-K-Mg+ Trace elements) (Belger 1977). According to this author, the ratio of N, P, K and Mg considered ideal for pepper is 13–14:6:18:4 and the above complex fertilizer (Nitrophoska special) closely meets these requirements and this fertilizer has been well established in the Sarawak pepper market.

Methods and time of application

Method and time of fertilizer application may considerably influence crop's response to fertilizer. A number of factors like growth stage, nutrient requirement, soil moisture condition, nature of the fertilizer, etc. should be taken into consideration. Some phosphate fertilizers, like rock phosphate, should be applied well before the requirement to obtain their effect, whereas better utilization of applied nitrogen is effected by supplying it at a time when crop needs it. Potassium uptake is more or less continuous throughout the different stages of growth. In order to avoid leaching loss, split application is generally recommended as pepper is raised as a rainfed crop in heavy rainfall areas except in countries like Thailand where it is raised as an irrigated crop. One third of the recommended dose is applied during first year, two-thirds in the second year and from third year onwards, full dose is given. In India, the fertilizers are applied in two doses. The first half in May, with the onset of monsoon, and the second half in August–September. Approximately 10–20 days after fertilizer application, buds develop and new leaves and spikes appear. In Sarawak, Malaysia, the elite growers use 110 gm per plant of either Nitrophoska 15–15–15 or Nitrophoska special 12–12–17–2+T.E every two months during the first year. In the second year 230 gm Nitrophoska per plant is applied six times at bimonthly intervals. In the third year onwards the fertilizer dose is increased to 1.8–2.3 kg per plant in four applications. Pepper is also manured with organic manures like prawn dust, soybean or bonemeal at the rate of 0.6–1 kg per plant (Belger 1977). Fertilizer is applied in a 3/4 circle

Table 4.1.7 Effect of slow release N fertilizer on organic matter, available and total nitrogen in soil, yield, uptake and recovery of nitrogen, agronomic efficiency and B/C ratio.

Urea source	*Soil*							
	Org. matter g Kg^{-1}	*Available N mg Kg^{-1}*	*Total N g Kg^{-1}*	*Yield Kg ha^{-1}*	*Uptake Kg N ha^{-1}*	*Recovery of N (%)*	*Agronomic efficiency*	*BC ratio*
Check	20.6^{c}	224^{b}	1.01^{b}	480^{c}	10^{c}	–	4.8^{c}	0.7
Urea	27.5^{b}	232^{b}	1.11^{b}	1710^{b}	39^{b}	29	17.1^{b}	2.6
Urea formaldehyde	31.0^{a}	299^{a}	1.17^{a}	1905^{b}	44^{aab}	34	19.1^{a}	2.9
Urea cycloid	36.1^{a}	309^{a}	1.23^{a}	2310^{a}	53^{ab}	43	23.1^{ab}	3.5
Urea neem	36.1^{a}	319^{a}	1.20^{a}	2580^{a}	59^{a}	49	25.8^{a}	3.9
Urea pellet	32.7^{a}	293^{a}	1.08^{a}	1765^{b}	41^{b}	31	17.7^{b}	2.6
CD (5%)	5.1	38.6	0.15	380	18	–	7.8	–

Figures with the same superscript are not significantly different at 5 per cent level.

Table 4.1.8 Effect of P sources on soil availability of nutrients and yield.

	Yield	Org. matter	Bray-P	K	Ca	Mg	Fe	Zn
	(kg vine^{-1})	(%)	(mg kg^{-1})					
Check	2.46^{d}	3.06^{d}	17.0^{e}	212	919	83	15^{c}	1.0^{b}
APP 25	4.92^{c}	2.76^{b}	34.0^{d}	190	901	91	17^{b}	1.2^{bc}
APP 50	5.56^{b}	3.92^{ab}	56.2^{e}	241	772	81	20^{a}	1.4^{ab}
APP 75	6.30^{a}	4.10^{a}	84.6^{a}	251	926	96	18^{ab}	1.5^{a}
DAP 25	4.30^{c}	3.46^{c}	36.2^{d}	232	901	95	20^{a}	1.3^{ab}
DAP 50	5.60^{b}	3.84^{ab}	53.8^{c}	283	891	97	20^{a}	1.4^{ab}
DAP 75	6.48^{a}	4.06^{ab}	72.8^{b}	248	703	95	18^{ab}	1.2^{bc}
CD(5%)	0.59	0.34	7.1	NS	NS	NS	3	0.2

Figures with the same superscript are not significantly different at 5 per cent level.

around the vine or in alternating parallel bands on either side of the vine underneath the edge of the canopy. The fertilizing season is mainly July to January.

Foliar spray is effective for the application of micro nutrients, only very small quantities of these elements are required, which can be more effectively and economically applied as sprays, even along with insecticide and pesticides.

Yield response

Nitrogen, phosphorus, potassium, magnesium and micro nutrients are the most important nutrients for growth, development and yield and their influence depend on their ratios in the soil as well as in the plant system. The levels of fertilizers used in India are much lower and this perhaps is one of the reasons for the lower yield (Table 4.1.9). Trials in farmers' fields over a period of four years, gave 250 per cent increase in yield due to the application of fertilizers and adoption of plant protection measures. The quantity of NPK fertilizers required to get high yield vary largely among locations (Sadanandan *et al.* 1990). Location specific recommendations for pepper advocated by the Kerala Agricultural University are given below (Anon. 1989).

* General recommendation of NPK—100:40:140 g vine^{-1} year^{-1}
* For Panniyur (northern most part of Kerala) and similar agro-climatic conditions—NPK 50:50:200 g vine^{-1} year^{-1}
* Calicut and similar agro-climatic areas-NPK 140:55:270 g vine^{-1} year^{-1}

Pillai *et al.* (1979) reported that the higher levels of N adversely affected the yield of the *Panniyur*-1 hybrid. According to them, it is not necessary to increase N level beyond 50 g vine^{-1} year^{-1}. It is noted that, in their experiment, no consideration was given to lime requirement because they did not get any response to lime application

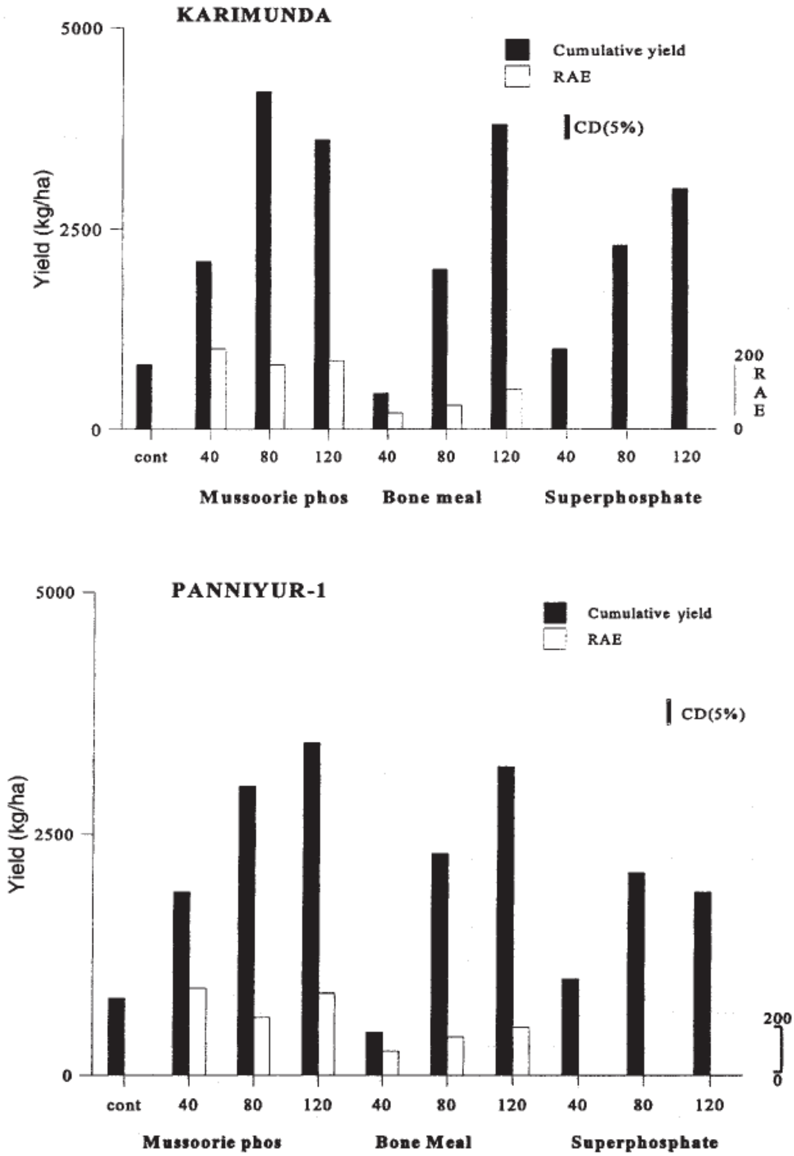

Figure 4.1.6 Effect of three phosphatic sources on the cumulative yield of two pepper varieties.

in pepper. Addition of lime without effecting a change in the pH of the soil, would not give any worthwhile results. Studies of Yufdy (1991) indicated that growth of black pepper cultivars were inhibited without liming. Lime treatment can eliminate exchangeable aluminium, and each cultivar requires a certain amount of lime to achieve its best growth performance. The results of Thalib *et al.* (1991) showed that

Table 4.1.9 NPK utilization by pepper and fertilizer recommendations[a].

Sl. No	*Author/year*	*Country*	*Nutrients removed (kg ha^{-1})*	*Dose recommended (kg ha^{-1} year^{-1})*
1.	Waard and Sutton, 1960	Malaysia (Sarawak)	cv. Kuching N 252, P_2O_5 32, K_2O 224	N: P_2O_5: K_2O: MgO 240:120:340:100 and 28 g trace elements
2.	Sim, 1971	Sarawak	N 233, P_2O_5 39, K_2O 207	
3.	Raj, 1972	Sarawak	–	N 340 g (Urea)*, P 113 g (S. Super)*, K 454 g (MOP)
4.	Azmil and Yau, 1993	Malaysia (Johore)	cv. Kuching	N 250, P_2O_5 100, K_2O 250 (+400 gm magnesium lime stone/plant)
5.	Pillai and Sasikumaran, 1976	India	var. Panniyur-I N 34, P_2O_5 3.5, K_2O 32* (vine^{-1})	N 100, P_2O_5 40, K_2O 140
6.	Pillai *et al.* 1987	India	N 34, P_2O_5 3.5, K_2O 32* (vine^{-1})	N 50, P_2O_5 50, K_2O 200
7.	Sivaraman *et al.* 1987	India	var. Panniyur-I	N 140, P_2O_5 55, K_2O 270
8.	Sadanandan, 1993	India	N 137, P_2O_5 61, K_2O 330	N 140, P_2O_5 55, K_2O 270

[a] For fertilizer recommendation in Brazil, see Annexure-1.
* vine^{-1}.

liming influenced growth, plant height, shoot and root dry weight, and restrict the intensity of *Phytophthora* infestation of seedlings. Studies conducted at IISR also showed that liming enhances yield and quality of pepper (IISR 1997).

Investigations on the mineral nutrition of var. *Panniyur*-1 in a laterite soil, poor in major nutrients, indicated that application of 140 g N, 55 g P_2O_5 and 270 g K_2O vine^{-1} year^{-1} resulted in significant increase in the availability of N, P and K (Sivaraman *et al.* 1987). The best fertilizer treatment for productive pepper plantations in Bangka is reported to be 400–600 g NPK Mg, 12:12:17:2 per plant, applied three times a year, plus 500g dolomite per plant applied two times a year (Wahid *et al.* 1990). Sadanandan (1994) by fitting the response equation for N, P and K application on yield of pepper in var. *Panniyur*-1 and working out the economics of yield, arrived at a level of 140 kg N, 55 kg P_2O_5 and 270 kg K_2O vine^{-1} year^{-1} as the optimum. The N and K fertilizers are to be applied in two equal split doses, first half in June and the second half in September, while the entire P is applied in one dose.

The nutrient removal of the variety *Kuching* was 252 kg N, 32 kg P_2O_5 and 224 kg K_2O ha^{-1} (De Waard and Sutton 1960). Sim (1971) and Sadanandan (1990) obtained more or less similar results. Adzemi *et al.* (1993) studied in detail the nutrient removal by pepper plants and breaking up the total nutrients removed into various components

Table 4.1.10 Nutrient removal by an adult (8 year) pepper vine (kg ha^{-1}).

Variety	*Panniyur-1*				*Karimunda*			
Parts	*Dry matter*	*N*	*P*	*K*	*Dry matter*	*N*	*P*	*K*
Stem	6.0	43.8	13.7	100.8	4.4	35.6	8.1	68.6
Leaf	6.0	151.8	28.9	195.6	5.8	98.6	30.5	221.3
Root	2.5	72.3	9.2	76.0	2.2	26.4	5.5	55.4
Berry	1.0	24.2	4.6	32.3	1.0	22.0	5.0	30.2
Total	15.5	292	56	405	13.4	183	49	376

such as leaves, branches, stem, fruit and flower and the following figures were reported: N 255.6, P 22.8, K 208.2, Ca 54.5 and Mg 36.4 (kg ha^{-1}). Table 4.1.10 gives the nutrient removal by two popular pepper cultivars *Panniyur*-1 and *Karimunda*. This data differ somewhat from the reports of the Malaysian workers especially in the case P and K values. Even between the two varieties differences existed mainly with regard to N.

Uptake of nutrients by pepper is appreciably higher, wherever high amounts of NPK fertilizers are added. For example, according to the schedule of DeWaard and Sutton (1960), the fertilizers added are 240 N, 120 P_2O_5 and 340 K_2O kg ha^{-1} and the uptake by the plant is 252 N, 32 P_2O_5 and 224 K_2O kg ha^{-1}. According to the schedule of Pillai *et al.* (1987) the doses to be applied are 100 N, 40 P_2O_5 and 140 K_2O which result in an uptake of N 34, P_2O_5 3.5 and K_2O 32 kg ha^{-1}. When the inputs are N 140, P_2O_5 55 and K_2O 270 kg ha^{-1}, the nutrients removed are of N 137, $P_2O_5$61 and K_2O 330 (Sadanandan 1990).

The present recommendation for Sarawak is 2043 g fertilizer mixture of 16 N: 6 P_2O_5: 18 K_2O: 4 Mg per yielding plant plus 454 g dolomite and 28 g trace elements. Rich farmers are reported to apply 4 to 6 kg fertilizer per plant in 7–8 splits (George 1982). For the Johore areas in Malaysian mainland the recommendation is 120 kg N, 80 kg P_2O_5 and 50 kg K_2O per ha for the first year, 200 kg N, 100 kg P_2O_5 and 100 kg K_2O per ha for the second year and 250 kg N, 100 kg P_2O_5 and 250 kg K_2O per ha for mature plants to give sustained high yield (Azmil and Yau 1993). In addition cattle manure or chicken manure at the rate of 1–2 kg/plant for the first and second year and 3–4 kg/plant in subsequent years are also applied.

Yield variability in relation to soil fertility in pepper plantations was examined by Mathew *et al.* (1995). Near neutral soil pH, high organic matter content and high base saturation with Ca and Mg were found to influence the nutrient uptake and productivity. The magnitude of the nutrients removed was on the order: N>K>Ca>Mg>P>S>Fe>Mn>Zn and they also strongly recommended the formulation of yield-based fertilizer recommendation for enchancing yield. One reason for the lesser response to fertilizers in India is perhaps, the shade effect of the support trees.

In a study conducted at Kerala Agricultural University (Anon. 1996) it has been shown that the additional nutrient requirement for an increase of 1.0 kg pepper berries is 6.35 g N, 6.33 g K, 1.11 g Ca, 0.47 g Mg, 0.44 g P, 0.29 g S, 42.82 mg Fe, 34.45 mg Mn and 4.2 mg Zn. This requirement was irrespective of the yield potential indicating that plants with higher production potential requires higher doses of nutrients. This in turn points to the necessity of revising the present fertilizer recommendations.

Major and Secondary Nutrients

Nitrogen

Soil fertility survey has been made to evaluate the nitrogen status of pepper growing soils, uptake and the dose of nitrogen to be applied, for getting optimum yields in pepper. (DeWaard 1964, Sim 1971, Pillai and Sasikumaran 1976, Pillai *et al.* 1979, Mohanakumaran and Cherian 1981, Pillai *et al.* 1987, Sadanandan 1994).

Studies on single elements, in isolation, do not project the real nature of nutrient requirement. It is only when all nutrients are taken in combination, with their interaction effects, that a real picture of nutrient utilization emerges. In this connection, nutrient ratios, both in the soil and in the plant (including in the different parts of the plant) have a significant role to play. Ratios on leaf nutrient status worked out by DeWaard (1969) showed their relevance in determining the nutrient deficiencies. Adzemi *et al.* (1993) worked out the N concentration in various plant parts and found the following values (%): leaves—2.30, branches—2.07, stem—1.96, fruit spikes—2.21, white pepper—1.82 and flower—2.11. In comparison, the N removed by a pepper plant year^{-1} is (mg/plant): leaves—30.0, branches 47.6, stem 35.3, spikes 0.7, white pepper 36.4 and flowers 2.1; the quantity on a hectare basis is 255.6 kg ha^{-1}.

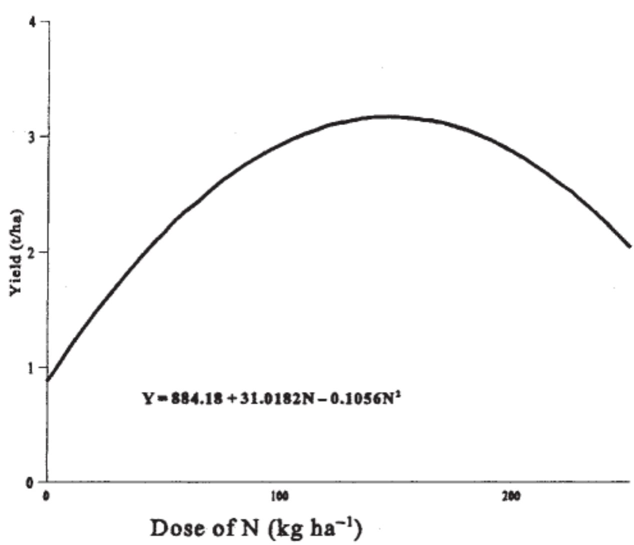

Figure 4.1.7 Yield response curve of N application in pepper.

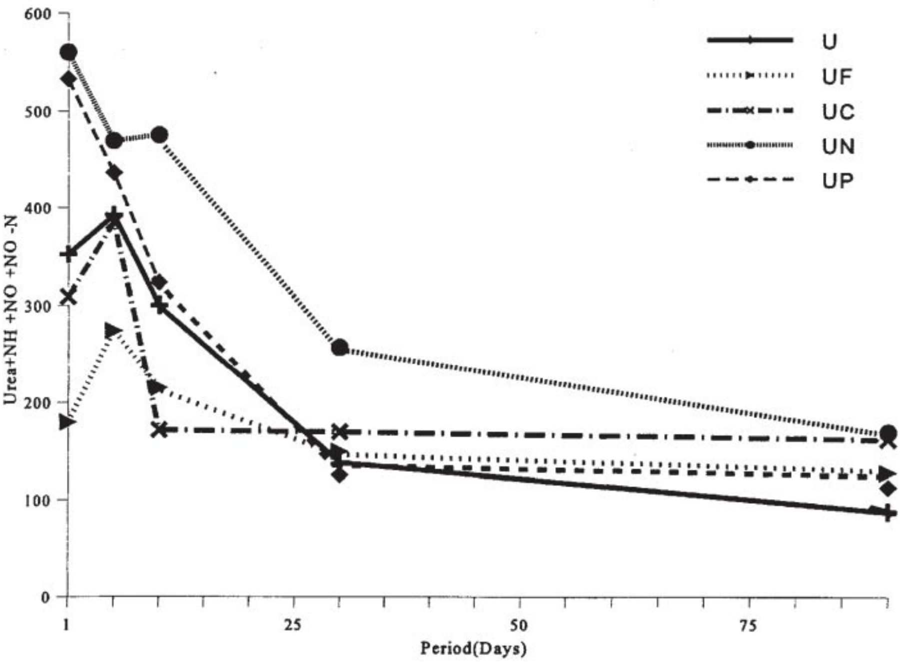

Figure 4.1.8 Effect of slow release N fertilizer on the release pattern of N in soil.

Sadanandan (1990) found that *Panniyur*-1 and *Karimunda* removed 292 and 183 kg ha^{-1} year^{-1} of N respectively. For *Panniyur*-1 N at 50 kg along with 100 kg of P_2O_5 and 150 kg of K_2O are reported to be optimum in a laterite soil (Pillai *et al.* 1987). Highest dry matter production and growth were observed with 2.0 g K_2O and 1.1 g N plant^{-1} as potassium chloride and urea under green house conditions (Murni and Faodji 1990). The response function fitted for N is given in Fig. 4.1.7. Sadanandan and Hamza (1990) after studying the effect of slow release N fertilizers for pepper in a laterite soil found that application of neem oil-coated urea increased the yield of pepper by 280 per cent compared to urea alone. The increased release of urea N, ammoniacal N, (NO_2+NO_3)-N and also total N in the soil was noticed and these must have contributed to the increased yield (Fig. 4.1.8). Laboratory incubation studies gave more or less similar results (NRCS 1990). Urea spraying influence the yield of pepper. An yield increase of 22 per cent was recorded by Sarawak workers when nine sprays of 0.7 per cent at weekly intervals were given (Anon. 1995)

Phosphorus

The availability of phosphorus depends on the dynamics of phosphorus fixation in the soil and uptake by the plant and in this process the pH and organic matter content of the soil play vital roles. A P_2O_5 dose of 55 kg ha^{-1} along with 140 kg N and 270 kg

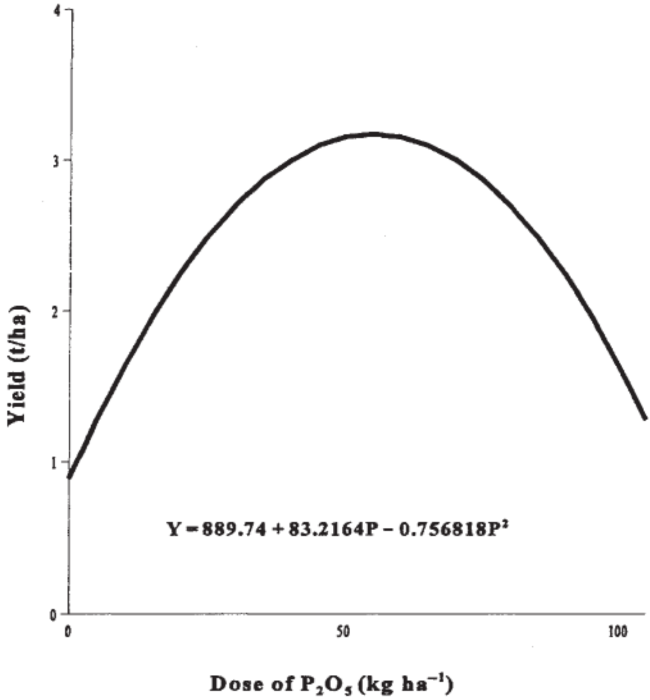

Figure 4.1.9 Yield response curve for P application in pepper.

K_2O is reported to be ideal for the proper nutrition of pepper plant, as revealed by the response function (Fig. 4.1.9). Suprato and Dwiwarni (1991) reported that higher doses of phosphate fertilizer (0.21–0.56%) increased the internode growth and the number of leaves compared to lower doses (0.00–0.14%). Evaluation of P sources with the pepper varieties *Panniyur*-1 and *Karimunda* at different levels, along with N and K at 100 and 140 kg ha^{-1}, have shown that both bone meal and mussoorie rock phosphate are superior to super phosphate in an acid soil (Sadanandan 1986). The cumulative yield of pepper for two years and Relative Agronomic Effectiveness (RAE) were higher in the case of mussoorie rock phosphate. This study shows that availability of phosphorus to the pepper plant cannot be assessed by finding out the water soluble or citrate soluble phosphorus in the fertilizer, as quantum of P fixed is different in the case of water soluble and water insoluble fertilizers. Adzemi *et al.* (1993) have shown that the following quantities of Pare removed by different parts of the pepper plant (g $vine^{-1}$): leaves 3.64, branches 2.58, stem 3.96, spikes 0.08, white pepper 3.20, flowers 0.18, equivalent to a total of 22.8 kg ha^{-1}. Several nutrient ratios were worked out, for getting a meaningful relationship between the status of nutrients in the plant and its yield. Sadanandan and Rajagopal (1989) worked out an index by finding the ratio of P in the plant to the sum of N+P+K+Ca in the plant. A high correlation was obtained between this ratio (termed as P index) and pepper yield.

The release of fixed P through the agency of organic ions in the soil, is well known. However, the efficiency of different sources of organic matter *viz.,* farmyard manure (FYM), poultry manure, different kinds of oil cakes, compost, green leaves from different plants on the efficiency of releasing P ions from the fixed states, has to be investigated in order to understand the effect of application of organic source in the uptake and translocation of P and other nutrients. It is known that P ions get fixed, not only in the soil, but also in the plant especially in the root, leaf, nodes, petioles etc. It will be worthwhile to find out how far the organic ions absorbed by the plant are effective in releasing such fixed P ions.

Potassium

Pepper requires large quantities of K for growth and fruiting and its requirement is associated with the content of the other nutrients in the plant, notably nitrogen. DeWaard (1969) reported that a critical level of 2 per cent K in the plant is associated with K deficiency.

Trials conducted with var. *Panniyur*-1 showed that 200 g of K_2O vine^{-1} was optimum (Pillai *et al.* 1987). Sadanandan (1990) concluded from response function analysis (Fig. 4.1.10) that 270 kg K_2O ha^{-1} is required for high yield. Systematically planned

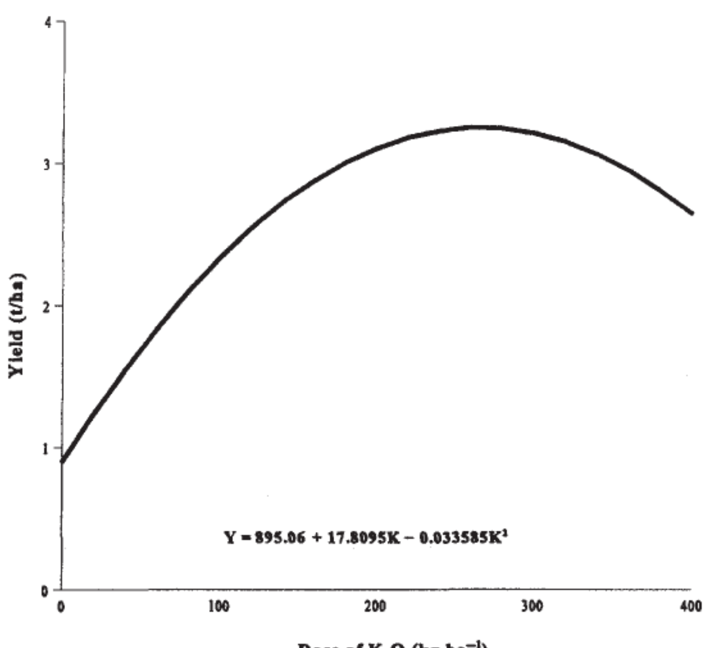

Figure 4.1.10 Yield response curve for K application in pepper.

experiments with the objective of finding critical levels of K in the plant in combination with different levels of other nutrients and at various stages of plant growth, in different seasons are worthwhile conducting, in order to find out the proper nutrient response. K removed by various parts of the pepper plant was worked out by Adzemi *et al.* (1993) and the values he obtained are (g vine^{-1}): leaves 28.73, branches 28.70, stem 19.60, fruit spikes 0.05, white pepper 42.0, flowers 1.40, the total being 203.2 kg ha^{-1}.

A soil fertility survey carried out in the major pepper growing tracts in the states of Kerala and Karnataka indicated that 10 per cent of the gardens were low, 31 per cent medium and 59 per cent high in available K status. However, integrated nutrient management with the application of NPK at the rate of 100:40:140 kg ha^{-1} and organics like FYM at the rate of five kg vine^{-1} annually, leads to build-up in the soil-fertility status. Most growers apply a combination of N, P and K where the N:P:K ratio varies considerably. Pillai *et al.* (1979) obtained highest yield with NPK ratio of 5:5:10 whereas, Sadanandan (1993) suggested a ratio of 2.5:1:5 for getting highest yield, and he (1990) further suggested an NK ratio of 1:2 for pepper.

Calcium, Magnesium and Sulphur

Nothing much is known about the yield response of pepper to application of Ca, Mg and S. Application of lime is mainly to correct soil acidity, and has little to do with Ca nutrition. Pillai *et al.* (1979) studied the response of var. *Panniyur*-1 to N and lime application and pointed out that, lime application had no significant effect on pepper yield. This may probably because lime had not been applied as per lime requirement of the soil which can be determined precisely by laboratory studies. Unless there is a change in soil pH no response to Ca can be expected. Application of Ca and Mg at 50 kg each ha^{-1} increase the exchangeable Ca and Mg in the soil and content in plant, thereby indicating the significance of these elements in the balanced nutrition of pepper (Sadanandan 1994) (Table 4.1.11). The Ca removal by plant parts are reported to be (g vine^{-1}): leaves 8.32, branches 11.50, stem 7.20, fruit spikes 0.11, white pepper 5.00, flowers 0.32; the total being 54.5 kg/ha. In the case of Mg the values are (g vine^{-1}): leaves 4.55, branches 5.98, stem 5.04, fruit spikes 0.10, white pepper 5.80, flowers 0.22, the total being 36.4 kg ha^{-1} (Adzemi *et al.* 1993).

Table 4.1.11 Effect of application of Ca and Mg on soil organic matter, soil and leaf status of Ca and Mg.

Treatment	*Organic matter (%)*	*Soil Ca (mg Kg^{-1})*	*Leaf Ca (g Kg^{-1})*	*Soil Mg (mg Kg^{-1})*	*Leaf Mg (g Kg^{-1})*
Check	2.75	268	21.0	54	2.0
N_{50} P_{60} K_{140}	3.35	986	22.0	46	3.0
N_{50} P_{60} K_{140} Ca_5OMgO	3.01	1278	34.0	45	2.9
N_{50} P_{60} K_{140} Ca_0 Mg_5O	3.18	742	22.0	65	3.5
N_{50} P_{60} K_{140} Ca_{50} Mg_5O	3.35	1368	24.0	79	2.8

Table 4.1.12 Yield response of pepper varieties grown on different standards (living and non living) to applied nutrients (kg vine^{-1}).

Variety	*Sreekara*		*Subhakara*	
Standard	*Living*	*Non-living*	*Living*	*Non-living*
Treatment				
T_1 Control	0.76	0.78	0.96	1.06
T_2 NPK @ 50, 20, 70 Kg ha^{-1}	1.06	1.18	1.02	1.12
T_3 " 100, 40, 140 "	1.16	1.22	1.14	1.18
T_4 " 150, 60, 270 "	1.74	1.80	1.40	1.42
T_5 T_2 + Zn, B, Mo @ 5, 2, 1 "	1.32	1.26	1.10	1.26
T_6 T_4 + " " " "	1.82	1.84	1.50	1.52
Mean	1.31	1.35	1.19	1.26

Yield response studies of pepper to S fertilization has been scarce. This probably is due to extensive use of single super phosphate (containing 11 per cent S) as phosphate source, which indirectly makes up any inherent deficiency of sulphur in soil (Sadanandan *et al.* 1991). Yield response can be expected for pepper when sulphur content in the soil is less than the threshold value of 6.0 mg kg^{-1}.

Micronutrients

Of the various micronutrients, most important for pepper nutrition are Zinc, Molybdenum and Boron, as these are likely to become deficient in acid soils by leaching or precipitation (DeWaard 1969). Molybdenum is found to increase with the application of organic matter, as it forms a complex which makes Mo more available to the plants for absorption. Boron deficiency can be expected in coarse textured soils low in organic matter, especially in high rainfall area. Preliminary studies carried out at IISR showed that for the var. *Subhakara* and *Sreekara,* application of NPK at the rate of 150:60:270 kg ha^{-1} together with micro nutrients Zn, B and Mo at the rate of 5:2:1 recorded highest yield (Table 4.1.12) (IISR 1997). Geetha and Nair (1990) reported that spraying 0.5 per cent zinc sulphate reduced spike shedding by 48.4 per cent. Effect of growth regulators on yield of pepper by reducing spike shedding and berry drop was studied by Salvi *et al.* (1988).

To achieve sustained high production, it is essential to maintain a certain level of nutrients in the plant body. Table 4.1.13 gives the desired level of nutrients in the plant body, the quantity of fertiliser to be applied to achieve this level and the sources of nutrients as applicable to Indian conditions.

Organic manuring

The organic ions released by the decomposition of organic matter complexes with Fe and Al, thereby blocking them from forming chelates with P, and making it available

Table 4.1.13 Nutrient levels and recommendations for sustainable pepper production (for India).

Soil nutrients	*Desirable level*	*Dose recommended*	**Source of fertilizer/Micro nutrients*
	mg kg⁻¹	*kg ha⁻¹*	*Kg ha⁻¹*
Soil pH	6–7		Lime @ 3 t in May 1st week.
Organic matter	2.5%	N @ 140	FYM and green leaf each @ 10 t ha^{-1}, Urea 150 kg × 2 in June/September.
Phosphorus	18	" 55	Super/Mussoorie 300 kg in June.
Potassium	150	" 270	Muriate of Potash 250 kg × 2 in June/September.
Calcium	1500	–	Lime applied takes care of Calcium.
Magnesium	300	" 20	Magnesium Sulphate @ 200 kg in September.
Sulphur (SO_4)	20	" 75	
Iron	10	" 10	Iron EDTA @ 90 kg in September.
Manganese	10	" 10	Manganese sulphate @ 35 kg in September.
Zinc	1.6	" 5	Zinc sulphate @ 23 kg in September.
Copper	0.6	" 5	Copper sulphate @ 20 kg in September.
Molybdenum	0.3	" 0.5	1.3 kg Sodium molybdate in September.
Boron	0.8	" 2	18 kg Borax in September.

* Wherever analytical results are less than the desirable level, apply fertilizer/micro nutrients 1.25 to 1.50 times of the recommended dose. If the levels are more than the desirable levels, apply only the recommended dose.

to the plant. These organic ions also block the "blocking spots" on the clay mineral complex where cations like K, Ca, Zn, Mg, etc. get locked up, thereby making them available to the crop.

In earlier times, pepper cultivation in India was done by manuring with organic materials only. The organic ions released by the decomposition of organic matter, chelate the P-fixing agents. The organic matter promotes the growth of antagonistic fungi and reduced the population of *Meloidogyne incognita* (Mustika *et al.* 1994). It is essential to find out the kind of organic matter, the mode of organic matter decomposition and the stability constants of chelate for assessing the proper kind of organic matter to be used for growing pepper. Several kinds of organic manures like farm yard manure, compost, poultry manure and organic cakes like neem and groundnut cakes are used by farmers in India. Sivakumar and Wahid (1994) reported substantial increase in growth and biomass production in plants treated with organic materials (leaves of *Erythrina indica, Garuga pinnata, Grevillea robusta, Piper nigrum* and *Coffea arabica*). However application of leaves of *C. arabica* and *Piper nigrum* at highest rates suppressed growth probably due to allelopathic effects of the decay products of these materials in the soil. In Brazil, Duarte and Albuquerque (1991) reported that mulching alone has contributed to higher yields. In cv. *Kuching,* when other factors were kept constant, mulching increased the yield to three kg $planr^{-1}$ $year^{-1}$ compared to 1.8 kg in plants without mulching. Legume leaves, rice hulls and sawdust are used for mulching. But mulching was also found to favour disease incidence. Bopaiah and Khader (1989) got increase in shoot and root weight of rooted cuttings of pepper by dipping in a peat based culture slurry in *Azotobacter, Azospirillum* and *Glomus mosseae* (VAM). Kandiannan *et al.* (1994) reported enhanced growth of pepper due to application of 10 g *Azospirillum* into five kg growing medium (soil:sand:FYM in the proportion of 1:1:1). Peat at the rate of five kg vine^{-1} served as a good source of nutrient supplement and as an efficient substitute to reduce the quantum of chemical fertilizer (Zulkifly 1996).

According to Purseglove *et al.* (1981) organic manures are extensively used in Sarawak for growing pepper and these include guano, prawn and fish refuse and soybean cake. The supremacy of prawn dust as plant food for pepper has been advocated in Malaysia. Guano (an organic manure composed chiefly of the dung of seabirds or bats accumulated along the coastal areas or in caves) application is very popular in Sarawak. Manures are placed in holes about 20 cm from the main stem, in quantities of about 85 g in every two months. Some farmers use prawn refuse and fish manure, putting them in considerable quantities in shallow trenches around the vine, every two months. More recently a potassium-fortified sterilized animal meat and bone meal has become popular.

Manuring with burnt earth

In Malaysia, the jungle land which is cleared for planting pepper, provides the raw material for the preparation of "burnt earth" (Hardon and White 1934, Bergman 1940). After felling the vegetation, a portion of the top soil is stripped off from the vacant land. This soil is then used to cover a pile of wood. Slow roasting is then resorted to, for a period of one to three weeks, followed by thorough mixing of the sterile soil. The wood ash and the soil provide the "burnt earth" which serves as fertilizer. The "burnt earth" has a pH of 7–8, as compared with a pH 4–5 for fresh soil. The "burnt earth" is applied at the rate of 18 kg vine^{-1} year^{-1}. The addition has multiple effects in improving the physical, chemical and biological properties of the soil. It alters the physical characteristics of the rooting medium, including reducing the bulk density of soil, increasing the soil pH and release of nutrients. Malaysian reports indicate that the application of "burnt earth" improves soil texture, increases potassium uptake and sterilizes the soil. DeWaard (1969) evaluated the investigations carried out in Indonesia prior to 1942 by Hardon and White (1934) and Huitema (1941) on the effect of burnt earth on the production of pepper in the island of Bangka. A comprehensive treatment about traditional methods of fertilization and uptake of nutrients are contained in a publication of Bergman (1940). The Government of Sarawak has banned the use of burnt earth in 1940 as the practice was creating many environmental problems.

The actual quantity of nutrients added to soil by following this processes are small, but these are offered in a form ideally suited for uptake by the roots (DeWaard 1978).

Deficiencies

Nutrient disorders and deficiencies are often encountered in the field and to assist in their proper identification DeWaard (1969) used sand culture to induce deficiency symptoms of major and secondary elements. Based on these experiments De Waard has described the deficiency symptoms of nitrogen, phosphorous, potassium, calcium and magnesium. Further studies were reported by Chin and Sim (1982) and Chin *et al.* (1986). Nybe and Nair (1986, 1987a,b,c) conducted a series of studies to assess the nutrient deficiency symptoms of major and micro elements. The "hunger sign" appear when a mineral continues to be deficient and these deficiency symptoms are useful in detecting nutritional deficiency and to adopt corrective measures. The general deficiency symptoms are given Table 4.1.14.

Toxicity of Nutrients

Aluminium toxicity

Aluminium toxicity shows up as bright green to yellowish discoloration and drooping of leaves. Individual leaves first show symptoms of necrosis mostly along the main veins, with each brown spot having a yellow halo and later the leaf falls off. These plants have a highly reduced root system. The incorporation of Mg limestone into the basin prevents this toxicity (DeWaard and Sutton 1960).

Manganese toxicity

The affected leaves show dark brown to black spots initially at the edges, then extending to a striking interveinal pigmentation. In normal leaf, manganese concentration is 700 ppm and that of affected leaf is 1000 ppm or more. The 0.1 per cent Mn in some commercial compound fertilizers is now believed to be too high and enough to cause manganese toxicity (Sim 1973).

Interaction of Nutrients

Nutrient interaction studies are gaining importance for precisely quantifying the application of nutrients for augmenting production and quality of pepper. The interrelation of P content in the leaf and yield of pepper in a laterite soil was studied by Sadanandan and Rajagopal (1989). They found significant correlation between leaf P index (P/N+P+K+Ca) of the youngest matured leaf with the yield of pepper (r=0.81**) underlining the importance of phosphorus nutrition. Interaction studies between elements in pepper vines by Sadanandan and Hamza (1992) showed that there are significant negative correlations between plant P *vs* Zn (r=-0.56*), P *vs* Cu (r=-0.72*) and P *vs* Mo (r=-0.76**). Similarly, significant negative correlation was obtained between soil K and leaf Mg (r=-0.30**). Wahid (1987) obtained negative correlation between leaf K and Mg (r=-0.63**) showing the antagonistic effect of K on magnesium. Among the micro elements, significant positive correlation was

Table 4.1.14 Symptoms of mineral deficiency in pepper.

Nutrients	*Deficiency symptoms*	*Reference*
Nitrogen	Chlorosis of older leaves and later followed by younger leaves. Growth retardation and reduction in leaf size. Leaf tips and margins at lower end become necrotic and brown in colour.	DeWaard 1969 Nybe and Nair 1987a
Phosphorus	Bright green to bluish green colour of the older leaves which turn to bronze green. Necrosis of leaf tips and margins, stunted growth, downward curving at the leaf margins.	DeWaard 1969 Nybe and Nair 1987a
Potassium	Necrosis of older leaf tips that spreads towards leaf margins. Necrosis spread to younger leaves. Affected leaf will remain on the plant.	DeWaard 1969 Nybe and Nair 1987b
Calcium	Tiny brown necrotic pin head spots over chlorotic area near leaf margins in young leaves followed by mature ones. Interveinal chlorosis and die back of vine tips. Immature leaves remain attached to the plant.	DeWaard 1969 Nybe and Nair 1987b
Magnesium	Pale yellow discoloration of the leaf margins and tips. The major veins remain green and laterals turn yellow, Necrosis and defoliation.	DeWaard 1969 Nybe and Nair 1987b
Sulphur	Younger leaves are chlorotic at later stages, which turn to bright yellow in the interveinal areas, premature leaf fall and die back of growing tip, older leaves. remain on the plant.	Nybe and Nair 1987b Chin *et al.* 1993
Iron	Interveinal chlorosis of younger leaves, the youngest leaves may be completely yellow or white.	Nybe and Nair 1987c Chin *et al.* 1993
Manganese	Reticulate pattern on green veins with a pale yellow back ground. Chlorosis between main veins, later leaves turn yellow or white with only the main veinal areas remaining green. Necrosis in mature leaves.	Chin *et al.* 1993 Wong and Chin 1987 Nybe and Nair 1987c
Copper	Interveinal chlorosis of young leaves, dark brown necrotic spots towards tip and margins, inward curling of necrotic margins.	Nybe and Nair 1987c
Zinc	Shorter internodes, small leaves, interveinal chlorosis, puckering of leaf margins.	Chin *et al.* 1993
Boron	Brown necrotic lesions appear with in the chlorotic area. Short internode, reduced branching, interveinal chlorosis of young and recently mature leaves at distal and central portion. Necrotic lesion on main vein.	Nybe and Nair 1987d Chin *et al.* 1993

obtained between iron and manganese (r=0.77**); negative correlation between Cu and Mo (r=-0.77**) and positive correlation between Zn and Mo (r=0.43**).

Foliar Diagnosis

DeWaard (1969) in a triangular diagram for N, P, K, Ca and Mg found that the vegetative health of pepper with respect to each of the five elements may be characterized by specific values for absolute levels of N, P, K, Ca and Mg for specific locations. This stresses the point that leaf concentrations of the elements are interrelated. The poor performance of pepper is found to be associated with high leaf concentrations of Ca and P, and lower concentrations of N, K and Mg. (Maintenance of leaf nutrients above the normal level by promoting consumption of nutrients prior to fruiting so that the vegetative portion of the plant is used as a temporary buffer stock for supplying nutrients). Thus, physiological exhaustion and instability of yield may be prevented by adequate nutrition (DeWaard 1969). Nybe *et al.* (1989) reported that foliar content of N, K, Ca and Mg increased in the rainy season following fertilizer applications. The nutrient elements P, K, Ca, Mg and S are found to exert direct and indirect effects on the yield, based on simple correlation and path coefficient analyses among the nutrients. P and K have greater influence on yield. The leaf nutrient status of elements for a few cultivars are given in Table 4.1.15.

Foliar diagnosis can be used as a tool for detection of nutritional aberrations in pepper. DeWaard (1969) indicated that throughout the season the balance of base nutrients should be carefully controlled; the concentration and ratio must be maintained in appropriate relation to yield. The level of productivity can be

Table 4.1.15 Leaf nutrient status of some pepper varieties.

Variety	*N*	*P*	*K*	*Ca*	*Mg*	*Fe*	*Mn*	*Zn*	*Cu*	*Al*	*Mo*
	(——— g 100 g⁻¹ ———)					*(——— mg Kg⁻¹ ———)*					
Arakkulammunda	2.31	0.15	2.77	1.56	0.19	78	161	30	631	68	1.24
Balankotta	2.42	0.13	3.15	2.37	0.24	125	227	19	248	87	4.54
Karimunda	2.64	0.16	2.92	2.30	0.24	129	542	27	800	85	3.40
Kottanadan	2.12	0.13	3.55	1.40	0.15	94	293	26	425	60	2.34
Kuching	2.40	0.14	3.13	1.48	0.20	91	298	26	390	59	3.24
Kuthiravally	2.32	0.14	3.00	1.93	0.27	127	327	27	501	68	4.00
Kalluvally	2.18	0.14	3.14	1.61	0.20	139	446	28	608	86	3.10
Neelamundi	1.75	0.15	2.79	1.51	0.22	111	310	25	317	92	3.26
Panniyur-I	3.12	0.13	2.70	2.13	0.25	94	285	19	405	82	3.40
Thommankodi	3.02	0.14	2.94	2.02	0.17	92	199	29	627	78	3.28
Valiakaniakadan	1.93	0.12	2.61	2.33	0.23	92	311	29	335	71	4.72
Thevanmudi	2.54	0.12	3.52	1.69	0.20	84	273	14	356	53	1.77
CD 5 %	0.24	0.02	0.33	0.23	0.04	14.6	89	5.2	126	13	0.70

manipulated by varying the value for log N/P, but simultaneously leaf K concentrations and related Mg and Ca must be adjusted to improve the yield. It is, therefore, appropriate to control the foliar concentrations and ratios within the range of fair to normal concentrations for achieving high yield. Rajagopal and Sadanandan (1985) standardized index leaf for foliar diagnosis as the youngest mature leaf (YML) and next matured leaf (NML) from fruiting laterals sampled with petiole during May within the middle one third position of the leaf canopy. Sushama *et al.* (1989) reported that first mature leaf of fruiting laterals just before flushing is most suitable for foliar diagnosis in black pepper.

DeWaard's (1969) work on fixing the critical levels for major nutrients revealed the values of 2.7, 0.1, 3.0, 1.0 and 0.2 per cent as the critical limits of N, P, K, Ca and Mg respectively in the leaves of pepper, lower than the above, indicate deficiency of these nutrients. Sadanandan and Hamza (1996) worked out DRIS (Diagnosis and Recommendation Integrated System) norms for black pepper leaves (Table 4.1.16). They reported that 1.65–2.79 per cent N, 0.11–0.26 per cent P, 1.18–2.84 per cent K, 1.42–3.33 per cent Ca, 0.40–0.69 per cent Mg, 0.09–0.29 per cent S, 126–1145 ppm Fe, 109–721 ppm Mn, 21–67 ppm Zn and 16–120 ppm Cu in pepper leaves are required for getting optimum yield.

Bush Pepper

Bush pepper is a welcome alternative to the climbing pepper as it has potential for cultivation in homestead situations.

Nursery techniques

The plagiotropic lateral fruiting branches of pepper exhibit sympodial growth and these branches when rooted and planted grow into a bush (Fig. 4.1.11). These bushes produce more fruiting branches and start flowering from the first year itself. The

Table 4.1.16 Nutrient DRIS norms for pepper.

Element	*Unit*	*Status*				
		Deficient	*Low*	*Optimum*	*High*	*Excessive*
Nitrogen	%	<1.06	1.06–1.64	1.65–2.79	2.80–3.40	>3.40
Phosphorus	"	<0.03	0.03–0.10	0.11–0.26	0.27–0.37	>0.37
Potassium	"	<0.33	0.33–1.77	1.78–2.84	2.85–3.68	>3.68
Calcium	"	<0.47	0.47–1.41	1.42–3.33	3.34–4.30	>4.30
Magnesium	"	<0.20	0.20–0.39	0.40–0.69	0.70–1.06	>1.06
Sulphur	"	<0.01	0.01–0.08	0.09–0.29	0.30–0.38	>0.38
Iron	ppm	<60	60–125	126–1145	1146–1796	>1796
Manganese	"	<30	30–108	109–721	722–1027	>1027
Zinc	"	<10	10–20	21–67	68 –100	>100
Copper	"	<6	6–15	16–120	120–200	>200

Figure 4.1.11 Bush pepper developed from plagiotropic shoot. Note the bushy growth habit.

flowering continue in all seasons of the year if proper watering and manuring are given. They can be easily grown either in pots or in field.

Rooting of the flowering laterals is more difficult. A method used by Ravindran *et al.* (1981) involves (i) selecting healthy lateral shoots of previous year's growth with two or three leaves (ii) dipping the cut end in a commercial rooting hormone (iii) planting them in moist rooting medium (weathered coir dust is used in the above work) contained in a 200 gauge poly bag of about 40 cm×25 cm size and filled to about one fourth with the medium (iv) tying the mouth firmly and keeping the bags in a cool, shady place. Before closing the bag air is blown into the bag. The cuttings get rooted in 30–35 days. After about 45–60 days the bags can be opened and allowed to remain like that for a few days before transplanting the rooted cuttings to pots. If properly done this technique can give above 80 per cent success.

Bush pepper can be planted at a minimum density of 2500 plants ha^{-1} at 2×2 m spacing but can be doubled by reducing the spacing. Bush pepper recorded a yield of 1600–1700 kg ha^{-1} and the variety *Panniyur*-1 recorded the highest yield (1960 kg ha^{-1}; IISR 1997). Similar studies with bush pepper have been carried out in Indonesia, Malaysia and in Philippines.

Soil availability of nutrients

Experiments conducted on the effect of chemical and organic nutrient sources on bush pepper grown in pots of 10 kg soil showed that nutrient availability increased significantly due to increasing dose of NPK application. Among the treatments, NPK at the rate of 1.0, 0.5 and 2.0 g $plant^{-1}$ was superior for optimum yield realization (Sadanandan and Hamza 1996).

Studies on the effect of potassium sources on bush pepper revealed the superiority of potassium sulphate. For bush pepper growing in pots, bimonthly application of NPK fertilizers at the rate of 1.0, 0.5 and 2.0 g pot^{-1} respectively is optimum.

CONCLUSIONS

For sustainable management of pepper, the following measures are suggested:

Soil management problems	Corrective measures
Soil erosion	Conservation practices
Loss of soil	Conservation tillage to suit soil types
Loss of nutrients	Appropriate soil management
Depletion of organic matter	Management of crop residue & animal waste. Develop technology for crop residue and animal waste management
Soil fertility	Revalidation of soil fertility.
Low soil fertility (low pH, org. matter & nutrient content)	Monitor changes in soil status, develop new soil test methods
Al toxicity	Use lime & organic matter
Accumulation of unused elements	Investigate dynamics and behaviour in soil-plant ecosystem
Lone use of fertilizer	New fertilizers
Chemical fertilizers	As per soil test crop response
Based on yield goals	Use of slow release fertilizers
Exclusive use leads to pollution	Use bio-fertilizers
	Improve phyto availability
Live stock waste	Organic resources recycling
Loss of organic resources	Adoption of mixed farming
Pollution problem	Efficient use of animal waste

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ANNEXURE-1

AGRONOMY OF BLACK PEPPER: ADDITIONAL INFORMATION PROVIDED BY THE EDITOR

Propagation of Pepper

Many experiments have been carried out in pepper growing countries for developing a successful method of propagation from stem cuttings. Some of the additional information are presented here.

Single node stem cuttings with the attached leaf quick dipped in IBA at a concentration of 2 mg/ml in 50 per cent alcohol gave 75 per cent rooting in 21 days in a standard cocoa propagator with coir dust as the medium (Copper 1955). Traditional Indian method of using semi hardwood cuttings with 3–4 nodes was reported to give only 15 per cent rooting after six months (Creech 1955). The same author described a method using bamboo poles covered with moist sphagnum moss. The pepper vines planted at the base of the bamboo, kept slantingly, were allowed to grow over the post. The vines got rooted at every node, the nodal cuttings along with leaves were planted in a green house. Such plants were ready for planting in six weeks (Creech 1955, Konstantinov and Bodreva 1962). Cuttings from selected plants were rooted in bamboo baskets, and those selected and planted in March gave 90–95 per cent rooting (Nambiar and Kurian 1963). Garayar and Corbera (1957) found that the most satisfactory shoots for rooting were those which had matured in shade and had ceased elongation, and that the cuttings were to be disinfected with 15 per cent ferbam and the base dipped in 0.2 per cent IBA and kept at 95–100 per cent RH and 20–30 lux light intensity. The rooting takes place in 20–30 days. Leite and Infrazato (1966) subjected softwood and hardwood cuttings to 15 hours preplanting treatment by immersing their bases in distilled water or in a 50 mg/liter solution of either NAA or IAA and they obtained the highest rooting of 62.5 per cent in NAA. Larcher (1970) reported better rooting and root growth in the cuttings treated with 0.2 per cent IBA. Single node cuttings gave 90–95 per cent rooting under glass covered mist spray in a vermiculite rooting medium (Hughes 1966). Dipping of nodal cuttings in 1000 ppm IBA for 45 seconds gave better rooting in polybags (Pillay *et al.* 1982, Shridhar and Singh 1990). IBA treated cuttings planted horizontally produced more roots than those planted vertically (Zaubin 1984). Cuttings treated with 25 per cent coconut water for 12 hrs increased root and shoot length, number of roots and shoot dry weight (Yufdi and Ernawati 1987). In South Andaman Islands 1, 2, 3 or 4-node cuttings of the van *Panniyur* 1 in sand-FYM (1:1) is recommended for rooting and for proper growth of the sprouts. (Singh and Singh 1989). Undefoliated cuttings of cv. *Belantung* treated with 2 per cent sucrose and 200 ppm IBA were reported to give high rooting percentage (80 per cent and 82.4 per cent respectively) (Suparman and Zaubin 1988). Almirante (1955) obtained earlier rooting with 7-node cuttings, but survival was better in 5-

node cuttings. Better rooting is reported under pH 7.8 to 8.1 (Sangakkara 1989). Medium composed of FYM-sand-soil (1:1:1) and soil-leaf mold (7:3) were reported to give better rooting (Yufdi and Hayani 1981). Detopping at 4–5 weeks or ringing at 3–4 weeks before taking cuttings increased rooting ability (Yufdy 1980). Semiherbaceous cuttings collected in June perform better (Shanthamallaiah *et al.* 1974). Nath and Mohan (1993) showed that cuttings planted in beds give better rooting than in polybags and that plastic house provided the best environment for rooting. Rau (1990) described a rooting technique in which single node cuttings with leaves are close planted in coir pith-soil-cattle manure (10:1:1) mixture in humid chambers. The cuttings are dipped in 1000 ppm IBA for 45 seconds. The cuttings after planting were enclosed in a polytunnel and watered profusely. The cuttings after rooting were transferred to the secondary nursery in poly bags for further growth. About 80 per cent rooting was reported in 25 days. Sasikumar and George (1992) found that single node cuttings planted in polybags and kept in pits covered with polysheet with frequent water sprays gave above 90 per cent rooting without any hormone treatment. Sujatha (1997) obtained 90 per cent rooting in two node cuttings dipped in 1000 ppm IBA and kept in a polytent, with regular watering.

In Philippines, marcotting (air layering) was tried to root the fruiting laterals (Anon. 1961). Dolar (1964) reported that watershoots produced at the ends of fruiting laterals during the flushing period could be successfully marcotted, and that the plants grown out of them were dwarf and bushy. Such bush peppers were first reported from Philippines (Anon. 1961). Dolar (1964) as well as Lawrence (1981) gave details of marcotting.

Pruning of Pepper

Pruning is a regular practice in most pepper growing countries though in India there is no such practice. Pruning is reported to be essential to shape the plants and to stimulate development of axillary shoots. Trials have been carried out in Sarawak, to test the efficiency of different pruning methods. Three methods of pruning are in vogue in Malaysia (Anon. 1981).

1. *Kuching method*

When the vines are six months old (having approximately nine nodes), the shoots are pruned back to approximately 30 cm (3–4 nodes) from the ground. Thereafter three terminal shoots are trained up the post and these shoots are allowed to grow to ten nodes and then pruned back to three nodes from the point of the first pruning. Pruning in this manner continues until the vine reaches the top of the post.

2. *Sarikei method*

When the vines are six months old, the terminal shoots are pruned back to 3–4 nodes from the ground. Three terminal shoots are then trained up the post and there is no further pruning until the vine reaches the height of three quarter post. Then top two or three nodes are pruned away and the vine is allowed to grow to full post.

3. *Semongok method*

When the vines are six months old, shoots are pruned back to 30 cm from the ground. Three terminal shoots are then selected and trained up the belian post. Here after the pruning is done only wherever there is a blank (unproductive) node.

Trials carried out in Sarawak did not give any significant difference among the above methods as far as the yield performance is concerned, though *Sarikei* method was slightly better. A seven year trial gave a pooled annual mean yield of 11,124; 10,140 and 10,380 kg ha^{-1} fresh fruits for *Sarikei, Kuching* and *Semongok* methods respectively (Anon. 1981). Kuching method of pruning results in column shaped plants and takes longer time to reach the top of the post as compared to the other methods. Pepper vines pruned by *Sarikei* or *Semongaok* method are cone shaped at the first few years and gradually become column shaped as they grow older.

Azmil and Yau (1993) concluded that three rounds of pruning is enough to obtain necessary number of climbing shoots as well as the appropriate bushiness of the pepper vines. Chong and Shahmin (1981) showed that there was no significant differences in yield between pepper vines having 3, 4 or 5 climbing shoots. In another trial Chong and Yau (1985) showed that vines with five climbing shoots produced more yield than those with 7 or 9 climbing shoots. Thus depending on the diameter of the pepper post 3–5 climbing shoots can be maintained.

Coiling and hurrying the pepper stem

In Kerala (India) as well as in certain areas in Indonesia and Sri Lanka, some farmers practice another method for producing more number of climbing shoots. The growing plants, one year after planting, are kept coiled around the standard under the moist soil. Usually this is done in the next rainy season. Before hurrying the stem under soil all leaves are removed from the portion that goes under soil. This results in all the axillary buds to develop and many shoots climb up and cover the standard quickly. But no experimental data is available on the advantages of this practice.

All leaves from the main stem are also removed. This is done because if they are allowed to remain they impede the circulation of air around the base and the centre of the vine and may lead to diseases (Lawrence 1981). Lawrence (1981) has listed the following advantages for pruning.

1. To ensure that all blind nodes are removed
2. To encourage bushiness of the vine
3. To ensure that the terminal leader stems grow evenly
4. To make harvesting easier
5. To encourage the vine to produce more fruiting spikes.

Land Preparation and Planting

In Kerala (India), pepper cultivation was not done in an intensive way, unlike in most other countries. When pepper is planted in an already cropped area, pits are dug usually at 3×3 m spacing. The recommended dimensions of pits are 50×50 cm, but usually the growers use smaller pits. Standards (stems of *Erythrina, Garuga* or *Glyriddia*) are planted on the west or south-west side of the pits. The pepper plants are planted usually only after one year. The pits are usually left fallow, allowing to accumulate organic matter, mainly stubbles, agricultural wastes etc. Some farmers resort to burning the pits. When new areas are cleared for planting (such plantings are no more possible due to the non availability of land) farmers usually plant *Erythrina* or *Garuga* stems in the first year and a crop of tapioca *(Manihot)* or other tuber crops or upland rice is grown. In the second year, pits are dug adjacent to the support trees, filled with top soil and organics and pepper cuttings are planted on the north or north east side of the support. The intercropping continues for another one or two years. When silky oak *(Grevillea)* or *Ailanthus* are used as standard, one year old seedlings are planted at 3×3 m spacing and pepper plantings are taken up only after three years. During this period the land is used for other crops. When pepper plantings are taken up in hilly tracts and on slopes, serious soil erosion problems arise as a result of the above cropping activities and the fertility of soil declines rapidly, which in turn leads to poor, unsustainable pepper crops. Contour terracing and other operations to prevent soil erosion and moisture conservation are usually not adopted by most growers.

The growers earlier used runner shoots for planting. Two to three nodes are kept below the soil and the top portion is tied to the standard. Now pre-rooted cuttings are used for planting. Application of a nematicide at the time of planting is recommended to prevent nematode infestation and to encourage better establishment.

In Sarawak (Malaysia), the Chinese growers have developed an intensive cultivation practice. Here most pepper plantations were raised earlier on virgin forest lands; now pepper is also grown in areas released from other crops. The land is given one to two good diggings to remove the tenacious grass weeds (such as lalang grass—*Imperata cylindrica* Beauv). The stubbles and roots etc are used for making burnt earth. Then mounds are made from top soil and subsoil over which the burnt earth is applied and mixed. The mounds are about 50–60 cm in diameter and 30 cm in height at the centre. These mounds are maintained by periodical addition of burnt earth, topsoil, compost etc. Temporary stakes are placed at the centre of the mounds and cuttings are planted in the mounds, usually using fresh orthotropic shoots. These cuttings that are 30–35 cm long with 5–7 nodes are taken from young vines only. Before cuttings are collected, the terminal bud of the shoot is removed and also most leaves, retaining only the top two or three. Such cuttings are separated after 7–10 days and planted in a nursery for rooting (Anon. 1967). The rooted cuttings are planted in the fields. In Micronesia the common practice is to place a bamboo pole down the centre of the bed and furrows 5 cm deep and 10–12 cm apart are taken and the lower portion of the cuttings are kept in the furrows. Before covering the cuttings with the nursery mixture a spray of 0.2 per cent fungicide (capstan) is given. The upper portion of the cuttings that carry the leaves are kept on the bamboo pole. When the terminal shoots grow and develop three to four leaves the cuttings are carefully removed from the furrows and planted in the field (Zaiger 1964). They are planted in shallow slanting furrows, four lower nodes of the cuttings are kept inside the soil and pressed firmly, and the aerial portions are tied to the stakes. These stakes are later replaced with the poles of Borneo iron wood. During the first year, annual crops such as chillies, soyabean, groundnut or tobacco are grown. Sometimes cuttings are also planted in furrows after 1–2 diggings without going on for preparation of mounds. In all cases the pepper basins are kept clean, often with the addition of rubbles or burnt earth. In the Malaysian mainland, in Johore region, pepper is raised mostly on living standards such as *Erythrina* and here pepper is planted in pits after filling up with top soil and organics and not in mounds.

In Lampung and Bangka, cuttings obtained from the pruning of one year old plants are used for planting. All leaves except those on the lateral shoots are removed before planting (Anon. 1967). Similar planting material is used in Brazil and Cambodia also (Alconero 1969).

In Philippines (especially in the Batangas Province) there is a unique way of planting pepper using the trench method (Anon. 1990, deGuzman 1991). Pepper cuttings—either rooted or unrooted—are planted in trenches of about 60 cm deep and 60 cm wide along the planting rows. Organic matter is allowed to accumulate with time in these trenches. Support trees are established on the edges of the trenches and pepper is established on them. The recommended spacing is 2.5×2.0 m, accommodating 2000 vines ha^{-1}. The growth of pepper planted like this is reported to be much better than the conventional method. Trench method of planting is also good for protecting the plants during prolonged drought. However, because of the high input cost, this method has not been adopted in most pepper growing provinces in Philippines.

Another method known as hedge growing has been introduced in Sarawak by the Department of Agriculture (Anon. 1967). Here the pepper vine is trained not only on the standards, but then growth is further extended to a wire net frame set up between standards. The frame work consists of Belian poles of about 3 m, sunk into the ground (about 0.5 m) and arranged at 1.5 m apart in 3 m rows. The supports are connected by galvanized wire which form a trellice like frame work. On the vines, seven leader shoots are pruned and then trained to grow along the frame work in a fan-like manner. Out of the seven shoots, three are allowed to grow up while two each are trained along the wire, before they were also allowed to grow up (Lawrence 1981). Such frame work can be established along rows in a field, and long hedges or walls of pepper can be developed. The advantage of the method is that it allows the expansion of surface area many fold. A comparison of the performance showed that the mound system is superior from an yield point of view (Lawrence 1981).

Spacing and Plant Density

Plant density varies very much among different cultivation methods and depending upon the standards used. In Kerala, India 2.5 rn×2.5 m or 3 m×3 m is most commonly used with dadap, *Glyricidia, Ailanthus* or Silky oak standards, accommodating about 1100 to 1600 plants/ha^{-1}. In Malaysia 2.4×2.4 m is the common spacing adopted, which gives a plant density of 1680 plants/ha^{-1}. A spacing trial was conducted at IISR on RCC posts in which various spacings are tried to give plant density ranging from 1100 ha^{-1} to 5000 ha^{-1}. Highest yield was recorded in the cv. *Karimunda* planted at 2×1 spacing, having a plant density of 5000 plants (Menon *et al.* 1982). In Malaysia, Azmil and Yau (1993) have reported the results of a trial where spacing of 2.44×2.44 m (square planting), 2.44×2.44 m (triangular), 1.83× 2.44 (rectangular) 2.13×2.13 (triangular) plantings were tested, giving a density of 1680 to 2535 plants ha^{-1}. Here average fruit yield was higher in 1.83×2.44 and 2.13×2.13 spacings gave significantly higher yield than the other two. In another trial in Sarawak, four spacings (1.22×2.44 m, 1.53×2.44 m, 1.83× 2.44 m, 2.14×2.44 m) were tested. The seven—year yield figures were 21,915, 19,528, 18,230 and 15,440 kg ha^{-1} (green fruits) indicating that the less spacing gave a higher yield on a unit area basis. At the same time, the individual plant yield was high in wider spacings (6.52, 7.28, 8.13 and 8.03 kg/vine respectively).

Standards or Supports

In India, pepper is trailed on a variety of trees. For large scale planting, dadap *(Erythrina indica, E. lithosperma), Garuga pinnata, Grevillia robusta* (silky oak, but wrongly called as silver oak, the latter is *Grevillia parallela* a small slender tree of north Australia) are used. *Glyricidia* is not very popular. *Ailanthus* and *Pajanalia rheedii* are two other common standards. When grown as an intercrop, pepper is trailed on arecanut and coconut. In the Dakshina Kannada, Uttara Kannada and Shimoga districts of Karnataka, pepper is mostly trailed on arecanut and are allowed to grow unrestricted. In the homestead garden, pepper is trailed on mango, jack and any other tree that is available. Non living standards are not used in India. Studies conducted at Kerala Agricultural University indicated that *Ailanthus* is the best standard for pepper (Anon. 1996)

In Sarawak, Malaysia, post of Belian wood (Borneo ironwood tree, *Eusideroxylon zwageri*—Lauraceae) poles are used as standards. But they are becoming very expensive now. Moreover most other hard woods tested did not last long. Trials conducted in Sarawak to identify alternate support materials indicated that *Shorea* sp. and *Hoppea pertaneria* are promising (Anon. 1979). Trials were also conducted to prolong the life of timber poles with pressure impregnation of preservatives (Anon. 1981). In Johore, Malaysia, *Kulim* posts *(Scorodocarpus borneensis)* are among the popular hard woods used as pepper supports. They are also becoming rare and costlier (Azmil and Yau 1993). Trials for identifying suitable live standards were carried out by Wong and Paulus (1993). In one such trial comparative performance of live standards (*Dillennia, Gliricidia, Leucaena* and *Adinanthera*) in comparison with Belian wood posts gave the following results: mean yield for the initial three years—Belian—10.4, *Dillenia*—7.8, *Gliricidia*—10.4, *Leucaena*—11.5 and *Adenanthera*—7.9. The result indicates that *Glyricidia* and *Leucaena* perform equally well as the non living standard. The same workers also reported that leaf nutrient status of pepper plants trailed on Belian post and living standards do not differ appreciably. *Glyricidia* and *Leucaena* had better establishments, faster regeneration after loppings and the former ranked first in terms of lopping material production and nutrient contribution from loppings. Mean light interception by pepper plants growing under the living standards vary; two weeks before lopping the values were 89, 29, 62 and 82 for *Dillenia, Glyricidia, Leucaena* and *Adenanthera* in comparison with 100 per cent two weeks after lopping. So periodical lopping, especially before the flowering season, is a must. In terms of biomass production and nutrient contribution *Glyricidia* and *Leucaena* were on par, and the estimated labour inputs for lopping were more for these two trees (Wong and Paulus 1993). In a later experiment conducted at Sarawak, an yield increase of 20 per cent was noted in plants grown over *Glyricidia,* though the result was not significant (Anon. 1995). *Glyricidia* is also the standard of choice in Sri Lanka and is also used widely in Indonesia.

For the Johore region of Malaysia, Varughese and Ghawas (1993) have shown that *Erythrina indica* is a very successful standard for the cv. *Kuching* and that with this support the establishment cost can be reduced by 70 per cent. Azmil and Yau (1993) have also reported that dadap is the most suitable support tree followed by *Angsana (Pterocarpus indicus)* and *Glyricidia maculata*. Auni (1992) estimated that the cost of establishing a pepper garden using dadap is only about 30 per cent of that using *Kulim* posts. Financial benefits were much, there is substantial increase in internal rate of return and benefit-cost ratio and hence the pepper-dadap system has now been recommended as a more promising alternative to the dead standard pepper system in Malaysia.

In Brazil, pepper is cultivated in the Amazon region in open, unshaded areas using posts of 2.8–3.0 m height, the plant population is 1300–2500 ha^{-1}. Live supports are not common. In Thailand and Micronesia RCC poles are common, in the latter many forest plants including tree ferns are used for trailing pepper. Brick pillers are also common in Thailand and Vietnam in addition to wooden poles.

Root Architecture

Preliminary studies on root architecture of pepper was carried out by Ipor *et al.* (1993,) using the excavation methods on a 3-year old pepper plant propagated from 5-node cutting. Here main roots were produced from each underground node of the cutting and the roots constitute 36.2 per cent of the whole root system. Main roots from three lower nodes produced long woody roots with length ranging from 0.24–2.52 m and diameter ranging from 0.01–1.72 cm. The bulk of the feeder roots (63.8% of the whole root system) developed from their main roots and were found at 0–0.5 m depth. The total area of feeder roots was 14,856 cm^2.

The cut end also produced 2–3 main roots, the longest was around 2.52 m having a diameter of 1.72 cm. These roots extend down and were mainly for anchorage. Roots also developed from upper nodes as a result of mounding. These roots ranged from 0.14–1.84 m in length with a diameter of 0.01–0.065 cm and feeder roots ranging in length from 164.6–512.3 cm were also found on the upper nodes (Ipor *et al.* 1993).

The above authors recommended mounding of pepper basin as a regular practice to facilitate more feeder root production. They also are of opinion that the triangular system of planting is better than the square planting sytem in view of the pepper root spread, because this system is reported to allow root expansion down the slopes and that it also allows better light interception (Ipor *et al.* 1993, Wong 1985).

Canopy Area, Biomass

Ipor *et al.* (1993) calculated the canopy areas of three year old pepper plant developed from five node cuttings. The average number of leaves were 3881 with the total area of 13,6276 cm^2. The total dry weight of leaves, branches and roots were 1215.3 g, 1102.58 g and 364.7 g respectively. The leaf area index was 322.4. The result indicated that the partitioning of biomass is more towards leaves than for branches and roots. Othman and Sim (1995) estimated the leaf area using data from all developmental stages of leaf. They calculated that the factor 0.66×leaf length× leaf width gives the best approximation of leaf area (Anon. 1995)

Intercultivation, Covercrops

Intercultivation in pepper plantations is a point of controversy. Maintenance of grass cover and practice of minimum tillage are advocated in India mainly as an insurance against the spread of foot rot disease (Thomas and George 1992, Sarma *et al.* 1991). Disease spread is reported to be much faster in plantations, where clean cultivation is practiced, compared to plantations where grass or legume cover crop is retained (Sarma *et al.* 1991). Cover crops are reported to reduce the movement and spread of contaminated soil in a garden through surface water and rain splashes. Cover crops enhance the organic matter content of top soil and are helpful in increasing the antagonistic microflora (Ramachandran *et al.* 1991). Practice of minimum tillage is advocated to avoid damage to root system and disease spread.

Cover crops are not popular in India because there pepper is grown together with other crops and there is no scope for cover crops in such a crop combination. But in countries where pepper is grown as a monocrop, trials have been conducted to find out the usefulness of cover crops. In Sarawak, cover crops together with legume mulch, lallang *(Imperata cylindricd)* mulch, etc. were tested and found that cover-crops have no special advantage (Anon. 1979). At the same time the commonly used leguminous cover crops climb on pepper plants, often choking the young growing plants and requires additional labour to remove them periodically. In Indonesia, cover crops were shown to cause yield reduction. Clean cultivation is advocated in pepper garden in these countries.

Despiking

In Malaysia, parts of Indonesia, Thailand, etc. it is a common practice to remove all the spikes produced during the first two years after planting. It is generally held by growers that early flowering will interfere with the normal development of pepper plant thereby affecting the yield. But this practice is time and labour consuming and adds to the cost of production. A study carried out by Yau and Azmil (1989) showed that early flowering and fruiting do not affect the growth or yield of pepper. Cumulative yield over a period of five years did not differ significantly among the non deflowered plants and plants deflowered for varying period from 6 months to 30 months (Yield figure mt/ha are: 18.95, 18.73, 18.35, 17.50, 17.76 and 19.33 respectively for no deflowering and deflowering for 6, 12, 18, 24 and 30 months respectively).

Despiking is not a practice in India, where the pepper plants come to flowering after 2–3 years

Productive Life Span of Pepper

The productive life span of pepper is around 10–15 years in countries where pepper is grown as a monocrop on dead standards. In Sarawak, pepper is replanted after 10–15 years on a regular basis. In India the effective life span of pepper is much longer as they are trailed on living standards. When pepper is grown restricting the height (as in the case of plants trailed on dadap, *Glyricidia, Pajanalia,* etc.) the plants can remain productive up to a period of 15–20 years. But when pepper plants are allowed to grow indefinitely, when they are grown over trees like *Grevellia,* arecanut, etc., they grow to much height and they go on giving good yield, where age is not a limiting factor. Pepper plants of 10–15 m high, producing around 50 kg fresh fruits are quite common in many plantations (Private communication). When it is trailed over large forest trees pepper plant can grow massively and there are examples of such plants giving even up to 140 kg fresh fruits (Private communication).

So productive life span of pepper depends on the mode of cultivation, when growing intensively as a monocrop on dead standards 10–12 years can be taken as the effective life span after which replanting is advisable. This is the practice in many countries. In Brazil the productive life span is estimated to be around 15 years (Fearnside 1980). But in many cases pepper plants are prevented from reaching this full life span due to many devastating diseases—*Fusarium* wilt in Brazil and the *Phytophthora* foot rot and slow decline in other pepper growing countries.

Yield Prediction from Soil Fertility—Management Parameters

Fearnside (1980) has done an effort to predict pepper productivity based on soil fertility and management parameters in the pepper growing areas along the transamazon highway of Brazil. According to this author, in Brazil black pepper is “doomed as a long term mainstay of colonist cash cropping due to its susceptibility to a number of devastating diseases.” Fearnside developed a regression equation of yield on fertility (Y=-12.119+0.292A+0.382B-0.0552 where Y=pepper yield, A=pH of soil, B=carbon (per cent dry weight) and C=phosphate ppm), and that regression equation was found to be highly significant ($p<0.0001$). The prediction model was developed after taking into account the soil fertility, fertilizer application and related factors. But the author stresses the point that the ultimate fate of pepper in the area is hinged on the disease problem, as pepper life span is seriously cut short by *Fusarium* wilt. Chemical treatments can slow the progress of disease, but cannot stop it completely. The colonists there, were playing a losing battle using fungicides, and in that process, several farmers suffered chemical poisoning. Any pepper yield prediction should also take into account the *Fusarium* wilt incidence. The following parameters have been suggested for modeling the incidences (Fearnside 1981):

1. The entry of the disease into a virgin area in any given year;
2. The attack of any given patch of healthy pepper within the area in any given year, given that the disease has already entered the area;
3. The death of a patch of pepper in a given year, given that it is diseased;
4. The availability of a new resistant variety, given that the resistance of the current variety has been broken.

In addition, for yield prediction, the proportion of pepper production expected from diseased plants should also be estimated.

The first of these parameters can be calculated from the equation $P=1–0.5\ 1/t$, where P=the yearly probability of the disease entering a virgin area, and t=the average number of years needed for the disease to make its first appearance.

The probability for the second parameter will also depend on how many other patches of pepper have been attacked. Fearnside has estimated around two years. The third probability also varies with time, and an estimate of three years has been made. The probability for the fourth parameter is very remote. The probability for pepper production from diseased plants is around 0.5, assuming that the pepper plants in a patch are killed at a constant rate during the disease incidence, and that the plants are killed instantaneously. The parameters estimated by Fearnside (1981) for *Fusarium* incidence is given below.

Table 4.1A1 Parameters for disease incidence*

Sl. No	*Parameter*	*Average year to occur*	*Probability per year*
1.	Entry of disease	3	0.206
2.	Affecting any given patch	2	0.293
3.	Death of a patch	3	0.206
4.	Availability of a resistant variety	0	0
5.	Proportion of pepper production = 0.5		

* Source: Fearnside (1981)

It was also assumed for prediction, that the pepper plants reach full production potential by fourth year (the proportion being 0.000, 0.40, 0.80 and 1.00 for 1, 2, 3 and 4 years). The productive life expectancy is 10–15 years (because dead standards are used), but *Fusarium* wilt prevents many of the plants from entering into this age group.

All the parameters were used by Fearnside in an AGRISIM model for developing the yield prediction. The author concluded that the prospects for pepper in the transamazon colonization areas are bleak.

Fertilizer Recommendations

The Brazilian Government (IPEAN 1966) has developed fertilizer recommendation based on the following scheme. Equations have been developed for predicting the changes in soil nutrient levels per kilogram of fertilizer active ingredient applied.

But in general practice, the growers apply 200 to 300 g NPK (12:12:17) mixture, 500 g of lime and 300 g thermophosphate per plant per year. Organics used are castor, cotton and carapnut cakes, 1–2 kg per plant or poultry waste 1–2 kg or cattle manure

Table 4.1.A2 Brazilian government's fertilizer recommendation.

Initial soil analysis	*Fertilizer active ingredient*	*Kg/ha active ingredients*			
		Pepper age (years)			
		1	*2*	*3*	*4*
$P \leq 10$ ppm	P_2O_5	70	100	150	300
$P \geq 10$ ppm	P_2O_5	30	40	50	100
$K \leq 45$ ppm	K_2O	60	80	100	200
$K \geq 45$ ppm	K_2O	0	0	25	50
N all levels	N	40	60	80	100
C all levels	Cotton cake	2222	2222	2222	2222
$Al^{+++} \leq 0.3$ meq/100 g and Ca^{++} & $Mg^{++} >$ 4 meq /100g	Dolomite lime	0	0	140	280
$Al^{+++} \leq 0.3$ meq/100 g and Ca^{++} & $Mg^{++} \leq$ 4 meq/100 g	Dolomite lime	122	140	280	560
$Al^{+++} > 0.3$ meq/100 g	Dolomite lime	0	0	0	0

3–5 kg. In addition, foliar sprays of micro nutrients (manganese, boron, molybedenum) along with magnesium and occasionally calcium as well are given (Duarte and Albuquerque 1991).

Different types of organics are applied in varying quantities in the pepper growing countries. In India green leaves, dry leaves, wood ash, cattle manure, oil cakes, neem cake and bone meal are the common organics used. In Malaysia organic cakes, prawn refuse, guano, fish meal, etc are used. In Micronesia every pepper field will have a compost pit also. In addition sea cucumbers (*Holothurian* sp.) are dug into the soil around vines. (Zaiger 1964). Here the recommended fertilizer dose is a mixture of urea, cottonseed meal, potassium chloride and superphosphate at the rate of 0.66, 6.6, 1.1, 1.8 pounds per vine per year (Lawrence 1981).

Time of spiking and harvesting

Pepper flowering and harvesting depend on the climatic factors, the most important being rainfall. In most growing countries the flowering coincides with the major rainy season (monsoon) and the crop takes about 7–8 months to come to full maturity. The flowering and harvesting seasons of major growing countries are given below (Lawrence 1981).

Table 4.1.A3 Spiking and harvesting seasons*

Country	*Spiking time*	*Harvesting time*
India	June	November–February (Plains) February–April
Bangka (Indonesia)	Jan–March	July–September
Lampong (Indonesia)	December–January	June–August
Brazil	February	August–November
Sri Lanka	November–December	March–May [Main (Maha) crop]
Cambodia	June	January–March
Thailand	June–August	February–March
Sarawak	December–January	April–July

* Source: Lawrence (1981)

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POST SCRIPT

The earlier area-production figures are far from accurate. Recent surveys indicated that Karnataka contributes roughly about 25% of production. In a recent publication on pepper production in Karnataka, the area and production figures indicated for 1998–99 are, 44500 ha and 27250 tonnes. The area is mixed-cropped. Karnataka thus contributes about 25% of production and not 5% as it was earlier thought. During 1998–99, the pepper production in India has touched the 100,000 tonnes mark.

Ref: John, T.D. (1999) Pepper production in Karnataka. **Spices India, 12 (12): 10–12**

4.2. MANAGEMENT OF PEPPER IN INDONESIA

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For Indonesia, pepper had been an important commodity ever since it was introduced, long-long time ago. Pepper was the first spice that Indonesia traded to Europe through Persia and Arabia. Now its value from export ranks fifth in Indonesia, after rubber, oil palm, coffee and tea. Before World War II Indonesia shared about 80 per cent of the total world pepper production. But after the war, production and share of Indonesia's pepper decreased much. During the Japanese occupation (1942–1945) many plantations in main producing areas were left uncultivated, in Bangka for example, only about 100,000 vines left in 1950 compared to 20 million in 1941.

Indonesian pepper industry is mostly owned by smallholders. Planting pepper in estates did not last long in Java. The characteristics of pepper cultivation and its labour and capital intensive nature have played important roles in determining the mode of farming system of pepper in Indonesia (Wahid and Chaniago 1977). It was noted that during the present century the pepper industry in Java had decreased sharply, and Java was replaced by Lampung, Bangka, Bengkulu, West Kalimantan, Aceh and West Sumatra. After the World War II, there were only three regions left as main producing areas, i.e., Lampung, Bangka-Belitung and Bengkulu.

At present, the main producing areas are Lampung and Bangka. Attempts have been made to increase productivity of pepper in main areas through several projects, under the Directorate General of Estate Crops. There seems to be good prospects for pepper industry in West Kalimantan, East Kalimantan, South Sulawesi, South-East Sulawesi and West Sumatra.

The share of Lampung to national pepper production decreased from about 73 per cent in 1976 to less than 50 per cent in 1993, showing that there is strong possibility of replacing Lampung as a centre of pepper production by other areas like Bangka, West Kalimantan, East Kalimantan and Sulawesi. In Bangka itself, pepper was first grown at Muntok, West part of Bangka and its product was well known in the world market as *Muntok White pepper*. Pepper from Muntok was then planted in Belinyu and Sungai Liat, North Coast of Bangka and in Dalil-Dul and Petaling, of Central Bangka. During the period of World War II until 1970s pepper plantations were developed in Petaling, Sungai Selan, Namang, Belilik and Kemuja. Only in the last few years, pepper was planted in Payung and Tobo Ali, South Bangka. However, there is no more pepper in Muntok and Belinyu, while there are only small areas with poor plants left in Kampung-Dul, Petaling and Sungai Selan. The above situation of pepper industry shifting from one place to another and one island to another happened, due to pest and diseases, accidents and degradation of soil fertility.

CROP ECOLOGY

Pepper can be grown in a wide range of environmental conditions. But in order to get profitable crops, considerations should be paid to certain components affecting the whole process of the plant growth. Generally there are similarities in pepper managements among all pepper producing countries, except for the area specific problems. Pepper industry in Indonesia is supported by suitable agro-ecological conditions, such as soil, climate, genetic resources, adaptability and rural sociology, which are considered as most important agro-ecological components for production of pepper. Among them soil and climate are very important in determining the success of pepper cultivation.

Soil

Pepper can be grown in various type of soils such as andosol, grumosol, latosol, podsol, regusol, etc., as long as the physical conditions are sufficient to support good drainage, texture and structure of the soils. Purseglove (1968) suggested that ideal soil for pepper growing is well-drained alluvium, rich in humus with a pH above 5.5. or 5.8 (Zaubin and Robbert 1979).

Generally, soil of most pepper growing areas in Indonesia is poor in fertility, texture, structure and lacking in organic matter. Two main pepper growing areas namely Bangka and West Kalimantan have poor, reddish brown and sandy clay soil. But with high inputs pepper productions are high enough here, higher than that of other pepper producing areas. Lampung, another centre of pepper production in Indonesia has predominantly reddish brown latosol soil and a higher content of organic matter compared to Bangka soil.

In fact, if climatic conditions are suitable, pepper can be grown in many parts of Indonesia. The poorer the soil the more inputs in term of fertilizers, mulch, organic matters, cultivation methods, are required to produce profitable crops. It should also be realized that pepper cannot grow well in waterlogged condition. Therefore, soil drainage is an important factor of the agricultural practices of pepper management.

Climate

The predominant climate in the centre of origin of pepper, the Western Ghats of India, is tropical with rainfall ranging from 1750–2500 mm per year. Based on this observation, Wahid, (1984) suggested that pepper requires a hot tropical climate and is usually grown in low altitude, 0–500 meter above sea level (asl), preferably 0–100 meter asl. Optimum rainfall for growing pepper range from 2000 to 3000 mm with an average of 2300 mm per year. The number of rainy days is also important ranging

Table 4.2.1 Indication for Pepper Growing Areas in Indonesia.

Symbol	*Rainfall (mm/year)*	*Dm*[1)]	*Altitude (m asl.)*	*Estimation Rd.*[2)]	*Constraint*	*Suitability*
L.1.1	2000–2500	<2	<500	110–150	none	very suitable
L.1.2	2500–3000	<2	<500	115–160	none	very suitable
L.2	2000–3000	3	<500	110–160	none	suitable
L.3	3000–4000	<2	<500	145–190	too high rainfall	fairly suitable
L.4	1500–2000	3	<500	90–135	too dry	fairly suitable
L.5	1500–4000	4–5	<500	90–175	Periodically dry	less suitable
L.6.1	–	–	>500	–	low temperatrure	not recommended
L.6.2	<1500	–	–	–	water shortage	not recommended
L.6.3	>4500	–	–	–	too wet, lack of solar energy	not recommended
L.6.4	–	>5	–	–	too dry	not recommended

–Unidentified: asl.=above sea level 1) Dm: dry month (<60 mm-month) 2) Rd: rain day/year.
Source: Wahid and Suparman (1986).

from 150 to 210 days with an average of 177 days yearly without dry months when rainfall is less than 60 mm/month.

The ideal temperature is 23°–32°C with an average day temperature of 28°C. But pepper can still be grown under wider range of temperature i.e., 20°–34°C. Furthermore, daily temperature required is as follows: 21°–27°C in the morning, 26°–32°C in the afternoon and 24°–30°C in the evening. Optimum soil temperature for root growing is 26°–28°C. Table 4.2.1 shows some determinant variables of pepper growing. Based on such data, a number of maps showing areas which are very suitable for pepper growing have been made. Such maps are useful in supporting the government programmes of diversification of pepper industry into new areas.

Although pepper can grow in a wide range of soil, it is always recommended to plant pepper in suitable environments to ensure profits and to minimize risks caused by drought, diseases and pests. In Lampung for example, Central Lampung has better conditions than North Lampung, particularly in the rain fall point of view. Rainfall condition in North Lampung is more suitable for foot rot disease incidence; where as in Central Lampung sunlight is more intensive, so better plant growth, higher plant productivity and lesser disease incidence.

CULTURAL PRACTICES

Land Preparation

Pepper is cultivated as a monocrop on open land using dead or/and live standards, and almost all holdings are owned by small farmers, including in the main pepper areas of Lampung and South Sumatra provinces (Bangka Island).

As a small holding, pepper productivity is low, mainly because cultural practices adopted in all areas are still traditional with limited adoption of new technology and inputs. There is still considerable potential for increasing the productivity of pepper in Indonesia. The average national pepper production is less than one ton ha^{-1} and this can be increased to 3–4 tons ha^{-1} yr^{-1} by following the recommendations of pepper package technology made available by Research Institute of Spices and Medicinal crops (RISCM).

Land for growing of pepper need to be cleared from trees, shrubs, weeds, etc., and then it is cultivated either by ploughing or digging. The preparation of the land is considered very important, as in many cases crops are poor due to improper cultivation and preparation of the land. In many cases, farmers in West Kalimantan, Bangka and Lampung usually used their new open land for growing paddy for a couple of years before they are planted with pepper. Good land preparation will reduce the risks of pests and diseases that may originate from the previous vegetations such as rubber trees, forest trees, etc. But farmers are mostly poor and the only preparation they usually do is burning shrubs, weeds and plant debris under forest trees and digging planting holes. It is realised that such preparation will not produce good quality of land to support good crops.

Planting distance ranging from (2.0–3.0 m)×(2.0–3 m) is used depending on the pepper variety and type of standard used. For varieties with wide canopy such as *Kerinci, Belantung, Jambi, Bengkayang* and *Lampung Daun Lebar,* the planting space should not be less than 2.5×2.5 m, and when the varieties are planted with live standards, a wider space i.e. (2.5–3.0 m)×(3.0–3.0 m) is suggested. For varieties which have small canopy size, the planting space can be narrower i.e. 2.0×2.0 m for dead standard and 2.5×2.5 m for live standard.

Planting Material

The planting material used is cuttings from orthotropic shoots. These cuttings, of an average 5–7 internodes, are taken from selected healthy and good plants from orthotropic climbing branches. They are cut in such a way that the cuttings are not too old or too young, as old cuttings do not grow well, while the young ones usually produce weak and stunted plants.

Usually good quality cuttings or young plants are collected from nurseries available in or near planting area. Cutting or well developed young plants from nursery will give better chance for the small holders to get good crops. Single-node-cuttings are planted on a hygienic sand medium for 2–3 months in an isolated nursery. The cuttings may be taken from the fields or from certain plants designated for propagations in a nursery site. The advantage of this method is in the quality and cleanliness of the planting materials. Its disadvantage is higher cost and requires more skill compared to the conventional methods.

Theoretically, vegetative materials or cuttings can be obtained from any part of pepper stem. i.e. runner, hanging shoot, climbing shoot and lateral branch. However, different plant materials will produce different type of plants. Climbing shoot produce vigorous vine, stolon and runners produce lanky type of pepper vine and lateral branch produce bushy type of pepper. Cuttings obtained from climbing shoot will give vigorous plants and high number of lateral branches which enables the plants to be more productive. At present, the prospects of plants originated from lateral branches are being investigated in several locations. Prospects for its development is bright. The expected advantages are: easier to harvest, easier to spray, without inputs of standards, easier to cultivate, high population per unit area and lower cost of production. Wahid and Nuryani (1996) showed that plant spacing for bushy pepper could be 1×1.5 m which meant plant density of about 6600 plants ha^{-1}. Even with a productivity of 0.3 kg $planr^{-1}$, production per hectare achieved is more than 1.8 tons, which is not less than the productivity of normal pepper plants.

Planting

In the conventional planting of 5–7 node cuttings, 2–4 nodes are buried, while the rest remain above soil surface. The position of the cutting is not vertical, but semi-horizontal with an angle of 34–45° towards the standard. All newly planted cuttings must be shaded to protect from direct hot sun and strong wind, the shade must be kept untill the cuttings start growing vigorously, normally 3–6 weeks. The recommended holes for planting cuttings is 0.6×0.8×0.6 m in size, but farmers in major producing areas mostly use smaller hoes 0.3×0.4×0.3 m or 0.4×0.5×0.5 m.

Similar procedures are used for pre-rooted cuttings, except that they have better ability to withstand exposure to sunshine, although they still need light shading initially. Such planting materials are selected from the nursery, and only well rooted and will grown cuttings in polyethylene bags are transplanted to the field.

Climbing Standard

In Indonesia, two kinds of standard are used, live and dead. Live standards are trees such as: dadap, *Glyriddia,* kapok, etc., while dead standards are made of hard timber poles, like iron wood, seram, seru, mendora etc. Experiments suggest that concrete poles give poor growth and productivity. Live standards are mainly used by small holders in Lampung while dead ones are widely used in Bangka, East Kalimantan and West Kalimantan. Now due to high price and the difficulty of getting good timber poles, live standards are being increasingly introduced in Bangka and West Kalimantan.

Under normal conditions, well rooted cuttings begin to grow after about 25 days, when shades may be reduced. The cutting with new shoots are to be tied around the standard in such a way that the young plant stands upward. Best string is made of plant materials such as leaf sheath of banana, fibre of jute, hemp, etc. However string made of plastic material can also be used but not advisable, mainly because such materials are commonly too tight and often affect vine or branch development of the plants. Proper management will help the plants to produce adhering roots and firm attachment to standard. The process of tying should continue, to make sure that all nodes are attached properly to the standard.

Cultivation

Weeding

Holdings should be kept clean by continuous, regular and proper cultivation. Excessive weeds and other foreign materials in the holdings can affect the growth of main crops, besides that, badly cultivated holdings are congenial for development of certain insect pests and plant pathogens. Normally, the bigger the plants the slower the weed growth.

Pepper is susceptible to excess water and water logging may easily occur in an uncultivated garden. To maintain good condition and good rooting for the plant, mound around each stem is required and is maintained high enough to support the growth of the pepper root system. Regular weeding and mounding can be practiced by using simple agricultural tools like hoe, fork, etc., or even with bare hands because many kinds of weeds are easily pulled out. Using agricultural tools in cultivating the holdings, care must be taken, as some roots may be damaged and cause bad effect to the plants.

Fertilization

Fertilizer application should be given based on soil, climatic and plant conditions. Predominantly poor soils in pepper areas in Indonesia, especially in Bangka require heavy fertilization and mulching. Mulching is considered as prerequisite input for the success of the pepper industry in Bangka and in some parts of West Kalimantan. Experiments suggest that pepper cannot be grown productively without proper fertilizers and mulch. Although available data of fertilizer experiments are still limited for some pepper growing areas, basic principle can be obtained from soil analysis. The required composition of chemicals in soils for pepper growing is: 0.26 per cent N, 0.29 per cent P_2O_5, 0.41 per cent K_2O, 0.18 per cent MgO and 0.5 per cent CaO. There are usually about 1,750 plants in one hectare of land and they take up chemicals from the soils as high as 250 kg N, 31 kg P_2O_5, 224 kg K_2O, 67 kg CaO and 22 kg MgO. More details of the association of plant growth and mineral contents in pepper are given in Table 4.2.2.

The analysis of pepper fruits gave the following components: 2.27 per cent N,

Table 4.2.2 The condition of plant growth and mineral contents in leaves of pepper.

	Plant growth condition		
Elements	*Normal*	*Critical*	*Insufficient*
N (% dry material)	3.40–3.10	2.80–3.10	less than 2.70
P (% dry material)	0.18–0.16	0.14–0.10	less than 1.10
K (% dry material)	4.30–3.40	2.62–2.00	less than 2.00
Ca (% dry material)	1.68–1.66	1.20–1.00	less than 1.00
Mg (% dry material)	0.45–0.44	0.30–0.20	less than 0.20

0.0009 per cent P_2O_5, 1.58 per cent K_2O, 0.45 per cent CaO and 0.135 MgO. Based on the above data and some experimental results, technical recommendation for certain types of soils have been released through Directorate General of Estate Crops, Department of Agriculture. In Bangka, an agronomic experiment showed that the highest yield was gained from a treatment of 2400 g Rustica Blue Special (RBS) and 500 g dolomite per plant per year in four splits. Dolomite was given once together with the first application of RBS. The above dosage, equivalent to 290 g N (650 g Urea), 290 g P_2O_5 (670 g TSP) and 400 g K_2O (650 g ZK), was given to 3 year old or more productive plants. Recommendation for younger plants is 1/6 and 1/4 of the above dosage for one year and two years old respectively in three splits. All fertilizers must be applied during rainy season of the year.

DeWaard (1969) suggested the following recommendation for productive vines: 250 g N (550 g Urea), 360 g P_2O_5 (1000 g TSP), 150 g K_2O (250 g ZK) per plant per year. In Kerala (India) 220 g N (480 g Urea), 340 g P_2O_5 (940 g TSP) and 170 g K_2O (285 g MP) per plant per year, and in Sarawak (Malaysia) about 250 g RBS (2:12:17:2 of $N:P_2O_5:K_2O:MgO$) are recommended. Another source (Anonymous 1979) suggested a fertilizer composition of 12–14 per cent N, 10–12 per cent P_2O_5, 14–18 per cent K_2O and 2–4 per cent MgO with trace elements. The rate of application for mature vines of three to eight year is 1600 g per vine per year split into four applications over a period of 6 months from September to March during the rainy season. In addition to that 500 g dolomite should be applied one month prior to the first application of recommended fertilizer. Most farmers in Sarawak, Malaysia as well as in Bangka prefer to use compound fertilizer as mentioned earlier and the rate of application vary from farmers to farmers depending upon their financial position, price of pepper and the fertility of the soils. When the price of pepper is good some farmers in Bangka fertilized their crops 20 per cent higher than recommendation.

Table 4.2.3 also shows that the optimum rate of fertilizer used was 400 g $vine^{-1}$ per application, which is equivalent to 1600 g $vine^{-1}$ $year^{-1}$, split into four

Table 4.2.3 The effect of pruning of live standard and the rate of fertilizer on pepper production (green berries/vine) in Central Lampung.

	Rate of pruning			
*Fertilizer dosage**	*1 time (g/tree)*	*2 times (g/tree)*	*3 times (g/tree)*	*Average (g/tree)*
0	4.829	3.207	5.087	4.374
200	4.483	3.383	5.902	4.589
400	4.703	3.210	6.450	4.788
600	3.713	3.267	3.573	3.518
Average	4.432	3.267	5.253	4.317

* Compound fertilizer with composition of 12:12:17:2 each for N:P:K:Mg in the form of Urea, TSP, KCl and Kiserit, applied four times during rainy season.

Table 4.2.4 The average dry yield in dolomite and compound fertilizer trial on pepper (kg/12 vines).

Name of insect pests	*Integrated approach*
1. *L. piperis*	Cut and remove infected vines and possible weed hosts, spray with insecticide i.e., Sevin 85 S, Ambush 2 EC, Lebaycid 550 EC, Thiodan 35 EC, at 2–3 weeks intervals during the dry seasons.
2. *D. hewitti*	Cut and remove infected flowers and possible weed hosts and spray with: Agrothion 50 EC, Ambush 2 EC, Bayrusil 250 EC, Sevin 85 S, Thiodan 35 EC, etc. at 3 weeks interval during flowering and setting fruit period.
3. *D. piperis*	Remove infected berries, weeds and spray with insecticides (see *D. hewitti*) at 3–4 weeks interval during fruiting period.
4. *Pseudococus sp.*	Clean the insects off by hands or by spraying with insecticides i.e., Sevin 85 S, Hostathion 40 EC, Thiodan 35 EC, normally 3–4 times a year.

HSD of sub plot: p. 01=2.49.

applications. Experiments conducted in Bangka island suggested that fertilizer needed by pepper is much higher than that in Lampung, because of the very low fertility of the soil (Table 4.2.4). The yield increased linearly with the increase of the fertilizer rate up to 2400 g (N, P, K, Mg/12:12:17:2) vine^{-1} year^{-1}, given four times at equal rate, with an addition of 500 g Dolomite vine^{-1} year^{-1} (Wahid *et al.* 1987). The rate is almost similar to the rate of fertilizer suggested by Kueh (1979) in Sarawak, East Malaysia.

As already mentioned, the soils in Bangka is lacking in organic matter and for that reason application of mulch is considered essential. By applying mulch, the soil physical conditions improve, fertility of the soils and population or microorganisms and their activity in the soil increase, as a result plant growth and health improve accordingly. Christie (1959) found that mulch could improve soil texture and structure, produce organic matter and suppress the activities of parasitic nematodes in the soil. Wahid (1976) proved that using alang-alang *(Imperata cylindrica)* as mulch of 10–20 cm thickness reduces the yellows disease by as much as 18 per cent in Bangka and almost doubled the yield of pepper. The application of mulch on to the top of the soil should be done twice at early and before the end of dry season each year, depending on rainfall and thickness of mulch applied each time.

Pruning

To maintain the crops in good and productive condition, pruning of both pepper and standard is required. Pruning of vines is needed not only for maintaining them in standard height and form, but also to stimulate production of more productive branches. Good pruning would enable the plants to receive maximum energy from the sun-shine which is required for photosynthesis.

Regular pruning start at five months of age followed by 5–6 prunings once every three month had shown to increase the yield but it's still not yet been adopted by farmers. Farmers in Bangka only prune their vine once at one year of age in order to get planting material and to encourage the formation of lateral branches, and to replace temporary standard with the permanent one. In West Kalimantan, farmers usually give two prunings at eight and sixteen months after planting. Lampong farmers never prune their pepper vines and as a compensation they do mound layering of the shoots at 12 months in order to get a good canopy and higher productivity.

According to Wahid (1984), pepper grown under dense shades will not come into good bearing, because only small proportion of the solar energy required for photosynthesis reaches the plant canopy. Therefore, standards must be pruned in such a way that enough sunshine passes through to the plants underneath. He further found that the fertilizers will not be taken up, if pepper plants are completely shaded by their live support. Table 4.2.3 shows the effect of pruning of live standards on pepper production as against the effect of fertilizers. The rate of pruning can be as many as three time or less per year, depending on the type of live standard and climatic condition especially rainfall. However, it depends much on the financial condition of the farmers and the profits they gain from selling their produce.

Pest and diseases management

Annual crop losses caused by plant pest and diseases have always been a serious problem for pepper industry in Indonesia. The main insect pests that can cause serious losses are stem borer *Lophobaris piperis,* flower sucking insect

Table 4.2.5 Some integrated approach to control insect pests of pepper.

Name of insect pests	*Integrated approach*
1. *L. piperis*	Cut and remove infected vines and possible weed hosts, spray with insecticide i.e., Sevin 85 S, Ambush 2 EC, Lebaycid 550 EC, Thiodan 35 EC, at 2–3 weeks intervals during the dry seasons.
2. *D. hewitti*	Cut and remove infected flowers and possible weed hosts and spray with: Agrothion 50 EC, Ambush 2 EC, Bayrusil 250 EC, Sevin 85 S, Thiodan 35 EC, etc. at 3 weeks interval during flowering and setting fruit period.
3. *D. piperis*	Remove infected berries, weeds and spray with insecticides (see *D. hewitti*) at 3–4 weeks interval during fruiting period.
4. *Pseudococus sp.*	Clean the insects off by hands or by spraying with insecticides i.e., Sevin 85 S, Hostathion 40 EC, Thiodan 35 EC, normally 3–4 times a year.

(*Diplogomphus hewiti,* berry sucking insect *Dasynus piperis* and mealy bug *Pseudococcus*. The losses due to the insect pests may be reduced or prevented by an integrated approach that comprises sanitation, cultivation and spraying with insecticides (Table 4.2.5.)

L. piperis has become a serious pest in the past five years in several pepper holdings i.e. Bangka, West Kalimantan and South of Lampung Province. The damages often in combination with other insects and diseases are considerable.

Damage and death of plants caused by diseases are in many instances, more serious than the problems caused by insect pests. Two most dangerous diseases of pepper are *Phytophthora* foot rot and yellows disease.

Other diseases which are considered less economically important like stunted growth, leaf spots and flower and berry rots, with exception of the first one, can be successfully controlled by spraying with one of the following fungicides: Dithane M 45, Difolatan 4F, Vondozeb 70 WP at concentration of 0.2–0.3 per cent with a 2–3 week interval for two months during rainy season or fruiting and flowering stages.

Sanitation and quarantine law enforcement are required to help prevent the diseases from spreading and infecting new areas. The movement of agricultural tools and workers from infected areas to healthy ones often stimulate the of disease incidence (Sitepu and Wahid 1987).

Some varieties seem to show high degree of tolerance to certain leaf spot diseases, but its advantages have not been exploited. However, most farmers do not take good care to such problems because of various reasons.

Harvesting and Postharvest Technology

The quality of pepper depends much on the maturity, cleanliness, processing and handling. In general there are three activities responsible for improving quality and quantity of pepper products, i.e., (1) harvesting efficiency, (2) on farm processing and (3) post harvest technology.

In Indonesia, two kinds of pepper products are produced, white and black pepper. White pepper, is produced from ripe berries by separating them from skin (pericarp). The peeling is done by submerging the ripe berries in running water for about 10 days, depending on the size of container/bag used for that purpose. The water help the pericarp to rot. Then the berries are washed and rinsed in running water, dried under natural sun shine to produce white pepper. Processing for black pepper is much more simple. The berries are harvested at maturity, separated from their spikes and dried under sunshine or in a drier or room using artificial heat. Contamination in black pepper is higher than in white pepper, foreign particles and microorganisms in the pepper are always becoming serious problems. Studies, conducted by Hasanah (1985) in Lampung revealed that contaminations occur in all levels concerned in trading and pepper processing: small holders, middlemen, exporters/processors. To improve pepper products in their quality, efforts should be made to improve all operations from harvesting until exporting.

Harvest efficiency

Pepper should be harvested at right time and in proper manner, in order to get good products. The efficiency of harvesting is aimed at increasing volume and quality of harvest, decreasing labour costs and damages to plants, shortening periods of harvesting and maintaining vines in good condition.

Harvesting is done 4–5 time in every 1–2 weeks, because berries grow and become mature gradually depending on time of setting. During picking care should be taken not to damage vines and leaves. To fulfill the aims of efficient harvesting, the following aspects must be taken care of:

(1) Time of picking must be based on maturity and kinds of peppers produced, viz., white or black pepper. The maturity is based on the color of berry, dark and shiny green for black pepper and yellow or red berries for white pepper. Normally, to get that conditions, it takes 6 and 8 months for black and white pepper respectively
(2) Bamboo ladder is used to reach the top of vines. Problems occur in plants using live standards, as vines climb the tree up to the top. To get efficient work of harvesting vines should be pruned as low as possible (2–3 m high)
(3) To limit varieties in area, i.e. high productivity, responsive to fertilizers and organic matters
(4) Berries should be separated from spikes before they get dried up into black pepper
(5) For white pepper facilities for soaking and washing should not be too far from gardens.

Plantation Management

As almost all pepper plantings are undertaken by small holders, so the sizes of holdings are relatively small ranging from 0.2 to 1.5 ha. The average size is about 0.65 ha. In general the economic condition of the family is low, except for small number of holders and in certain periods of good prices and good harvest. There are two types of pepper plantings applied by small holders in Indonesia (1) extensive cultivation in Lampung and (2) fairly intensive one in Bangka, South Sumatra. In Lampung, pepper is planted under live standards and little inputs are given to the crop in terms of fertilization, cultivation, pest management, pruning- both pepper and poles, while situation in Bangka is better where pepper is grown on dead standards. The soil in Bangka is poor, lack organic content and very sandy, therefore fertilizers and mulch are regularly needed. In general, the features of pepper cultivation systems are part of traditional cultural practices including harvesting and processing of the products.

Some of the advantages of using dead standards are: (1) the use of dead standards produce firm attachment of the aerial roots, (2) no competition between vines and standards in terms of light, nutrient, water and CO_2, (3) no extra labor is required to prune and regulate growth of the support. However, the use of dead standards requires high cost, because of their high price. In Bangka, West and East Kalimantan, one pole might costs more than US$1.0 or more than US$2000 per hectare. Only a few farmers can manage to purchase such poles. Another problem concerning the dead standards is that good poles (iron wood) become rare and difficult to find in the above mentioned pepper areas.

On an average, there are about 2000 vines in a hectare of a land, with (2–21/2)×(2–21/3) m^2 of planting space. In the predominantly poor soil in Bangka, using dead standards may be suggested to plant more vines compared to that in Lampung. Experience shows that pepper cannot be grown successfully, particularly in Bangka, without inputs of fertilizers and organic matters. The applications of different fertilizers is reflected in the productivity of pepper. However, green manure such as cover crops is not commonly applied in pepper plantations. One of the reasons is the competition between vines and the cover crops, as cover crops overgrow the pepper and need extra labour cost. The source of the organic matter in Bangka is mainly from mulch of shrubs, alang-alang, ferns, debris, etc.

Clean weeding and planting on mound in a systematic pattern with remounding with fresh soil and proper pruning are necessary in pepper planting. Unfortunately these cultural practices are not well adopted by small holders. Therefore, the productivity of pepper in Indonesia (which, at present, ranged from 850 kg in Lampung to 2500 kg/ha in Bangka), can still be increased to 3 to 4 tons per hectare by adopting proper agricultural practices. Weeds for example are not properly removed in most small holdings.

Crop losses due to diseases and insect pests are always serious problems to the pepper industry in Indonesia. Particularly in certain areas and seasons many pathogens and insect pests cause severe damage and loss to productive plants. Two major diseases are foot rot and yellows disease as has been mentioned earlier. Other diseases caused by *Fusarium* sp., *Pythium* sp., *Cephalosporium* sp., *Colletotrichum* sp., *Corticium* sp., *Rhizoctonia* sp., etc., are usually not considered dangerous to the plant productivity. In some cases they may disturb the young cuttings in the nursery, but in general they are less serious problems.

To manage all the pathogens and insect pests, an integrated control measure is recommended. Most of the farmers carry out blanket spraying of insecticides and fungicides during the rainy seasons as well as during flowering and fruit setting periods, combined with other measures such as clearing of the infected vines, making isolation drain, disinfecting used materials or tools and applying fertilizers and mulch. The combination of cultural and chemical methods gave better result of the control of diseases and pests of pepper. Proper management is needed in achieving such a result.

It is also observed that centres of production of pepper seemed to move from one area to another, it could be outside a provinces or inside a province. Three major factors are considered as the reasons for such changes namely: (1) the decline of soil fertility, which was the main reason of the movement of pepper plantation from one to another in Bangka (2) the damage due to diseases and insect pests as happened in

Lampung, and (3) the combination of the two and some non-technical reasons (price fluctuation, preference to other crops etc.)

It is now realized that in future the contribution of Lampung as main producer of back pepper may decrease. In the 1970s Lampung shared more than 70 per cent of the whole national production while in the last few years the production dropped to less than 50 per cent. New potential pepper producing areas, such as South Sulawesi, West and East Kalimantan, etc. started to give significant contribution to the national pepper industry. Even from productivity point of view, East Kalimantan has highest productivity and hence is more suitable compared to other areas.

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5.1. DISEASES OF BLACK PEPPER

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Black pepper is affected by several diseases caused by fungi, bacteria, virus and mycoplasma, besides nutritional disorders. Crop losses due to diseases and pests are identified as major causes of low productivity of pepper in India (Sarma and Anandaraj 1997). The earliest record of diseases of pepper in India was that of Barber (1903, 1905). Butler (1906) also recorded the death of pepper and Rao (1929) isolated *Phytophthora* from diseased pepper, but the etiology remained inconclusive. Ridley (1912) referred to three important diseases of pepper namely, canker, hyphae in vessels and wilt. The cause of wilt was not confirmed but assumed to be due to fungi such as *Nectria, Cephalosporium and Fusarium*. Menon (1949), while reviewing the diseases of pepper, reported that stump rot was due to *Rosellinia bunodes, "pollu"* disease caused by *Colletotrichum* sp. and root disease or wilt due to an unknown pathogen. From the diseased plants *Nectria* sp. was recorded, but pathogenicity was not proved. Crop losses caused by diseases are a major production constraints in all pepper producing countries. In Brazil root rot and stem blight caused by *Fusarium solani* f. sp. *piperis* and the mosaic disease caused by cucumber mosaic virus are the major diseases (Duarte and Albuquerque 1991), whereas, in India, Indonesia and Malaysia *Phytophthora* foot rot is the major disease (Sarma *et al* 1992c, Holliday and Mowat 1963, Kueh and Sim 1992d, Manohara *et al.* 1992). Other diseases include slow decline, anthracnose, viral diseases which are referred to as stunted disease (Sarma *et al.* 1991), stunted growth (Sitepu and Kasim 1991) and wrinkled leaf disease (Kueh and Sim 1992b). In India, although wilt disease was the major disease causing death of plants, *Phytophthora* as the causal organism was reported only in 1966 by Samraj and Jose. Several diseases were recorded subsequently and now 17 diseases are known to affect pepper (Sarma *et al.* 1991).The diseases of pepper are reviewed recently (Sarma *et al.* 1991, 1994, Anandaraj and Sarma 1995). Among these diseases, *Phytophthora* foot rot, slow decline which were previously referred to as "quick wilt" and "slow wilt" respectively (Nambiar and Sarma 1977, Nambiar 1978, Das and Cheeran 1986), anthracnose and stunted disease cause severe crop losses. *Phytophthora capsici* occur both in the nursery as well as in the main field affecting all parts of the plant while others are confined to specific plant parts. Based on the severity of crop losses caused, pepper diseases are classified into major and minor diseases. The major diseases are treated here with greater details.

MAJOR DISEASES

Phytopbthora Diseases in Pepper

Phytophthora capsici occurs on all parts of the plant and cause severe economic damage. The symptom expression depends upon site of infection and extent of damage (Mammootty 1978, Anandaraj and Sarma 1995). *Phytophthora* infections in pepper is broadly classified into aerial and soil infections. Aerial infection occurs on the runner shoots, foliage, spikes and branches causing blight, spike shedding, defoliation and die back and at times death of plants. Infection on the runner shoots often reach the collar causing foot rot.

Symptoms of foliar infection

On leaves one to many dark spots having characteristic fimbriate advancing margins occur, which later coalesce leading to defoliation even before the lesions spread to the entire lamina. Infections on runner shoots (stolons) that arise at the base of the vines and trail on the ground occur both on the tender leaves and shoots. The fungus sporulates abundantly forming a white covering on the blighted tender shoot. Infection on tender shoots upon reaching the stem, cause, collar infection and sudden wilting of plant. Infection on spikes causes blackening of developing fruits and peduncle. Infection can start on any part of the spike and in due course affected spikes are shed. Infection on branches causes drying and defoliation (Fig. 5.1.1). In Brazil, *Fusarium* infection on pepper is severe and occur both on stem and root. Infection of root results in destruction of feeder roots leading to flaccidity, yellowing and defoliation. Stem infection results in yellowing and blighting of stem and complete death of plants (Duarte and Albuquerque 1991).

Symptoms on roots and collar

Infection on below ground parts such as roots and collar is fatal. Infections of feeder roots causes their rotting and degeneration resulting in yellowing, defoliation and drying up of plants. Feeder root infection reaches the collar through main roots and causes foot rot (Anandaraj *et al.* 1994). Pepper being vegetatively propagated, roots arise at each node of the main stem which remain below the soil. If the infection reaches the collar, either through the runner shoots or through the roots closer to the soil level, plants show only wilting symptoms, whereas, infection reaching the collar through roots of the lower nodes leads to yellowing and defoliation before succumbing to the infection. Such plants may remain alive for 2–3 years (Anandaraj 1997).

Etiology of Phytophthora foot rot

Foot rot results in sudden wilting and death of plants and hence the disease was previously referred to as either “quick wilt” or “wilt’, and the causal organism was

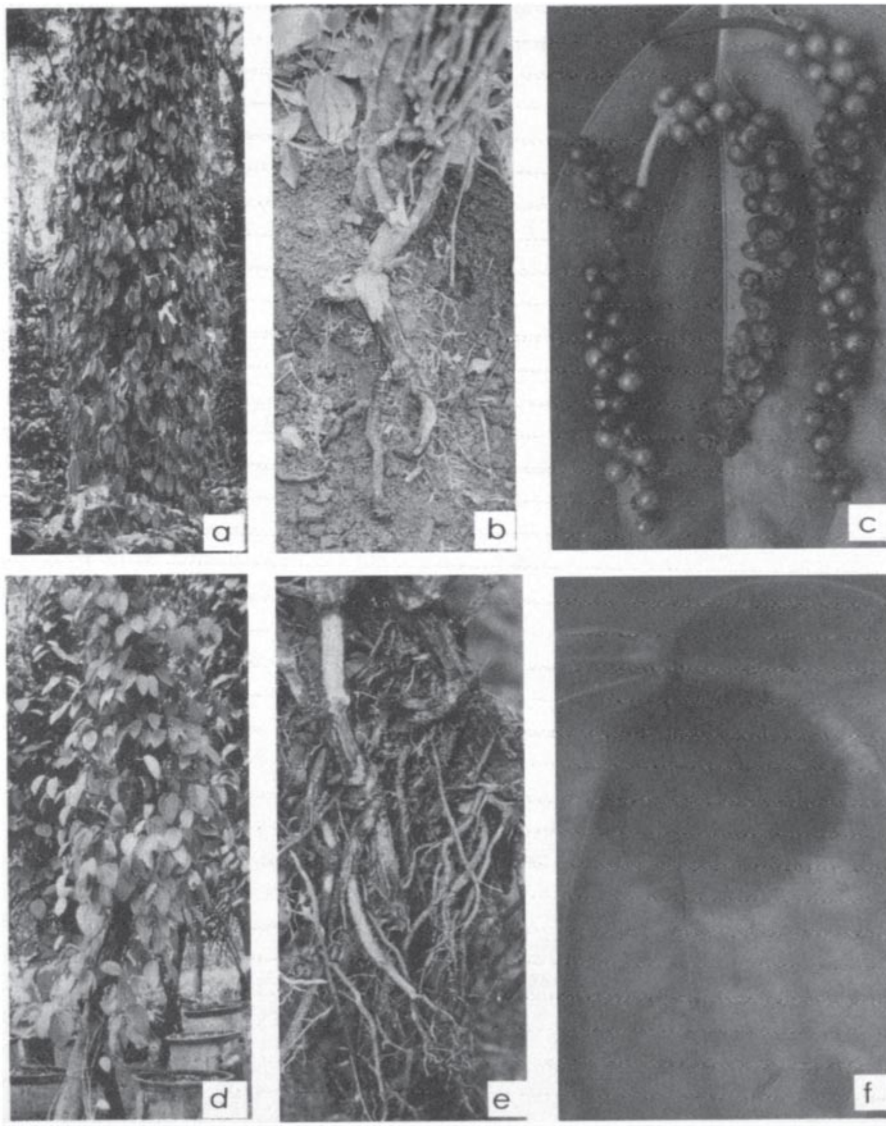


Figure 5.1.1 Symptoms due to *Phytophthora capsici* infection on black pepper

a. A wilting pepper vine due to collar rot
b. Infection of upper tier of roots culminating in collar rot
c. Infection on spikes
d. Foliar yellowing caused by root rot
e. Infection on feeder roots spreading to main roots and collar
f. Leaf spot showing fimbriate margins at the advancing edge of lesion

identified as *Phytophthora palmivora* var *piperis* (Samraj and Jose 1966), *P. palmivora* (Holliday and Mowat 1963, Manmohandas and Abicheeran 1985, Nambiar 1978, Nambiar and Sarma 1977, Sarma and Nambiar 1982, Sarma *et al.* 1982, Nambiar *et al.* 1978), *P. palmivora* MF_4 (Ramachandran *et al.* 1986, Sastry 1982, Sastry and Hegde 1982a, 1982b, 1987a, 1987b, 1991). Foot rot resulting from root infection takes a longer time to kill the affected plants and they remain in the field showing declining symptoms. A method to index the level of infection based on foliar symptoms has been developed (Abraham *et al.* 1996).

Identity of the pathogen

Phytophthora isolates from infected pepper plants when cultured on carrot agar, incubated for 72 h in dark followed by incubation of culture discs of 1 cm in Petri's mineral solution under fluorescent light for 24 h lead to abundant sporulation. The sporangial ontogeny is umbellate with caducous sporangia. Sporangia are borne on long stalks which were ellipsoidal with tapering base, obvoid or fusiform and with a clear papilla. The mean L×B is 24.6×16.34 μm, the L×B ratio 2.0–2.05 in 58.5 per cent of sporangia and 1.5–1.8 in the remaining. Based on the sporangial characters, the isolates from foot rot affected pepper plantations are identified as *Phytophthora palmivora* MF_4 (Sarma *et al.* 1982, Tsao *et al.* 1985, Tsao and Alizadeh 1988, Manohara and Sato 1992). In Johore region of Malaysia, *P. parasitica* var *nicotianae* and *P. botryosa* are reported to cause sudden wilt of pepper (Varughese and Anuar 1992).

Isolation from soil

P. palmivora MF_4 from pepper can be isolated from soil and plant tissues using selective media. Among the selective media tried, PVPH medium (Tsao and Guy 1977) is found to be the best. Direct isolation from soil is not successful always, but, pepper leaf (Kueh and Khew 1982) or pepper leaf discs (Ramachandran *et al.* 1986) are good baits. The fungus could be isolated by using castor seeds as baits (Sastry and Hegde 1987a, 1987b). *Albizia falcataria* leaflets when used as baits, the fungus sporulate on the baits facilitating confirmation of positive baiting by direct observation of infected baits and this could be brought into pure culture by plating on selective medium (Anandaraj and Sarma 1990). This technique is also adopted for assaying chemicals applied to soil to control *Phytophthora* foot rot (Anandaraj and Sarma 1991).

Biology of the pathogen

Growth was studied on potato dextrose agar (PDA), cornmeal agar and oats agar. The effect of temperature on the growth of the fungus was studied at 10°C–35°C. Growth was least at 10°C (6 mm) and abundant at 24°C (46 mm) after 72 h and there was no growth at 35°C. Pepper isolates are heterothallic and oospores are produced when pepper isolates are paired with isolates from cocoa and rubber (Sarma and Nambiar 1982). Oospores are produced when compatible types are inoculated on pepper and incubated in dark at 20°C and also in the presence of *Trichoderma viride* but, oospores are not produced at 30°C (Brasier 1969, 1978). The production of toxin was studied by culturing the fungus in Bartnicki-Garcia's liquid medium (Ribeiro 1978). Cell free culture filtrate from pepper isolates are reported to cause vascular browning and flaccidity of leaves in bioassay (Sarma and Nambiar 1982).

Taxonomy of pepper Phytophthora

The foot rot pathogen of pepper *Phytophthora,* has been referred to as *P. palmivora* in the literature (Holliday and Mowat 1963, Kueh 1979, Nambiar and Sarma 1977, Sarma and Nambiar 1982). As the isolates are different from the typical *P. palmivora,* it was called as an atypical *P. palmivora* (Waterhouse 1974), and was named *P. palmivora* MF_4 in the revised tabular key by Stamps *et al.* (1990). Most *Phytophthora* isolates from pepper have an umbellate sporangial ontogeny with long caducous sporangia resembling that of *P. capsici* (Tsao *et al.* 1985). After detailed morphological and biochemical studies, *P. palmivora* MF_4 was merged with *P. capsici* as most isolates from pepper resembled *P. capsici*. The species was redescribed (Tsao and Alizadeh 1988, Tsao 1991) and is currently named *P. capsici*. *Phytophthora* isolates from pepper from Indonesia belong to both A1 and A2 mating types (Kasim and Prayitno 1979, Manohara and Sato 1992, Bandra *et al.* 1985). In India, during the International Pepper Community Workshop in Goa, it was decided to refer this disease as *Phytophthora* foot rot and the organism as *P. capsici* (Nair and Sarma 1988). Since then extensive biochemical studies of *P. capsici* collected from all over the world have revealed the presence of three electrophoretic types Cap1, Cap2 and Cap3 (Oudemans and Coffey 1991). Based on analysis of 113 isolates of *P. capsici* for morphological, physiological and isozyme data for 18 loci for 15 enzymes, two sub groups CapA and CapB were recognized. Indian isolates from pepper have been reported to belong to both sub groups (Mchau and Coffey 1995). Holliday (1998) in his Dictionary of Plant Pathology (2nd edition) designated it as *P. capsici* f. sp. *piperis,* as this only attacks *Piper* and therefore differs from the f. sp. *capsici* which is mainly on *Capsicum* but has a much wider host range.

Crop loss

In India, pepper is traditionally grown in the Western Ghats, in the states of Kerala, Karnataka and Tamilnadu, recently it is introduced to non-traditional areas of Andhra pradesh and North Eastern States. Foot rot has been reported from the introduced areas such as Tripura (Sarkar *et al.* 1985). The crop losses due to foot rot of pepper is reported to range up to 30 per cent (Samraj and Jose 1966, Nambiar and Sarma 1977). Crop loss surveys conducted during 1982–1986 in two major pepper growing districts of Kerala (Calicut and Cannanore) has shown that 3.4 per cent and 9.4 per cent of the plants respectively are lost annually amounting to a corresponding production loss of 118 and 904 tons (Balakrishnan *et al.* 1986, Anandaraj *et al.* 1989a, 1989b). Every year farmers replant to compensate for the loss of plants, not only due to disease but also due to drought. The annual crop-loss due to foot rot in Cannanore district of Kerala remains the same as indicated by the recent survey report, with an estimated loss of 9.2 per cent (Prabhakaran 1995). Foot rot takes a heavy toll in all pepper growing countries and 5–10 per cent loss has been reported in Malaysia and up to 95 per cent loss in individual gardens (Kueh and Sim 1992a), similar situation prevails in India also.

Spatial pattern of foot rot spread

Nambiar and Sarma (1982) studied the pattern of spread of foot rot disease within a garden over a period of six years and found that the disease spread is in centrifugal pattern from the source of inoculum. The initial occurrence and subsequent spread of foot rot was monitored over a two year period in a pepper plantation at Indian Institute of Spices Research farm, Peruvannamuzhi and the data were analysed using Spatiotemporal distance class analysis developed by Nelson (1995a, 1995b). The analysis indicated that both initial occurrence and subsequent spread followed a strictly non-random pattern and the infection clustered around the previously infected plants (Anandaraj 1997) suggesting the role of initial infection serving as the source and focus of subsequent spread (Zadocks and Van den Bosch 1994). The root infection culminating in foot rot has a long incubation time and takes nearly 2–3 rainy seasons. During this time the infected plants remaining in the gardens with decline symptoms serve as a source of inoculum for subsequent spread. The foliar infection spreads within the bush through rain splashes from the lower portions to upper portions, whereas, spread to the adjacent plants is through both rain splashes and also through wind blown water droplets (CPCRI 1986, Ramachandran *et al.* 1988c).

Influence of weather on disease incidence

Aerial infection results in defoliation and in severe cases death of plants. The spread is dependent on the prevalence of favourable weather. The occurrence and spread of foliar infection was studied in an arecanut-pepper mixed cropping system and correlated with the weather factors. A combination of factors such as daily rainfall of 15.8–23.0 mm, temperature range of 22.7–29.6°C, relative humidity of 81–99 per cent and sunshine 2.8–3.5 h /day favour the spread of aerial infection (Ramachandran *et al.* 1988c, 1990). In the soil phase, the pathogen activity is confined to the wet monsoon period and depend upon the availability of soil moisture (Anandaraj 1997). The onset of monsoon season also triggers the growth of pepper plants through production of new foliage and roots, maximum being in July when the South West monsoon is at its peak. The weather conditions during monsoon along with high soil moisture (>25%), temperature ranging from 22–29°C, relative humidity >80 per cent, are favourable for rapid multiplication of the fungus

(Anandaraj 1997). Attempts were also made to correlate the occurrence of *Phytophthora* foot rot with the weather conditions (Nair *et al.* 1988, Mammotty *et al.* 1991). Since root rot culminating in foot rot has a very long incubation period, correlation of weather factors recorded at the time of observing foliar symptoms may not be a correct indication of the weather requirements for disease development.

Role of weather on the growth of pepper plants

Pepper plants being perennial, the growth also depends upon the availability of soil moisture. The production of new foliage was monitored in two cultivars of pepper, *Karimunda* and *Panniyur* 1, by tagging the fruiting lateral branches and counting the new leaves. Highest leaf production occurred in July in both the cultivars (Fig. 5.1.2).

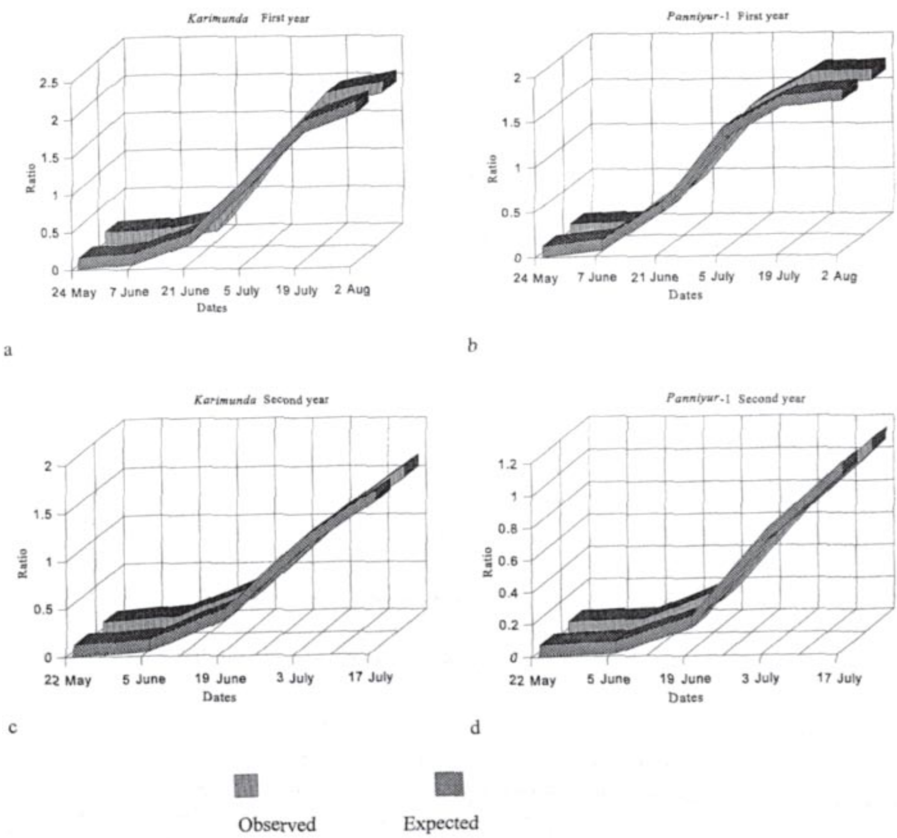
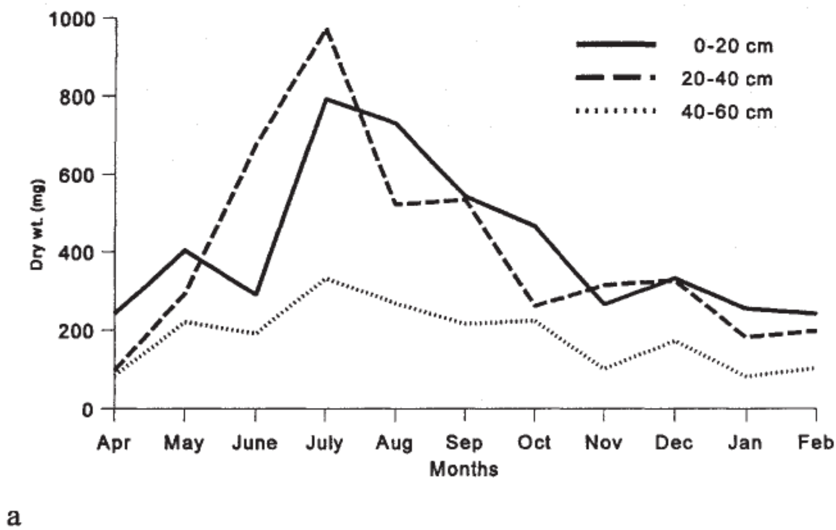


Figure 5.1.2. Proportion of new leaves to old leaves observed and expected for two-year period.

a) *Karimunda* first year b) *Panniyur*-1 first year

c) *Karimunda* second year d) *Panniyur*-1 second year



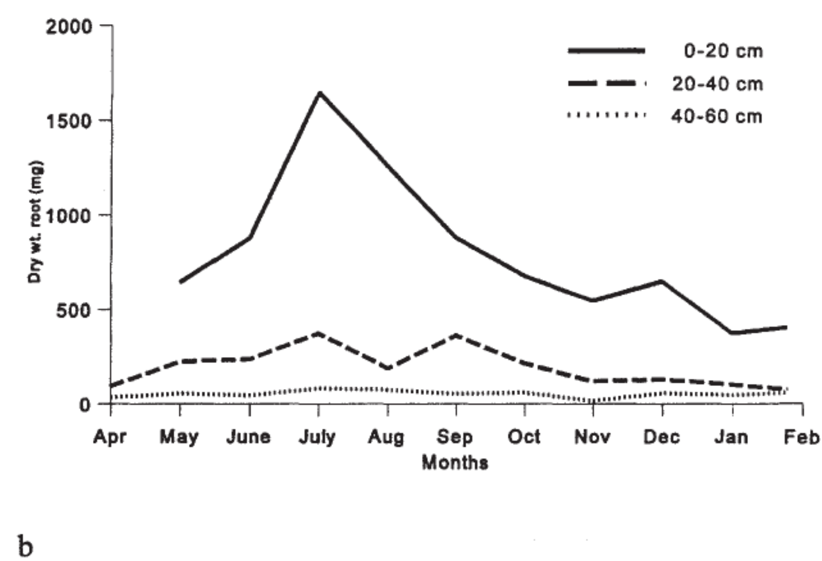


Figure 5.1.3 Feeder root production in pepper.
a) At three distances b) At three depths

Feeder root production was estimated by soil core method by collecting soil cores at 20, 40 and 60 cm away from the base of the vine and at 20, 40 and 60 cm depth at each distance at monthly intervals. Highest feeder root production was in July and the feeder roots were concentrated at 0–40 cm from the base of the vine upto 40 cm depth (Fig. 5.1.3). A similar pattern of feeder root concentration was reported from Indonesia. Ipor *et al.* (1993), while studying root architecture of pepper in Indonesia, recorded 63.8 per cent of feeder roots in the top 0–50 cm. Thus, production of the most susceptible tender tissues, both foliage and feeder roots, occur at the peak monsoon season (Anandaraj 1997). The wet monsoon season in India, not only activate the pathogen but also affects the growth of the host plant. Growth of host indirectly influence the pathogen by the increased root exudation and availability of more susceptible tissues for colonization.

Survival

In the soil phase contaminated soil is the main source of inoculum. The inoculum survives in the soil up to 19 months in the absence of host plant (Kueh and Khew 1982, CPCRI 1986). The soil inoculum was monitored by Ramachandran *et al.* (1986) in a pepper plantation by collecting soil samples at various depths and distance from the infected vine. The study has shown that the pathogen was concentrated on the surface 0–30 cm and it gets reduced as the distance and depth increase from the source of diseased plant. The main survival structures of *P. capsici* in the soil are chlamydospores and thickened mycelium (Anandaraj 1997). Soil moisture was found to have a positive correlation on the activity of the fungus in soil. *P. capsici* has a low competitive saprophytic ability, hence addition of organic amendments to soil promotes growth of saprophytic organisms which in turn reduce the populations of *P. capsici* (Anandaraj 1997). Production of oospores under laboratory conditions and their possible role in the disease have been suggested (Sastry 1982, Sastry and Hegde 1987a, 1987b, 1988, Santhakumari 1987). *Trichoderma viride* stimulate oospore formation and also when two compatible types are inoculated on to pepper (Brasier 1969, 1978, 1991). However, oospores as resting structures in infected plant tissues has not been recorded from India. Oospores as survival structures have been recorded in Sarawak and were found to be viable after passing through the alimentary canal of snail (Kueh and Khew 1982). A technique for germinating the oospores of *Phytophthora* by passing the oospores through the guts of snail has been suggested (Dutta *et al.* 1984).

Disease resistance

Screening the germplasm of pepper is done adopting stem and root inoculation techniques (Nambiar and Sarma 1979, Sarma *et al.* 1994). Root inoculation is done by dipping the root system in zoospore suspension while the stem inoculation consists of inoculating the fungus at the third internode of a pepper cutting with 4–5 leaves. The fungus, in the form of 5 mm diameter mycelial disc cut from the edge of a 48 h old culture, is placed at the third internode with a pin prick and covered with moist cotton wad and incubated in humid chamber. Observations are recorded after 72 h on the lesion size and depth of penetration. The lesion size range from 5 mm–120 mm, and depth of penetration can confine to surface or can lead to the rotting of the entire internode. After 72 h of incubation under humid conditions, those cuttings showing lesion size of less than 5 mm and penetration restricted to the surface are rated as tolerant and preserved for future work. In India, all the cultivated germplasm are susceptible to this disease. Among the cultivars, *Narayakkodi, Kalluvally, Balankotta, Neelamundi, Mundi* and *Uthirankotta* have been identified as tolerant (Sarma and Anandaraj 1997). Among other taxa, *Piper colubrinum,* a distant South American species, is highly resistant to *P. capsici*. Several open pollinated progenies of *Perambramundi, Kalluvally Cholamundi* and hybrids involving *Panniyur* 1×*Karimunda,* and *Narayakkodi*×*Neelamundi* have recorded tolerant reaction (Sarma *et al.* 1994). In Malaysia, *Cheriakaniakadan* and *Balankotta* were less susceptible than *Kuching*. Whereas in Indonesia cvs. *Kalluvally, Palau Lauta, Belantung, Bangka, Natar I, Merefin, Banjarmasin* and *Duanteber* were rated as less susceptible (Sitepu and Kasim 1991, Manohara *et al.* 1992). In India, currently, researches are directed to understand the mechanism of tolerance to *P. capsici*. Among the biochemical parameters, the ratio of total phenols to orthodihydroxy phenol (OD phenols) was higher in susceptible cultivars than in tolerant cultivars. Higher peroxidase activity was recorded in *P. hirsutum,* a *Phytophthora* resistant line, and low levels in *Daun Leber,* a susceptible cultivar (Rahayuningsih 1990). Regeneration protocol for pepper has already been developed so as to attempt biotechnological methods for transferring resistance to the cultivated varieties (Shaji *et al.* 1995a, 1995b, 1996, Sarma *et al.* 1996).

Disease Management

An integrated disease management involving cultural, chemical and biological control is recommended (Ramachandran *et al.* 1991, Sarma *et al.* 1988, 1992b, Anandaraj and Sarma 1995, Sarma and Anandaraj 1997).

Cultural control

Provision of drainage: Population build-up of *P. capsici* is dependent on weather and is positively correlated with soil moisture (Anandaraj 1997). High precipitation during rainy season leads to water logged conditions. Such conditions predispose plants to *Phytophthora* infections. During water stagnation, temporary anaerobic conditions result in low oxygen and together with increased root exudation stimulates germination and growth of pathogen propagules. Such conditions enhance host susceptibility due to decreased production of phenol oxidases, reduced phytoalexin production, suppression of mycorrhiza and reduction in nitrogen fixation (Drew and Lynch 1980). Thus adequate drainage is essential to reduce the population build-up of *P. capsici* and subsequent infection of pepper plants.

Phytosanitation

Pepper *Phytophthora* is reported to survive up to 19 months in plant debris. The initial occurrence and spread of the disease is also non-random and tend to cluster around the previously infected plants (Anandaraj 1997), hence the infected plants serve as the foci of infection (Zadocks and van den Bosch 1994). Removal of infected plants would reduce the inoculum level and spread of the fungus.

Shade regulation

Pepper is trailed on live supports like *Erythrina indica, Garuga pinnata, Glyricidia sepium* etc. During monsoon season the canopies of the support trees also grow and generate a microclimate under their canopies with high humidity and low temperature, which is ideal for *P. capsici* to multiply and infect. Lopping of the branches during rainy season is essential to facilitate penetration of sunlight and reduction of high humidity thereby altering the microclimate. The lopped branches could be used as mulch to prevent soil splashes.

Cover crops

The main source of initial inoculum of *P. capsici* in pepper plantation is the contaminated soil. Infection on the foliage occurs through soil splashes often initially to the tender shoots trailing on the ground, and from these shoots to other parts of the canopy through rain splashes (Ramachandran *et al.* 1990). To prevent soil splashes live mulch in the form of legume and grass cover are suggested (Ramachandran *et al.* 1991, Sarma *et al.* 1992c). But, recent studies have shown that population of *P. capsici* increases under weed cover and death of plants is faster with weeds than without weeds (Anandaraj 1997). Although weed cover reduces soil splashes and restrict movement of propagules along with soil, it also supports the population build-up of *P. capsici*. In Malaysia, studies with *Desmodium trifolium* as cover crop for pepper has indicated that plants showed faster and better growth in clean weeded plot than with cover crop and concluded that it was economical to grow pepper in clean weeded plot (Ahmed 1993). In India, after the monsoon, there is a prolonged drought from November to May. During this period weeds compete for soil moisture and the population of *P. capsici* also survives longer. Hence, after the rainy season it is better to remove the weeds in pepper plantations and rake up the top soil. Removing weeds and turning the top soil would help to conserve soil moisture, as the capillary pores are broken (Brady 1984, Russell 1973) and soil moisture removal by weeds during summer is also reduced. Once weeds are removed the saprophytic survival of *P. capsici* on weeds would also be reduced. In view of this, a post monsoon clean cultivation is suggested (Anandaraj 1997). Root exudates of some of the plants such as *Allium* spp. are inhibitory to zoospores of *Phytophthora* (Manohara *et al.* 1992). Aqueous extracts of *P. colubrinum, Azadirachta indica, Strychnos nuxvomica, Lantana camera* extract and *Chromolaena odorata (Eupatorium)* were tried on *P. capsici* and *C. odorata* extract was found toxic to *P. capsici* (Anandaraj and Leela 1996). Mulching with this plant has been reported to increase the yield in Cambodia (Litzenberge and Lip 1961). Although the mulching was done to reduce the nematode infestation on pepper, there was no reduction in the nematode population but recovery of plants have been reported.

Chemical control

Although the disease occurs every year during rainy season, a fixed fungicide scheduling is advocated against both aerial infection and collar infection. The control measures include: spraying of Bordeaux mixture 1 per cent (BM), pasting the collar with BM and drenching the basins with either BM or with copper oxychloride (Ramachandran *et al.* 1991, Sasikumaran *et al.* 1981, Nair and Sasikumaran 1991, Malebennur *et al.* 1991, Lokesh and Gangadarappa 1995). Based on the epidemiological studies and nature of occurrence of collar infection, the practice of pasting the collar with Bordeaux mixture is discouraged (Anandaraj *et al.* 1994, 1996a, 1996b, Sarma *et al.* 1992c). Among the systemic fungicides, several formulations of metalaxyl such as Ridomil granules and Ridomil-ziram have been reported to be effective against foot rot of pepper (Ramachandran and Sarma 1985, Ramachandran 1990, Ramachandran *et al.* 1988b, 1991, Sarma *et al.* 1992c, Kueh and Sim 1992a, Kueh *et al.* 1993). In experiments with granular formulations of Metalaxyl, Ridomil 5G at 50 g per plant gave protection up to seven weeks and granular formulations were better than foliar spray (Kueh *et al.* 1992, 1993). However, owing to the cost of systemic fungicides and the poor socioeconomic conditions farmers seldom use them. While reviewing the control of four soil-borne *Phytophthora* diseases, doubts about the success of chemical control of *Phytophthora* foot rot was expressed by Coffey (1991). Studies with various concentrations and frequency of application revealed that it is safe to apply the chemical six months prior to harvest to prevent the traces of metalaxyl residues in the final product (Sarma *et al.* 1992c).

Use of beneficial microorganisms

Several beneficial organisms like vesicular arbuscular mycorrhizae (VAM) are associated with pepper (Ramesh 1982, Manjunath and Bagyaraj 1982). Incorporation of VAM alone or in combination with other beneficial microorganisms like *Azotobacter* and *Azospirillum* enhance rooting and growth of pepper (Govindan and Chandy 1985, Bopaiah and Khader 1989). VAM inoculation has been found to enhance rooting, growth and suppress root damage caused by *P. capsici, R. similis* and *M. incognita* under artificial inoculation and under field conditions (Anandaraj and Sarma 1994a, Anandaraj *et al.* 1991a, 1991b, 1996c, Sivaprasad *et al.* 1990a, 1990b, 1995). Occurrence VAM has been a rule rather than an exception in crop plants (Harley 1989). Colonization of mycorrhiza alters the nature of root exudate and the rhizosphere microflora due to the influence of mycorrhizosphere effect (Dehne 1982, Linderman 1988, Graham 1982,1988).VAM fungi have been reported to suppress the root rot caused by *Phytophthora* in citrus (Davis and Menge 1981, Davis *et al.* 1978, 1980). VAM fungi not only enhance growth but also suppresses diseases caused by soilborne pathogens (Ewald 1991, Graham and Egel 1988). Colonization by VAM is described as a prelude to biological control. Realizing the importance of this, incorporation of VAM in the nursery is recommended both for enhancing growth and suppressing root infection (Sarma *et al.* 1996).

Organic amendments

Organic matter such as neem oil cake (Sadanandan *et al.* 1992, Nair *et al.* 1993) soyabean meal, ground nut cake, coconut cake and chicken manure are added to the soil to supplement nutrition and enhance the growth of saprophytes (Kueh and Sim 1992a). In soils amended with organic matter the saprophytic activity is enhanced and *P. capsici* population drops to undetectable levels (Anandaraj 1997).

Biological control

Soil borne pathogens are amenable to biological control (Cook and Baker 1983). In the rhizosphere of pepper several antagonistic microorganisms belonging to *Trichoderma* and *Gliocladium* occur (Dutta 1984, Anandaraj and Sarma 1994b, Anandaraj and Peter 1996). *P. capsici* being soilborne, and the main source of inoculum is contaminated soil, growth of antagonistic fungi would prevent the population build up. The competitive saprophytic ability of *P. capsici* is very low and addition of organic matter to the soil containing *P. capsici* promotes the growth of saprophytes and reduces the population of *P. capsici* (Anandaraj 1997). Several strains of biological control agents effective in protecting pepper against *P. capsici* have been isolated, screened and mass multiplied on inexpensive carrier media and applied in the field with promising results (Anandaraj and Sarma 1995, Sarma *et al.* 1996). Mature coconut water, which is an agricultural waste, supports good growth of *Trichoderma* and *Gliocladium* and could be used for the mass multiplication of these antagonistic fungi (Anandaraj and Sarma 1997).

Thus integrated control involving phytosanitation, cultural, chemical and biological controls are being followed to check *Phytophthora* infections in pepper (Ramachandran *et al.* 1988a). Attempts are also being made to incorporate resistance in the cultivars by adopting biotechnological means. For this the necessary regeneration protocols have already been developed (Shaji *et al.* 1995a, 1995b, 1996).

Fusarium Wilt of Pepper

In Brazil, the major disease that is creating havoc to pepper cultivation is the *Fusarium* wilt, and this disease is causing severe losses in that country (Duarte and Albuquerque 1991).

Root rot and stem blight

The symptoms of *Fusarium* infection is root rot leading to flaccidity and yellowing of foliage. The affected plants are killed within a short period. The organism is identified as *Fusarium solani* f. sp. *piperis*. The perfect stage has been identified as *Nectria haematococca* f. sp. *piperis*. In affected plants the fungus produces abundant perithecia. *Fusarium* infection in plantation is reported to reduce the economic life of plantation from 20 to 6–8 years and the productivity per plant from 3.0–1.5 kg (Duarte and Albuquerque 1991).

Disease management

Phytosanitary measures like removing infected plants and burning and application of 200 g calcium cyanamide per mound are practiced. Chemical control measures with both systemic and contact fungicides are resorted to depending on the nature of damage. Benomyl, carbendazim and thiobendazole at 0.5 and 0.6 per cent are reported to be effective against *Fusarium*. Prophylactic application of fungicides at fortnightly interval, systemic fungicide followed by contact fungicide to the foliage and soil drenching with Benomyl (0.05%) and thiobendazole (0.06%) were found effective in controlling the disease. In the nursery, benomyl or thiobendazole at 500 ppm for *Fusarium* and metalaxyl at 500 ppm or Bordeaux mixture at 10,000 ppm for *Phytophthora* infections, Pencycuron 500 ppm for *Thanatephorus cucumeris* are followed. None of the cultivars was found resistant whereas, *Piper attenuatum, P. cariconnectivum, P. betle and P. colubrinum* were resistant (Duarte and Albuquerque 1991). Mutation breeding by irradiation of seeds was found promising (Poltronieri *et al.* 1991). [Note: The etiology of this disease is still not completely understood. Holliday informed that he has not come across any proper evidence that any *Fusarium* sp. causes a wilt of any virulence anywhere. More studies are needed to establish the *Fusarium* etiology beyond doubt (Holliday, private communication, ed.]

Slow Decline of Pepper

Slow decline disease of pepper is a debilitating disease, where the affected plants survive for several years and death of plants occur gradually over a period of 3–4 years. This disease was earlier referred to as “slow wilt” (Nambiar, 1978, Nambiar and Sarma 1977, Sarma and Nambiar 1982) as slow decline in Malaysia (Kueh and Sim 1992c, Varughese and Anuar 1992) and “Yellow disease” (De Waard 1979, Zaragoza *et al.* 1991) or “Yellows disease” in Indonesia (Sitepu and Kasim 1991). Studies on the etiology has shown that this disease is caused by feeder root damage by *Phytophthora capsici, Radopholus similis* and *Meloidogyne incognita* either alone or in different combinations (Anandaraj *et al.* 1996a, 1996b). (For details see the chapter on nematode induced diseases)

Anthracnose of Pepper

Anthracnose in pepper is referred to as *“pollu”* disease in India, which means hollow fruits and as black berry disease in Malaysia and Indonesia. This occurs both on the leaves and on spikes. Although sporadic in nature in the major pepper growing state of Kerala, this disease is becoming severe in parts of Karnataka where pepper is grown on shade trees in coffee plantations.

Symptoms

The symptoms on fruits depend on the stage of maturity. On younger fruits infection lead to blackening. On mature fruits brownish lesions are formed (Ayyar *et al.* 1918, Sebastian 1982). If the infection occurs on the stalk end of spike, the entire spike is shed prematurely, and brown lesions are produced on the leaves.

Etiology

The fungus *Colletotrichum necator* is the cause of this disease (Rao 1926, Thomas and Menon 1939). From India, *Colletotrichum* sp., *C. gloeosporioides* are also recorded. The severity of the disease vary and a range of 28–34 per cent has been reported causing a crop loss of 1.9–9.5 per cent (Nair *et al.* 1987). The fungus is reported to survive on *Dioscorea triphylla* as an alternate host (Wilson 1960).

Disease Resistance

There is no report of resistance to this disease. In a mixed cropping system experiment involving coconut and five cultivars of pepper, all five cultivars have been reported to show disease incidence. Berry infections recorded were 9.3, 9.8, 16.3, 19 and 23.2 per cent in *Karimunda, Kottanadan, Narayakkodi, Balankotta and Panniyur*-1 respectively (Radhakrishnan and Nair 1983). *Panniyur*-1 recorded highest incidence followed by *Balankotta*.

Disease management

As the disease occurs during the rainy season, Bordeaux mixture (1%) spray is recommended (Sundararaman 1928, Nair *et al.* 1987). Apart from Bordeaux mixture spray, Difolatan at 0.2 per cent was also reported to give adequate control. In Sarawak, Benomyl, Thiophanate ethyl, Thiophanate methyl, Carbendazim, Captofol and Tridemefron were also effective in controlling this disease. Anthracnose is reported to be reduced when 40 per cent shade is provided by using shade nets (Kueh *et al.* 1993).

Stunted Disease

This disease, also known as little leaf disease, was recorded during 1975 in Idukki district of Kerala which is one of the major pepper producing areas (Pailey *et al.* 1981). Earlier it was sporadic, but now found in all major pepper growing tracts of Kerala and Karnataka. A survey has indicated that number of plants affected in Wynad district of Kerala ranged from 0.6 to 18.6 per cent (NRCS, 1994). This disease is known as mosaic disease (Prakasam *et al.* 1990) and as “little leaf” in Sri Lanka (Randombage and Bandara 1984), mosaic disease in India, (Prakasam *et al.* 1990) “wrinkled leaf disease” in Malaysia (Kueh and Sim 1992b) and as “stunted disease” in Indonesia (Sitepu and Kasim 1991, Firdausil *et al.* 1992).

Symptoms

In severely affected plants the symptoms are as follows. The leaves become narrow and leathery in texture, with puckering and chlorotic streaks, internodes become shortened and the branches appear as witches broom, at times the leaves show narrowing and vein banding. The appearance of symptoms are pronounced in neglected gardens and older plants recovering after slow decline infection. In the nurseries, chlorotic streak and vein banding are more common. Kueh and Sim (1991) differentiated four categories of symptoms namely, stunting, reduction in size of internodes, narrowing of leaves, marginal necrosis and chlorosis. Detailed studies on morphology of healthy and infected plants has shown reduced height, girth of column, internode length and leaf area (Eng *et al.* 1993).

Etiology

Transmission tests carried out in India has shown that the disease is graft transmissible. ELISA tests indicated that the disease is caused by cucumber mosaic virus (CMV). Recent electron microscopic studies showed CMV particles in the infected tissues and it is concluded that the disease is caused by cucumber mosaic virus (IISR 1995, 1997, Sarma *et al.* 1992a). In Malaysia, based on serology tests and fluorescent microscopy the involvement of cucumber mosaic virus and chilli veinal mottle virus were ruled out (Eng *et al.* 1993). Studies with immunosorbant electron microscopy, transmission electron microscopy using ultra thin sections also did not reveal the presence of virus in infected tissues. However, purified extracts have been reported to contain bacilliform virus particles measuring 120×30 nm, isometric virus of 30 nm and rod shaped virus related proteins. Gel electrophoresis also reported to show the presence of ds RNA indicating plant viruses. Based on this study presence of badna virus transmitted by mealy bugs and clostero virus are reported (Eng *et al.* 1993). Recently Lockhart *et al.* (1997) have shown that a previously undescribed Badna virus is a causal agent of this disease. The virus named as Piper Yellow Mottled Virus (PYMV) has non-enveloped bacilli-form virions, averaging 30×125 nm in size and containing double stranded DNA genome. The virus is transmissible mechanically as well as by citrus mealy bug.

Disease management

Presently, roguing of infected plants and following quarantine measures to prevent introduction of this disease to disease free areas are recommended

MINOR DISEASES

Phyllody

This disease has been reported from Wynad district of Kerala which is a major pepper growing area (Sarma *et al.* 1988, Sarma and Anandaraj 1992), this is also called as antholysis (Remila and Neelakandan 1994).

Symptoms

The spikes and flowers are converted into leaf-like structures instead of normal flowers and the stalk of the affected spikes are also elongated. The leaves of the affected plants become smaller and shows chlorosis. In the same vine both normal spikes and berries are also produced.

Etiology

Based on electron microscopic studies, the disease is reported to be caused by phytoplasma (Sarma *et al.* 1988, 1991).

Disease management

As the disease is confirmed to be caused by phytoplasma, removal of affected plants and following of quarantine measures are suggested (Sarma and Anandaraj 1992).

Bacterial Leaf Spot

This disease is caused by *Xanthomonas compestris* pv *betlicola* and occurs sporadically in certain pockets (Mathew *et al.* 1978) and in the vicinity of other *Piper* spp. (Bhale *et al.* 1984). The causal organism is *Xanthomonas compestris*. The symptoms appear as small water soaked lesions on the leaf lamina and margins which later become dark with a chlorotic halo and at time cause defoliation. Chloramphenicol at 200 ppm was reported to be effective in inhibiting the growth of the bacterium (Mathew *et al.* 1979). However, control measures to prevent this disease in the field are not available.

Thread Blight

This disease occurs on pepper leaves and spikes (Ramakrishnan 1957). The fungus grows underneath the leaves and on stem causing drying up of leaves and spikes. *Pellicularia filamentosa (Corticium solani)* is reported as the causal organism.

Stump Rot

The occurrence of stump rot caused by *Rosellina bunodes* was recorded by Menon (1949) in Wynad areas of Kerala. The fungus affects the root system which results in drying up of plants. The fungus also affect *Grevillea robusta* on which pepper plants are trailed. Isolation of affected plants by making trenches is recommended to prevent the spread of the disease to adjacent plants.

Red Rust

Red rust caused by the alga *Cephaleuras mycoidea* occur on older leaves in certain pockets. This was reported to cause black fruit in Malaysia (Menon 1949, Sarma *et al.* 1991). This occurs on the surface of leaves, there by cutting off light required for photosynthesis. The exact nature of damage has not been assessed. When the growth occcur on the spikes and fruits the appearance of the berries are affected and the quality is reduced.

Dodder

The occurrence of parasitic flowering plant (*Cuscuta reflexa*-Convolvulaceae) on pepper is recorded in some pepper growing areas. Affected plants are fully covered by the parasite and the productivity of the vine is affected. Removal of the affected branches is the suggested control measure (Sarma *et al.* 1991).

Velvet Blight

The velvet blight is caused by *Septobasidium* sp. The fungus grows on the surface of the fruits and forms a coating but does not penetrate the fruits. Whereas, when it occurs on the branches it results in die back symptoms. Pruning of the affected branches would prevent the spread of the fungus (Sarma *et al.* 1991).

White/Yellow spots

White/Yellow spots occurs on the stem and are caused by lichens. Brown spots caused by unknown pathogen have been recorded on pepper (Sarma *et al.* 1991). These diseases seldom occur and do not cause serious losses. No detailed information is available on them.

NURSERY DISEASES

Black pepper is propagated vegetatively through cuttings. Three types of planting materials are used for propagation. In the first type orthotropic terminal shoots are taken from the plants during rainy season and planted directly in the field. In the second type, the runner shoots which are produced from the base of the vine during rainy season, are allowed to trail on the ground or are kept coiled around the base of plants and taken at the time of producing the cuttings. The third type, the cuttings are allowed to trail on 1.2 m long bamboo splits filled with potting mixture and arranged in an angle of 45°. As the vine grows, it is tied to the bamboo split to ensure contact with the potting mixture. Roots are produced at each node and when the cutting has grown to the length of the bamboo split, the plants are cut from the bottom leaving 2–3 nodes and cut into bits, each node with a leaf and roots,and planted in individual polythene bags (Sivaraman 1991). In the latter method cuttings are produced the year round and the conditions are favourable for the diseases to develop. Depending on the type of nursery the disease problems also vary.

Leaf Rots and Blights

In the nurseries raised using the runner shoots, stem cuttings with 2–3 nodes are planted in polythene bags containing nursery mixture made up of forest soil, sand and farm yard manure in the proportion of 1:1:1. As the cuttings sprout, several diseases such as leaf spots and blights develop on the young sprouts. *Rhizoctonia* sp.

cause greyish sunken spots on the leaves and infected leaves remain attached to one another. The spots caused by *Colletotrichum* sp. are characterized by yellowish halo surrounding the necrotic spots. (Mammootty *et al.* 1980, 1992; Mammootty and Pillay 1981).

Basal Wilt

Invasion of *Sclerotium rolfsi* on pepper seedlings in the nursery causes rotting and wilting of the cuttings. The affected plants show greyish lesions on stems and growth of the fungus as whitish mycelium with numerous sclerotia. On the leaves greyish spots with whitish mycelium at the advancing edges of lesion and sclerotia on lesions are seen. Carbendazim and mercuric fungicides are reported to be effective in checking the germination of sclerotia under *in vitro* tests (Choudhury 1943, Brahma *et al.* 1980).

Phytophthora Infections

Phytophthora infections are severe during rainy season when the cuttings are exposed to rain. Infection occurs on leaves, stem and roots. Infection starts as spots on the tender leaves with the characteristic fimbriate advancing margin and the leaves are blighted within 2–3 days and spread to the adjacent cuttings through rain splashes. Infection on the stem results in withering of the entire cutting. Root infection results in sudden wilting of the cutting. The inoculum for the outbreak of *Phytophthora* infections is carried from diseased gardens inadvertently to the nursery in the form of incipient infection on the roots of runner shoots and passively in the form of soil particles adhering to the runner shoots. In case of rapid multiplication in nurseries, as the conditions are favourable year round infection can occur.

Disease Management in Nurseries

Pepper being a perennial crop, producing disease free planting material is the first step in disease management. *P. capsici,* which occurs on all parts of pepper and infect all stages of the plants, calls for greater precaution to prevent the introduction of the fungus to newer areas. The disease management strategy includes collection of disease free planting material, disinfection of nursery mixture and an integrated control measures (Sarma *et al.* 1988a, 1988b, Anandaraj and Sarma 1995).

Collection of planting material

Runner shoots used for multiplication must be collected from disease free gardens. The roots present on the runner shoots which were trailing on the ground has to be removed and the material washed throughly with water to remove all the adhering soil particles and the cuttings dipped in a fungicide such as Mancozeb or any copper fungicide before planting in polyethylene bags.

Preparation of nursery mixture

After preparing the mixture it may be sterilized using methyl bromide or through solarization by spreading the mixture in an open area up to a height of 30 cm, moistening with water and covering with polyethylene sheet (Sarma *et al.* 1996). After solarization, the mixture is fortified with vesicular arbuscular mycorrhizae and antagonistic fungi like *Trichoderma* and *Gliocladium*. As the cuttings grow and show symptoms of infection, infected cuttings are separated and a prophylactic spray with a fungicide such as Bordeaux mixture (1%) is given to prevent the spread of the disease (Mammootty *et al.* 1980, Mammootty and Pillay 1981, Mammootty *et al.* 1992, Sarma *et al.* 1988a, 1988b). To protect the cuttings from *Phytophthora* a foliar spray with 200 ppm of metalaxyl was found very effective. Metalaxyl is compatible with biocontrol organisms, and application of biocontrol agents to the soil together with spraying the foliage with metalaxyl would offer better protection. In short, nursery diseases could be managed by using cuttings from healthy gardens, by adopting phytosanitation and spraying the cuttings with Bordeaux mixture (1%) or metalaxyl 200 ppm as and when such necessity arise.

CONCLUSIONS

In pepper all the fungal diseases described above occur during the wet monsoon season under Indian condition. In other pepper growing areas also *Phytophthora* infections occur during the wet period. Although the weather requirement for *Phytophthora* diseases are studied in detail, in the integrated management of diseases a fixed fungicide schedule is followed as the favourable weather conditions are attained during the monsoon period every year. The fungicide application to the foliage at the onset of monsoon would protect the plants against the infections caused by *Phytophthora, Colletotriehum* etc. The application of organic manures along with biocontrol agents would prevent the population build-up of *P. capsici* in soil and protect the roots against the damages. Present research efforts are concentrated on host resistance, by understanding the mechanism of resistance and incorporating the same through biotechnological means, so that host resistance becomes an important component of integrated management of diseases of pepper.

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5.2. NEMATODE INDUCED DISEASES OF BLACK PEPPER

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Black pepper is cultivated as a monocrop in most of the pepper growing countries like Indonesia, Malaysia, Brazil etc. while in Kerala, India, it is mostly grown as a mixed crop in homesteads, trailed either on arecanut or coconut palms or other trees, or as a companion crop in coffee or cocoa plantations. Crops like banana, elephant foot yam, colocasia, ginger, turmeric and a variety of vegetables are also grown along with pepper in homestead gardens in India. Such crop combinations play an important role in building up populations of certain polyphagous pests and pathogens, and they are major constraints limiting production and productivity of pepper.

Among such constraints, the most serious ones are diseases induced by fungal pathogens like *Phytophthora* sp., *Fusarium solani* and plant parasitic nematodes viz., *Radopholus similis* and *Meloidogyne incognita*. Interactions among these organisms lead to disease complexes in all major pepper growing countries. Abiotic factors like soil moisture, temperature and nutritional status of the soil also have definite roles in the onset, progression and severity of the diseases.

PLANT PARASITIC NEMATODES OF PEPPER

Plant parasitic nematodes are recognized as a serious constraint to crop productivity in almost all countries. Out of the 15,000 nematode species described, 2200 are plant parasites. The nematodes may be major pests in their own right, in addition they can cause damage to crops when they interact with other disease causing organisms. Nematode damages often go unnoticed or are overlooked as the damages caused by them are not easily identifiable, and often confused with nutrient deficiency, moisture stress, etc. Roots damaged by nematodes cannot absorb water and nutrients effectively. Nematodes spend their lives either in host tissues or in the rhizosphere. The most severe nematode problems occur when susceptible host crops are grown continuously or too frequently on the same land.

Several plant parasitic nematodes belonging to different groups are reported in association with pepper (Table 5.2.1). Based on their parasitic habits they can be classified as ectoparasites, endoparasites and semi-endoparasites. Further, they can be grouped as migratory or sedentary on the basis of their movement in host plant

Table 5.2.1 Plant parasitic nematodes associated with pepper.

Ectoparasites
Acontylus sp.
Aglenchus sp.
Aphelenchoides sp. *A. dactylocerus*
Aphelenchus sp. *A. avenae*, *A. isomerus*
Basiroliaimus columbus, *B. indicus*, *B. seinhorstii*
Criconemoides sp.
Dipitherophora sp.
Discocriconemella limitanea
Dolichodorus sp.
Helicotylenchus sp., *H. abunaamai*, *H. dihystera*, *H. erythrinae*, *H. paracanalis*, *H. pseudorobustus*
Hemicriconemoides gaddi, *H. mangiferae*
Hemicycliophora sp.
Hoplolaimus sp.
Longidorus sp.
Macroposthonia onoensis, *M. ornata*
Neolobocriconema braziliense
Rotylenchoides variocaudatus
Rotylenchus sp.
Scutellonema sp., *S. siamens*
Trichodorus sp.
Tylenchorhynchus sp., *T. clarus*, *T. mashhoodi*
Xiphinema sp., *X. elongatus*, *X. radicicola*, *X. vulgare*
Semi endoparasites
Paratylenchus sp., *P. leptos*
Rotylenchulus reniformis
Trophotylenchulus piperis
Tylenchulus semipenetrans
Sedentary endoparasites
Heterodera sp., *H. marioni*
Meloidogyne sp., *M. arenaria*, *M. incognita*, *M. javanica*
Migratory endoparasites
Pratylenchus sp., *P. coffeae*
Radopholus similis

tissues. The compilation of plant parasitic nematodes associated with pepper in the major growing countries by Sundararaju *et al.* (1979) listed 48 species belonging to 29 genera, while Ramana and Eapen (1998) listed 30 genera and 54 species on pepper. In India, 17 genera of nematodes were recorded in Kerala and Karnataka, the two major pepper growing states (Sundararaju *et al.* 1980). Plant parasitic nematodes belonging to 14 genera in association with pepper were reported in the detailed surveys conducted during 1980's in Kerala and two districts in Karnataka. (Ramana and Mohandas 1987, 1989). A new species of a semi-endoparasitic nematode, *Trophotylenchulus piperis,* was reported on pepper from India (Mohandas *et al.* 1985). The occurrence of this nematode on pepper has not been reported from any other country. In Indonesia, 14 genera of plant parasitic nematodes were associated with pepper (Mustika and Zainuddin 1978, Bridge 1978). Among them *Meloidogyne* spp., *Radopholus similis, Trophotylenchulus piperis, Helicotylenchus* sp. and *Rotylenchulus reniformis* are predominant in India (Jacob and Kuriyan 1979b, 1980, Ramana and Mohandas 1987, 1989), while in Indonesia and Malaysia only *Meloidogyne* sp. and *R. similis* are predominant (Mustika 1990). According to Sher *et al.* (1969), *Meloidogyne* sp., *Tylenchulus semi-penetrans* and *R. reniformis* are more prevalent in black pepper plantations in Thailand. In Para, Brazil, *M. incognita., Xiphinema* sp., *Helicotylenchus* sp. and *Macroposthonia onoensis* are commonly associated with black pepper (Freire and Monteiro 1978). Similarly in Sri Lanka, root knot and burrowing nematodes are of common occurrence in pepper (Lamberti *et al.* 1983, Gnanapragasam *et al.* 1985). Other plant parasitic nematodes like *Hoplolaimus seinhorsti* and *Xiphinema ifacolum* are also known to affect the growth of pepper adversely in Sri Lanka (Lamberti *et al.* 1983). The economic damages caused by many of these species are yet to be established. However, *Meloidogyne* spp. and *R. similis* are of much economic significance as they cause severe damage to pepper and are implicated in the slow decline/yellows disease, a major production constraint in all pepper growing countries (Fig. 5.2.1). Though *T. piperis* is very much prevalent with high infestation levels, its impact on pepper cultivation is yet to be evaluated and research in this direction is in progress in India.

Root Knot Nematodes (*Meloidogyne* spp.)

On a global scale, root knot nematodes (*Meloidogyne* spp.) are the most destructive of all the nematode parasites of crop plants. They belong to the family Meloidogynidae which are sedentary endoparasites with specialized and complex relationships with the host plants. The genus *Meloidogyne* is one of the most intensively studied among different genera of plant parasitic nematodes. Out of several species identified in the genus, the most prevalent ones are *M. incognita* (47%), *M. javanica* (40%), *M. arenaria* (7%) and *M. hapla* (6%). Of these, *M. incognita* and *M. javanica* are widely distributed in tropical, subtropical and warm temperate regions.

Survey and distribution

The first record of root-knot nematode infestation on pepper was from Cochin-China (presently a part of Vietnam) by Delacroix (1902). Almost during the same period, Barber (cited by Ridley 1912) observed root-knot nematode infestation on pepper in Wynad, Kerala, India. He described a series of tumours (root knots) on plant tissues due to the eelworm *(Heterodera radicicola=Meloidogyne incognita)* and that when

Figure 5.2.1 Pepper vine showing slow decline symptom (yellowing).

these tumours decay it is not easy to detect the remains of the eelworms. Butler (1906) in his further investigations on the disease in Wynad, also reported the association of root-knot nematodes with the diseased plants. Later Ayyar (1926) reported the wide spread occurrence of root-knot nematodes on pepper in Wynad. Root-knot nematode infestations were also reported from many pepper growing countries like Malaysia (Holliday and Mowat 1963, Kueh 1975, Ting 1975, Razak 1981), Indonesia (Ichinohe 1976, Bridge 1978), Brazil (Sharma and Loof 1974, Ichinohe 1975), Thailand (Sher *et al.* 1969), Fiji (Swaine 1971), Guyana (Biessar 1969) and Sri Lanka (Lamberti *et al.* 1983).

Among the four major species of *Meloidogyne, M. incognita* is a major parasite on pepper. Three species namely, *M. incognita, M. javanica* and *M. arenaria* were reported on pepper in Sarawak (Kueh 1975), the first two are widely distributed (Kueh and Sim

1992). However, Siti Hajijah (1993) found that only *M. incognita* is widely distributed in all the plantations surveyed in Sarawak and both healthy as well as diseased plants (pepper plants showing foliar yellowing) harboured the nematode. In Sri Lanka, *M. arenaria* was also observed to affect the growth of black pepper (Lamberti *et al.* 1983). In Kerala and Karnataka about 70 per cent and 54 per cent of plants, respectively, were found infested with *M.incognita* (Ramana and Mohandas 1987, 1989) and both apparently healthy and slow decline affected vines harboured high populations of the nematode (Ramana *et al.* 1987).

Symptoms

Root knot nematodes are sedentary obligate endoparasites. They have a specialized and complex relationship with the host plants. Infestation by them leads to the development of elongated swellings on the thick primary roots due to multiple infections and typical knots or galls on secondary/fibrous roots due to hypertrophy and hyperplasia of the infested tissues (Fig. 5.2.2). In thick primary roots a number of

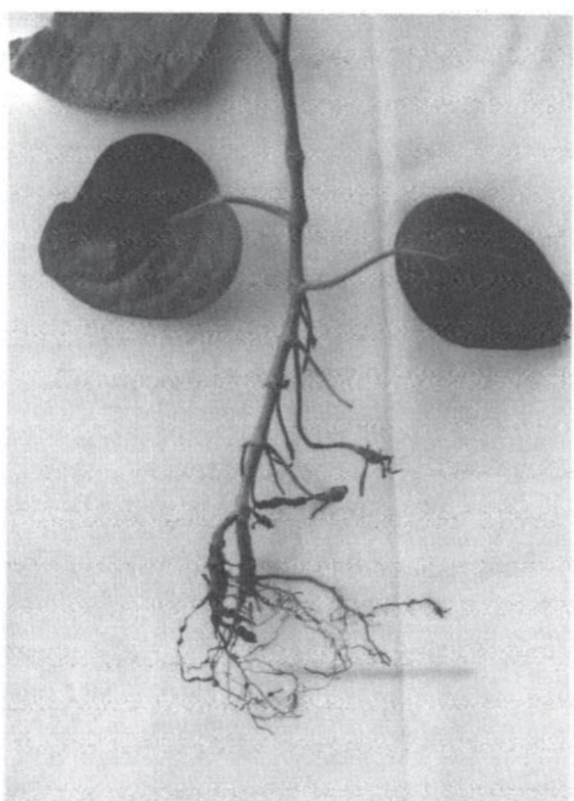

Figure 5.2.2 Root system of pepper plant showing root knot nematode infestation.

adult females with egg masses are situated deep below the epidermis and the whole length of the root turns in to a gall and hence appear almost smooth with occasional swellings here and there (Mohandas and Ramana 1987). Nematodes feed on vascular tissues and cause disruption in the arrangement and continuity of vascular tissues affecting absorption and translocation of water and nutrients. The galled roots decay in due course and considerable amount of root is lost under severe infestation (Mohandas and Ramana 1991, Siti Hajijah 1993).

Pepper plants infested with root knot nematodes generally exhibit foliar yellowing, poor growth and gradual decline in health and vigour. Sometimes leaves of infested vines show dense yellowing of interveinal areas making the leaf veins quite prominent with deep green colour (Ramana 1992, Ramana *et al.* 1994). Kueh (1979, 1990) reported that in the plants infested with root knot nematodes, leaves were held inward and upward followed by defoliation. In the pathogenicity trials with *M. incognita* and *Fusarium solani,* Mustika (1990, 1992) could not reproduce the symptoms like stiff droop and yellowing of leaves in plants inoculated with *M. incognita* alone. Similarly, severe foliar yellowing could not be observed in the plants inoculated with lower doses of nematode inoculum in pathogenicity tests conducted in India under simulated field condition (Mohandas and Ramana 1991). Nematodes occupy the stelar portion of roots and feed on giant cells. In due course many giant cells coalesce and stelar portion is completely destroyed (Mustika 1990).

Pathogenicity and economic significance

Several experiments were conducted to establish the pathogenicity of root knot nematodes on pepper. Winoto (1972) found significant reduction in the growth of cv. *Kuching* when inoculated with *M. incognita* and *M. javanica*. Ferraz and Sharma (1979) found significant reduction in shoot and root dry weight in the same cultivar inoculated with *M. incognita*. Freire and Bridge (1985c) found *M. incognita* highly pathogenic to black pepper seedlings at an inoculum level of 100–1000 second stage juveniles. Similar effects on the growth of pepper plants inoculated with *M. incognita* were reported from Sri Lanka (Lamberti *et al.* 1983) and India (Koshy *et al.* 1979, Jacob and Kuriyan 1980, Mohandas and Ramana 1983). In all these pot culture experiments under green house conditions, the actual loss in yield could not be estimated, as plants were not exposed to natural weather conditions to reproduce the symptoms caused by nematode damage under field conditions. This gap was bridged by the large scale pathogenicity tests conducted under simulated field conditions using grown up plants. These tests showed that foliar yellowing and defoliation were low in the plants inoculated with lower inoculum levels (100 and 1000 nematodes). Characteristic interveinal chlorosis of the leaves was observed in plants which received higher doses of inoculum (10,000 and 100,000 nematodes). The reduction in yield was significant in the plants inoculated with higher inoculum levels, 37 per cent and 46 per cent, respectively (Mohandas and Ramana 1991).

Certain physiological changes were also observed in plants infested with *M. incognita,* like reduction in absorption and translocation of P, K, Zn, Mn, Cu, Ca and

Mg and these elements accumulated in the leaves (Ferraz *et al.* 1988). Total chlorophyll content of leaves was significantly low (Ferraz *et al.* 1989) resulting in growth retardation. Plants inoculated with *M. incognita* accumulated high concentration of total phenols but without expression of any resistance to the pest (Ferraz *et al.* 1984). The changes in host physiology and nutrient absorption capacity may account for reduction in leaf chlorophyll content in the diseased plants. Several changes in the levels of amino acids, organic acids and sugars were also observed in the plants infested with *M. incognita* (Treire and Bridge 1985b).

The Burrowing Nematode *(Radopholus similis)*

The burrowing nematode is an obligate migratory endoparasite. It belongs to the family Pratylenchinae. It is widely prevalent in most of the tropical and sub tropical regions of the world, has a host range of about 370 plant species and is a major constraint in agricultural production (Peachey 1969). This nematode is a serious problem to citrus, avocado, coffee, tea, banana, pepper, ginger, several palms and indoor decorative plants (Holdeman 1986). *R. similis* was first reported in Kerala, India on banana by Nair *et al.* (1966).

Survey and distribution

Pepper as a host of *R. similis (=Angiullulina oryzae)* was first reported by Goodey (1936). During 1950's pepper plantations in the islands of Bangka, Indonesia were affected by a devastating disease known as 'yellows', resulting in the death of several million pepper plants that led to a major economic disaster for the island inhabitants (Christie 1957, 1959). van der Vecht (1950), after thorough investigations, found that *R. similis* is responsible for the yellows disease in pepper. Due to this disease the life span of new plantations was reduced to 3 to 5 years (Thorne 1961). Association of this nematode with pepper in India was first reported by D'Souza *et al.* (1970) and subsequently its wide spread occurrence in pepper plantations in South India was confirmed (Kumar *et al.* 1971, Venkitesan 1972, Koshy *et al.* 1978, Jacob and Kurian 1979b, Ramana and Mohandas 1987, 1989). *R. similis* is also recognized as a major pest of pepper in Malaysia (Reddy 1977), Thailand (Sher *et al.* 1969) and Sri Lanka (Gnanapragasam *et al.* 1985).

Symptoms

R. similis invades any succulent underground plant part but favours the area near the root tip. Nematodes take feeding position inter and intra cellularly and the cortical cells immediately around the nematode turn necrotic and further feeding and movement of the nematode in the root tissues lead to the development of large necrotic lesions throughout the root cortex (Fig. 5.2.3). Under artificial inoculation the nematodes penetrated the pepper roots within 24 hours (Venkitesan and Setty 1977). The nematodes starve to death in less than 6 months in the absence of a host

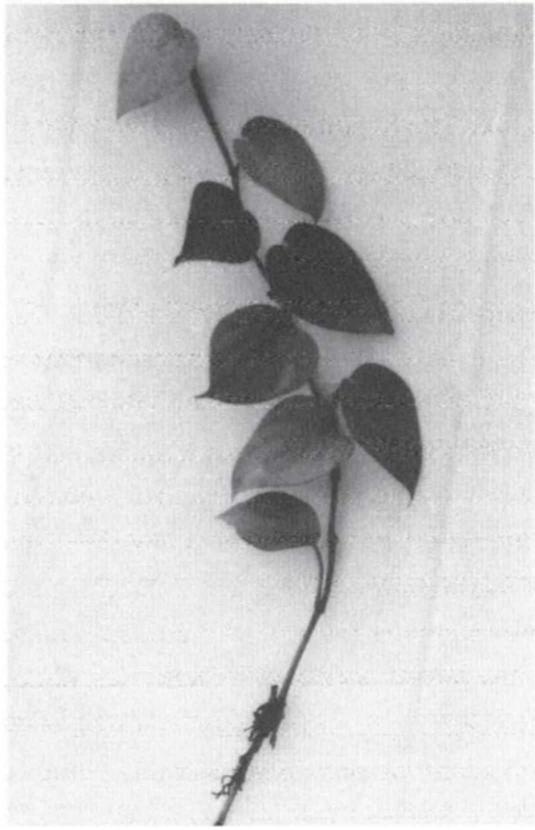

Figure 5.2.3 Pepper plant infested with burrowing nematode showing total destruction of roots.

plant. All stages of the nematode after hatching from egg, except the adult males, are infective. *R. similis* feeds on cortical tissues and produces elongated dark brown necrotic lesions on the roots at the infection sites. After draining the cell contents, nematode pushes through the cell wall to the next cell, thus destruction of successive cells results in the formation of tunnels or burrows in the root tissues. When the infestation is severe many lesions coalesce and encircle the root cortex. Due to damage to cortical tissues, root portion distal to these lesions gradually disintegrates. Plants tend to produce new roots which are also in turn infected resulting in a bunch of decayed root mass (Mohandas and Ramana 1987). *R. similis* do not invade stelar portions of the root, but plugging of the xylem vessels with 'gum like' substance has been reported (Freire and Bridge 1985a).

Pepper plants infested with *R. similis* express through above ground symptoms like foliar yellowing, defoliation, lack of vigour and retardation in growth, van der Vecht (1950) correlated the occurrence of 'yellows disease' characterized by foliar yellowing with *R. similis* infestation in Bangka, Indonesia. Similarly in India also a high correlation was noticed between the foliar yellowing and infestation with *R. simils* in pepper plantations (Ramana *et al.* 1987). Freire (1982) found that *R. similis* predisposed pepper seedlings to a weak pathogenic isolate of *F. solani* and root rot was more severe.

Pathogenicity and economic significance

Pathogenicity tests conducted under greenhouse conditions established the pathogenic effect of the nematode on pepper. Mustika (1990) observed yellow leaves with stiff droop in the plants inoculated with *R. similis*. However, Venkitesan and Setty (1977) could not observe yellowing of leaves under artificial inoculations, but the nematodes caused considerable reduction in all growth parameters like height, number of leaves and nodes, leaf area, dry weight of shoot and root and the severity increased with the increase in the inoculum level in these tests. Further, plants inoculated with higher nematode levels lacked feeder roots and the roots present were black and almost decayed. The pathogenic tests of *R. similis* on pepper, conducted under simulated field conditions on adult plants, showed that *R. similis* is highly pathogenic to pepper (Mohandas and Ramana 1991). Nematode infestations caused foliar yellowing, defoliation and intensity of these symptoms increased with the increase in the inoculum level and with time, typical of slow decline disease. All growth characters namely height (0.2–20%), number of primary shoots (13–57%), dry weight of shoot (25–61%), leaf (25–77%), root (33.5–82%) and yield (0.3–59%) were significantly reduced in the pepper plants inoculated with *R. similis* @ 100 to 10,000 nematodes/plant (Mohandas and Ramana 1991). The burrowing nematodes could alter the nutrient balance of the infested plants. Leaf Ca, N, and Mg increased in plants infested by *R. similis, M. incognita* and *F. solani* and this is attributed to be due to reduction in leaf size and alteration in the overall nutrient balance within the plant system (Mustika 1990).

R. similis populations from arecanut and pepper in Kerala complete their life cycle in 25–30 days at temperature of 21–23°C (Koshy 1986, Geetha 1991). This nematode species has two morphologically indistinguishable races, ‘banana race’ infecting banana but not citrus and ‘citrus race’ which infects both citrus and banana (Du Charme and Birchfield 1956). The ‘banana race’ is identified from most of the banana growing regions of the world, whereas ‘citrus race’ is known to occur in Florida, USA. The banana and citrus races have chromosome numbers of n=4 and n=5, respectively (Huettel and Dickson 1981). However, a number of biological differences, including karyotypes, isozyme and pheromone mediated behaviour were detected between these two races (Huettel 1982, Huettel and Dickson 1981, Huettel *et al.* 1982, 1983a & b). The lack of common isozyme bands at seven loci indicated that gene flow does not occur between these two races and therefore reproductive isolation is complete, even though they are sympatric. *R. similis* population of pepper from Indonesia and Kerala, India have haploid chromosomes of n=4 (Huettel 1982, Huettel *et al.* 1984a, Koshy 1986). Further, pepper race from Kerala did not infest 16 varieties of citrus and it was confirmed as banana race (Ramana 1992). Huettel *et al.* (1984b) separated citrus race and described it as a new species, *Radopholus citrophilus*.

The Pepper Nematode *(Trophotylenchulus piperis)*

The pepper nematode is a sedentary, semi-endoparasite, belonging to the family Tylenchulidae. The nematode was described from the roots of pepper in Kerala, India (Mohandas *et al.* 1985). The adult females on the root surface are covered with hard dark brown cases. This nematode is widely prevalent in all major pepper growing areas in Kerala and Karnataka (Ramana and Mohandas 1987, 1989, Ramana and Eapen 1997) but so far not reported from any other pepper growing country.

The second stage juvenile of the nematode is infective. After penetration, the head portion only is embedded in the root tissues with the distal portion of the body remaining outside the root. The nematode starts feeding once it takes a position on the root and development of the nematode progresses. The protective covering (case) starts developing at 30–40 days after infection. This developing cover looks like jelly initially which becomes hard and the whole nematode is covered with the case in about 40–50 days after infection. Once the case is fully formed, the nematode lays about 25–35 eggs. Each case contains eggs in different stages of development, second stage juveniles and an adult female. At 50–55 days, most of the cases are empty indicating the second stage juveniles had emerged out of the cases for further infesting the host roots (Sundararaju *et al.* 1995). The nematode is able to infest and develop on thick main roots as well as on tender fibrous roots, though more of them occur in fibrous roots (IISR 1995, Ramana and Eapen 1997). The studies conducted at Indian Institute of Spices Research have shown that the cases have developed from the secretions of excretory glands in the developing nematodes. The nematode penetrates only 3–4 cell layers deep in the roots and necrotic lesions develop at the feeding sites. The infested roots also show shrinkage and drying at the site of infection. Besides pepper, *Glyricidia sepium* and *Artocarpus heterophyllus,* which are used as live standards for trailing pepper, are also hosts of this nematode (Ramana and Eapen 1997).

SLOW DECLINE DISEASE

Slow decline disease of pepper, otherwise known as ‘yellows’ disease is a major problem for pepper cultivation that has upset the economy of Bangka islands in Indonesia where millions of pepper plants died during 1950’s (Christie 1959). About 30 per cent of the plants are damaged by this disease in Guyana (Biessar 1969). The disease is prevalent in most pepper growing countries like India (Nambiar and Sarma 1977), Malaysia (Kueh 1979, 1990), Brazil (Sharma and Loof 1974, Ichinohe 1975), Thailand (Sher *et al.* 1969, Bridge 1978). The disease, was first observed in Bangka (van der Vecht 1950), spread to other areas in Indonesia and in the islands of Bangka and Belantung, almost all plantations were affected. The annual loss of production was estimated to be up to 32 per cent (Skepu and Kasim 1991).Yellows disease is one of the reasons for low productivity of pepper in Indonesia (Mustika 1990). This disease is also widely prevalent in Johore and Sarawak in Malaysia, and yield losses range from 25–90 per cent and the life span of the vine is reduced to 8–10 years

(Varughese and Anuar 1992). In the Kampot region of Cambodia, the pepper industry suffered heavily due to a nematode-fungal complex disease and pepper population was reduced from 2.5 millions in 1942 to 0.5 millions in 1953 (Hubert 1957). Crop loss estimates due to this disease in India are not available though Menon (1949) reported about 10 per cent mortality of pepper plants in Kerala. Wahid and Sitepu (1987) reported that annual loss may reach up to 10–32 per cent as almost all plantations in Indonesia are affected by this disease. According to them the symptoms of this disease are foliar yellowing and leaf fall in both young and older plants. The yellowing of leaf starts from the bottom of the plant and spreads to the top, covering the whole plant at later stages of the disease. They are also of the opinion that the disease is mainly due to plant parasitic nematodes, *R. similis, M. incognita* and the fungus *Fusarium* sp. combined with agronomic disorders.

Slow decline is a debilitating disease over a period of time. The above ground symptoms of the disease are yellowing of leaves, defoliation, die-back, loss in vigour and productivity, leading to slow death (Fig. 5.2.1). On roots, nematode infestation results in the formation of galls due to root-knot nematodes, necrotic lesions and rotting caused by *R. similis* resulting in total loss of feeder roots (Fig. 5.2.2 & 5.2.3). Infested plants sometimes recover with the onset of monsoon when the plants put forth new roots and leaves. However, the plants succumb to the disease as the root regeneration cannot compensate the root loss due to nematode damage (Mohandas and Ramana 1987).

Barber (Ridley 1912) observed that in pepper plantations in Wynad, Kerala, many pepper plants died due to nematode disease after a period of phenomenal success in pepper cultivation. He also found a series of tumours (root galls) in plant tissues due to eelworms *(Heterodera radicicola=Meloidogyne incognita)*. Butler (1906) in his investigation on the disease in Wynad, observed drooping of leaves as the first aerial symptom of the disease followed by yellowing and leaf shedding. The diseased plants could not be recovered once leaf drooping commenced and the disease came to be known as ‘slow wilt’.

Similarly during 1930s in the Indonesian island, Bangka, pepper plants with foliar yellowing and defoliation were observed and the disease was termed as ‘yellows ‘by Bregman (1940). Further detailed investigation on the disease by van der Vecht (1950), showed that plant parasitic nematode, *R. similis* is responsible for the disease. Now this nematode disease of pepper with characteristic symptoms of foliar yellowing and defoliation is known as ‘slow decline’ for the sake of uniform terminology.

The disease is primarily attributed to *R. similis* or *Meloidogyne* spp. in all the pepper growing countries (Christie 1957, Ting 1975, Ichinohe 1976, Nambiar and Sarma 1977, Venkitesan and Setty 1977, Mustika 1978, Ramana *et al.* 1987, 1992). However, there are different opinions on the etiology of the disease. Hubert (1957) and Bridge (1978) were of the view that though *R. similis* is primarily responsible for the disease, combined infestation of *Fusarium solani* along with the nematode results in the yellows disease. Infestation by the nematode and fungus together enhanced the root damage and severity of foliar yellowing (Lopes and Lordello 1979, Freire 1982, Hamada *et al.* 1985, Sheela and Venkitesan 1990). Mustika (1990), in a pot culture test, observed that *R. similis* alone can cause yellowing of leaves with stiff droop but these symptoms were more severe when plants were inoculated with *R. similis* along with *M. incognita* or *F. solani* thus indicating that pepper is more affected by *R. similis* than *M. incognita* causing more root damage and thereby severe growth inhibition. Pathogenicity trials conducted in micro plots under simulated field conditions in India confirmed that *R. similis* causes more damage to pepper than *M. incognita* (Mohandas and Ramana 1991). The possible role of *Fusarium* sp. in the disease complex is not elucidated in the large scale field trials conducted in India (Ramana *et al.* 1992). It was also reported that both *R. similis* and *M. incognita* were mutually suppressive under greenhouse experiments (Eisenback 1985). *Pythium* sp. (Nambiar and Sarma 1977, Varughese and Anuar 1992) and *Rhizoctonia bataticola* (Nambiar and Sarma 1977) were also reported in association with the roots of diseased pepper plants. However, no further attempts were made to understand their role in the disease incidence.

Phytophthora sp. is a major fungal pathogen of pepper and causes the foot rot disease. Winoto (1972) observed that plants infested with root-knot nematodes were more susceptible to *Phytophthora* infection, but the relation between, *M. javanica* infestation and the occurrence of foot rot caused by *P. palmivora* (the species infecting pepper is now known as *P. capsici*) could not be established (Holliday and Mowat 1963). In India, *P. capsici* is a major constraint in black pepper cultivation. Roots of diseased plants show infestation of *R. similis, M. incognita* and *P. capsici* either alone or in combination and there is no spatial segregation under field condition. Feeder root damage caused by *P. capsici* was reported to lead to slow decline symptoms (Anandaraj *et al.* 199la, 1996b,c; Ramana *et al.* 1992). Their role in the disease development was assessed under simulated field condition in micro plots and the results showed that all of them are highly pathogenic. The plants inoculated with either *R. similis* or *P. capsici* alone or together showed foliar yellowing and defoliation and root rotting, typical of slow decline disease. Further, these trials showed that even though enough soil moisture and nutrients were available, the plants exhibited declining symptoms due to damage of feeder roots. When the fungal infection reaches the collar region through roots, it results in foot rot disease (Anandaraj *et al.* 199la, 1996b). In another study by the same authors, *P. capsici* and *R. similis* together caused rapid damage to root system leading to faster disease development. The damage caused by *M. incognita* alone is less but in combination with *R. similis* and *P. capsici* the damage is synergistic. So an integrated approach to check all the three pathogens is essential for the management of slow decline disease (Anandaraj *et al.* 1996c).

MANAGEMENT OF NEMATODE DISEASES

Soil borne diseases, in general, are elusive to management as the chemicals or other agents employed for the control do not reach in sufficient quantity/concentration to the target pathogen/pest in the soil. In nematode diseases, the visible symptoms are noticeable only after severe damage to roots. The symptoms can be confused with those caused by soil factors, nutritional deficiency or drought and they are not exclusively diagnostic of nematode damage. It is well known that nematodes cannot be eliminated from agricultural soils in any given situation particularly in perennial cropping systems. Hence, the concept "live with the nematodes" by managing their populations below economic threshold levels is appropriate. In India, pepper is cultivated in homestead gardens along with a variety of crops. This type of agroecosystem adds further dimensions to the nematode management. The roots weakened by nematode infestation are prone to attack by otherwise weak pathogens particularly fungi like *Fusarium* spp. Frequent monitoring of nematode populations and diagnostic services are essential to bring the nematode population down to noninjurious levels by adopting appropriate management technology.

The nematode management programmes should be in line with the present day concepts of organic farming, eco-friendly management of pests and diseases and demand for pesticide residue free produce. Considering the complex nature of slow decline disease, the aim should be to develop an integrated disease management schedule to reduce the nematode population and associated fungal pathogens below threshold levels and providing favourable conditions for growth of pepper. Cultural practices, host resistance and biocontrol agents can be profitably used with minimal use of chemicals (Ramana and Eapen 1995).

Cultural Methods

Nematode management through cultural methods are generally less expensive, but have to be modified and adopted depending on the situation. They are primarily preventive and aim at suppressing the nematode population by providing favourable conditions for the growth of the plants and associated rhizosphere microorganisms antagonistic to pathogens. Crop rotation, mulching with organics, soil amendments, flooding, fallowing, phytosanitation, planting nematode free plants are some of the cultural practices recommended for nematode management. Pepper being a perennial crop, many of these practices cannot be adopted, and many require further modification.

In nurseries

Nurseries are the main source for the spread of insect pests and pathogens. The conditions provided in the nurseries for plant growth are also highly congenial for nematode multiplication. Phytosanitation and hygiene in nurseries are essential in nematode disease control. Pepper is propagated through stem cuttings. Runner shoots or stolons from the base of the vine are also used as planting material. Three - node cuttings are planted in polythene bags containing nursery mixture for rooting. In the rapid multiplication system the planting materials are generated from single nodes rooted on bamboo splits (NRCS 1993). Planting materials are produced throughout the year in this method and are retained in the nurseries for longer periods before planting in the fields than in the conventional method. The nodal roots of runner shoots collected from field should be removed before planting in nursery.

Planting rooted cuttings infested with nematodes leads to slow decline disease in course of time. Denematization of nursery mixture either through solarization or fumigation with chemicals is highly effective in reducing the initial nematode load and for production of healthy rooted cuttings.

Incorporation of biocontrol agents like vesicular arbuscular mycorrhizal fungi (VAM) suppressive to nematodes and fungal pathogens to solarized soil mixture is recommended (Anandaraj and Sarma 1994a,b, Sarma *et al.* 1996). VAM fungi also enhance growth and vigour of pepper rooted cuttings besides suppressing nematodes and fungi (Anandaraj *et al.* 1996a). *Trichoderma* species in combination with soil solarization suppresses *M. incognita* in cardamom nurseries (Eapen 1995). These fungi suppressed the hatching of *M. incognita* eggs from pepper in laboratory assays (IISR 1995). *Paecilomyces lilacinus* also suppress the root knot nematodes in cardamom and pepper (Eapen and Venugopal 1995, Ramana 1994). Hence, incorporation of these fungi in the nursery mixture would be advantageous.

In plantations

Phytosanitation, nutrient management, mulching, proper drainage, addition of soil amendments like oil cakes would help to suppress the nematode populations in pepper plantations. To reduce the source of inoculum and the spread of the pathogens, destruction of the diseased plants along with root mass is very essential. Barber (cited by Ridley 1912) suggested that all the galled roots and underground plant parts should be collected and burned and on no account replanting should be done in these pits for many years. DeWaard (1979) reported that application of fertilizers at 400 kg N, 180 kg P, 480 kg K, 425 kg Ca and 112 kg Mg/ha/year effectively controlled the disease in Bangka, Indonesia. Mustika (1990) also was of the opinion that the disease could be controlled by application of fertilizers along with mulch and chemicals.

Green manuring with legumes is a traditional practice with Indian farmers to improve the organic matter and nitrogen status of the soils. Addition of organic matter (mulch) to the soil increases water holding capacity of the soil, besides enhancing the fertility status leading to improved growth of plants that can withstand nematode attack. Addition of organic matter and soil amendments enhances the activity of natural enemies particularly the antagonistic fungi suppressive to plant parasitic nematodes. The chemicals released during organic decomposition like azadirichtin (neem), ricin (castor), ammonia, nitrates, hydrogen sulphide, organic acids are all toxic to nematodes (Stirling 1991). DeWaard (1979) observed that the pepper yellows appeared early in the plots without mulching compared to the plots applied with mulch. Mulching with green manure plants reduced root knot nematode population and the incidence of the disease in pepper plantations in Indonesia and Amazonian region (Wahid 1976, deWaard 1979, Ichinohe 1980, 1985). Hubert (1957) was of the opinion that the nematode-fungal complex disease can be controlled by mulching the plants with *Eupatorium*. The effect of mulching pepper plants with *Chromolaena odorata (Eupatorium odoratum)* in controlling the nematodes and yellows disease in Cambodia was also reported (Litzenberger and Lip 1961). However, this was found not effective in pot culture tests in India (Ramana 1992). Barber (cited by Ridley 1912) suggested planting of goat weed *(Ageratum conyzoides)* in the abandoned pits to get rid of the root-knot nematodes as these weeds attract the nematodes and after a time the weeds can be pulled out and burnt. By repeating this process the nematodes may be eliminated. However, this method involves the risk of increasing the nematode populations, if the weeds are not properly removed and destroyed in time.

Addition of chopped leaves of *Glyricidia maculata* (10g/kg soil) under pot culture tests, reduced *R. similis* populations in pepper and increased plant growth (Jasy and Koshy 1992). Kueh and Sim (1992) suggested in addition to adequate fertilization, growing a leguminous cover crop in pepper plantation for improving the growth and vigour of plants as increased root regeneration compensated the root damage caused by nematodes. Growing non-host plants like *Macroptillium atropurpureum, Centrosema pubescens, Clitoria ternatea Cajanas cajan, Arachis hypogea* and *Crotalaria* sp. as cover crops in pepper plantations in Brazil reduced *M. incognita* populations. *Denis elliptica* and *Indigofera hirsuta* are also detrimental to nematode multiplication (Mustika 1991). Nematode antagonistic plants such as *Tagetes patula* is also useful in suppressing root knot nematode populations in black pepper (Mustika 1991, Ramana 1992). However, the feasibility of cultivating such crops in pepper plantations is doubtful.

Addition of organic amendments like organic manures, crop residues, green manures, oilseed cakes, plant extracts etc. improves the soil texture and also enhances the growth of useful microorganisms suppressive to pests and pathogens. Certain oilseed cakes like neem, *karanj (Pongamia glabra), mahua (Madhuca indica),* castor *(Ricinus communis),* mustard (*Brassica* spp.) are commonly used in India (Mishra and Majumdar 1995). Nematicidal properties of neem oil cake is well known and it is attributed to several chemicals occurring in neem such as nimbidin, thionemone, azadirachtin, nimbin, nimbidic acid, etc. However, not much information is available on the effectiveness of these oil cakes for nematode management in pepper. Application of neem cake @ 2 kg/vine twice a year along with fertilizers was found highly effective in suppressing the populations of *M. incognita,* but its effect was not that encouraging against *R. similis* (Ramana *et al.* 1992).

Plant Resistance

Plant resistance is one of the potential, probably the most economical and practical solution. But resistance to nematode pests are not available in many crop plants. Polygenic-horizontal resistance to nematodes is more desirable than vertical monogenie resistance (Fassuliotis and Bhatt 1982). Existence of physiological races or pathotypes in nematodes particularly in *Meloidogyne* species is another factor to be considered in breeding programmes for resistance. The present trend is to evolve varieties tolerant to nematodes rather than aiming at absolute resistance. The tolerant varieties have the ability to grow and yield in the presence of nematodes. In pepper no serious efforts were made in these lines except screening the available cultivars for their reaction to nematodes. Degree of resistance/susceptibility of various cultivars of pepper to nematodes has been reported from India, Malaysia and Sri Lanka.

In Sarawak, Kueh (1986) found cv. *Uthirancotta* as most susceptible, while cultivars like *Balancotta, Belantung, Cheriakaniakkadan, Jambi* and *Kalluvally* are less susceptible to root knot nematodes under field conditions. Among the cultivars tested by Mustika (1990, 1991), cv. *Kuching* appeared to be tolerant to *M. incognita* and *R. similis* compared to *Kalluvally, Jambi* and *Cunuk*. In India, none of the cultivars tested was found resistant to *M. incognita* (Koshy and Sundararaju 1979, Jacob and Kuriyan 1979a, Ramana and Mohandas 1986) and to *R. similis* (Venkitesan and Setty 1978, Ramana *et al.* 1987b). However, Ramana and Mohandas (1986) reported that cv. *Pournami,* a selection from the germplasm, is tolerant to *M. incognita* and field evaluation trials also showed that this cultivar supported less population of nematodes compared to other susceptible cultivars. This is having an average yield of 4.7 kg/plant and a potential yield of 10.8 kg/plant. (Ravindran *et al.* 1992). Paulus *et al.* (1993) screened 45 pepper lines under greenhouse conditions and reported that cultivars like *Balancotta, Jambi* and Hybrid-10 (F1 hybrid of *Balancotta* and *Kuching*) were less susceptible to *M. incognita* and none was resistant to nematode infestation. Though no resistance was reported to *R. similis* from India, Indonesia and Malaysia, in Sri Lanka a variety (Pw 14) was reported resistant to this nematode (Gnanapragasam 1989).

Sources of resistance to plant parasitic nematodes in wild and related species of crop plants is also important which can be incorporated to cultivated species. Attempts made in this direction showed *Piper colubrinum* and *P. aduncum* as highly resistant to *M. incognita* (Ramana and Mohandas 1986, Paulus *et al.* 1993). Wild species, *P. hymenophyllum* and *P. attenuatum,* recorded least root reduction (less than 30%) and minimum nematode multiplication on testing with *R. similis* (Venkitesan and Setty 1978). *P. colubrinum* was immune to *R. similis* also (Ramana *et al.* 1994). Crosses between *P. nigrum* and *P. colubrinum* have not succeeded so far. Hence efforts should be made to identify the gene(s) responsible for the resistance in these species and transfer them to cultivated species through biotechnological approaches to solve the major nematode problem in pepper.

Biological Control

According to Sewell (1965) biological control is “the induced or natural, direct or indirect limitations of a harmful organism or its effects by another organism or group of organisms”. A variety of microorganisms, inhabit soil, some of which are either predatory or antagonistic to plant parasitic nematodes. Perennial cropping systems are sources of potentially useful antagonists of nematodes and they possibly are providing natural suppression of nematodes to some extent (Stirling and West 1991). However, the efficacy of biological control as the sole means of nematode management is still debatable and the present consensus is that this approach can be an integral part of the overall management schedule (Ramana *et al.* 1993). Though several organisms possess antagonistic potential against nematodes, a few fungi and bacteria only are generally considered as biocontrol agents. Very limited research efforts have gone into this area for pepper nematode management. Eapen and Ramana (1996) reviewed the status of biological control of plant parasitic nematodes of spice crops.

Paecilomyces lilacinus

This is an opportunistic fungus present in many types of agricultural soils and has been tested for its potential against root knot nematodes and cyst nematodes of several crops. Sedentary plant parasitic nematodes such as root knot and cyst nematodes are more vulnerable to attack by this fungus. On contact with the egg masses of nematodes, it colonizes and grows rapidly on the eggs that are in the early stages of embryonic development. The chitinolytic enzymes produced by this fungus help in penetration of eggs. Apart from the embryonic disruption, it can also cause suppression through production of diffusible toxic metabolites. Jatala (1986) in his review stated that this fungus has proved its efficacy in suppressing root knot nematodes in various crops. This has the ability to readily colonize the reproductive structures of the nematodes, and it can survive under host free conditions in the soil and is easy to culture in the laboratory.

Inoculation of *P. lilacinus* to rooted cuttings/seedlings of pepper significantly suppressed *M. incognita* populations as evidenced by less damage to roots and increase in total root mass (Friere and Bridge 1985d, Ramana 1994, Sosamma and Koshy 1995). The efficacy was low against *R. similis* (Geetha 1991, Ramana 1994). Freire and Bridge (1985d) also reported from Brazil that this fungus parasitized root knot nematode eggs and suppressed the infestation on pepper. These studies suggest a wider scope for using this fungus as a biocontrol agent against root knot nematode in pepper, but requires large scale field evaluation before inclusion as a component in the integrated nematode management schedule.

Trichoderma species

Trichoderma belongs to hypomycetous group and members of this genus are being used against several pathogenic fungi. Recently they were tested for suppression of root knot nematodes in spice crops particularly pepper and cardamom in India (Eapen and Ramana 1996). In preliminary *in vitro* tests, several isolates of *Trichoderma harzianum, T. hamatum, T. viridae, T. aureoviridae, T. polysporium, T. longibracheatum, T. koningi, T. pseudokoningi* and *Gliocladium virens,* though not colonized, destroyed the root knot nematodes collected from pepper by preventing their embryonic development. Culture filtrates of these fungi also showed nematicidal property (IISR 1995). Further, they are also effective in suppressing *Phytophthora capsicii* (Anandaraj and Sarma 1994b, Sarma *et al.* 1996). Hence they are useful in checking the slow decline disease particularly in India where nematodes and *P. capsici* are involved in the disease.

Vertidllium chlamydosporium

This fungus is a biocontrol agent for root knot and cyst nematodes (Kerry 1990). It readily colonizes rhizosphere and rhizoplane, infects adult females and egg masses and reduces nematode multiplication by inhibiting egg hatching. Freire and Bridge (1985d) reported from Brazil that root knot nematode eggs were parasitized by *V. chlamydosporium*. The occurrence of this fungus in pepper plantations of India was reported for the first time in association with *Trophotylenchulus piperis* (Sreeja *et al.* 1996). This suppressed hatching of *M. incognita* eggs by 41.4 per cent within 5 days and the egg masses were heavily colonized by the fungus in an *in vitro* test. This fungus needs further evaluation as a bicontrol agent for use in pepper.

Vesicular arbuscular mycorrhizal (VAM) fungi

VAM fungi are obligate dependants on plants for their nourishment. Their symbiotic association with roots of crop plants increase the plants' ability to absorb water and nutrients, particularly phosphorus from soil. This increases the tolerance to nematode damage due to higher P status of the plants or by the competitive or antagonistic effect (Smith 1987). The beneficial effects of VAM fungi in several crops are now well established. *Glomus fasciculatum, G. microcarpum* and *Gigaspora gigantea* are associated with the roots of pepper (Sarma *et al.* 1996). The occurrence of VAM fungi on pepper roots was reported by Manjunath and Bagyaraj (1982). Addition of these fungi to the nursery mixture enhanced the growth and root production in pepper rooted cuttings (Anandaraj and Sarma 1994a). In pot culture trials, significant increase in growth and reduction in *M. incognita* infestation and their multiplication were observed when pepper plants were inoculated with VAM fungi, *Glomus mossae, G. fasciculatum, G. etunicatum, Acaulospora laevis* and *Gigaspora margarita* (Anandaraj *et al.* 1991b, Sivaprasad *et al.* 1990, 1992). *G. fasciculatum* was also reported to suppress *R. similis* and *P. capsici* in black pepper (NRCS 1991). These fungi are obligates and need the host plants for their multiplication, so alternative methods for mass production have to be explored.

Pasteuria penetrans

Bacteria as biological control agents against plant parasitic nematodes have not been fully investigated in pepper except for a couple of studies. *Pasteuria penetrans* is an obligate parasite of some nematode species particularly the second stage juveniles of root knot nematodes. It infects the nematode by direct penetration through the cuticle by germinating spores sticking to the body surface of the nematodes. Studies on its efficacy for suppressing the nematodes showed that inoculation with this bacterium suppressed *M. incognita* and *R. similis* infestations and their multiplication. It also improved the growth of the plants (Geetha 1991, Sosamma and Koshy 1995). This bacterium colonized heavily the second stage juveniles of *M. incognita* in laboratory bioassays (IISR 1996).

Other Bacteria

Bacillus pumilis, B. macerans and *B. circulans* also suppressed *M. incognita* populations on pepper and also increased the growth of the plants (Sheela *et al.* 1993).

Attempts were also made to test the efficacy of fluorescent pseudomonads especially *Pseudomonas fluorescens* on root knot nematodes. Several isolates of the bacterium showed inhibitory action on the multiplication of *M. incognita* in pot culture studies (Eapen *et al.* 1997).

Biological control of plant parasitic nematodes in black pepper is only in the initial stages. Many of these potential biocontrol agents have to be evaluated under field conditions before adoption. Methods have to be developed for large scale multiplication and delivery systems particularly for highly potential microorganisms like VAM fungi, *P. penetrans* etc. Attempts have to be made in potentiating these biocontrol agents through biotechnological techniques.

Chemical Control

Nematicides are chemicals used to kill or stall the activity of nematodes and consist of two groups, soil fumigants and systemic nematicides. Most of the nematicides are applied to soil and are translocated from roots to shoots. Use of nematicides was a major component in the management programmes of plant parasitic nematodes in several crops before the importance of the biological control was realized. However, high cost and environmental hazards due to their indiscriminate use are limiting factors in chemical control. But no effective alternative methods are available for large scale adoption so far. Fumigants like DD, Methyl Bromide, Ethylene di Bromide, etc. are highly effective in eliminating nematode populations in the nursery mixture.

Various nematicides like phenamiphos (Nambiar and Sarma 1980), aldicarb-sulphone (Venkitesan and Setty 1979), phorate, DBCP (Venkitesan and Charles 1980) were found effective in controlling nematodes. The granular nematicides namely, Temik 10 G (aldicarb), Thimet 10 G (phorate), Furadan 3 G (carbofuran), applied @ 3 g. a.i./plant, twice a year significantly reduced the populations of *M. incognita* and *R. similis* and improved the health of the plants (Mohandas and Ramana 1987, Ramana *et al.* 1994). In Malaysia carbofuran @ 114 g/plant (Kueh and Teo 1978), phenamiphos and oxamyl (Kueh 1979) were found effective. In Indonesia, Shell DD, Vapam EC, Nemagon 75 EC, Temik 10 G, Furadan 3 G, Nemacur 5 G, Mocap 10 G, Hostathion 5 G, Dasanit 5 G and Basudin 60 EC. were all effective in controlling the nematodes of pepper (Mustika and Zainuddin 1978). Leong (1986) reported that phenamiphos was the most effective nematicide in controlling nematodes in Sarawak. Similarly, in Brazil, Ichinohe (1980) found application of Temik 10G @ 12.5 g or Furadan 5 G @ 50 g/plant twice a year reduced nematode population and improved the growth of the plants. However, in recent years many of these chemicals have been banned for use in agricultural crops due to several reasons. Demand for "pesticide residue free" produce also limits the usage of these chemicals. Hence, research should continue to identify safer chemicals with high potential for nematode control.

CONCLUSIONS

Plant parasitic nematodes, particularly *Radopholus similis* and *Meloidogyne* spp., are major economic constraints in pepper cultivation in all major pepper growing countries. They either on their own or in association with fungi like *Phytophthora* sp. or *Fusarium* spp. cause severe damage to roots leading to slow decline disease. Though a number of chemicals were found effective to manage nematode damage, they are seldom used due to several reasons. An integrated approach with priority to plant resistance and biocontrol agents has to be formulated. Several biocontrol agents suppressive to plant parasitic nematodes have been identified, but their potentials under field conditons on a large scale have to be worked out. Biotechnological approaches for incorporating resistance from wild species to the cultivated and potentiating the biocontrol agents would help in the management of plant parasitic nematodes and in increasing the production and productivity of pepper.

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5.3. DISEASES OF BLACK PEPPER AND THEIR MANAGEMENT IN INDONESIA

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The history of pepper diseases in Indonesia has started with the commercial cultivation in Sumatra and Java. In several places in Sumatra there were great losses for pepper plantations and farmers suffered severely. The experiences suggest that once the diseases occur in a pepper field it is practically impossible to eradicate the pathogen. It was also noticed that the more intensive the cultivation of pepper, in the sub sector of small holdings, the more the problems from diseases as they persist. The specific agroecological conditions seem to favour the development of diseases wherever pepper is cultivated.

In Indonesia, pepper is mostly cultivated by small holders, characterized by low inputs in planting materials, land preparation, fertilization, cultivation, pests control as well as quality of management. Such conditions are experienced by all farmers throughout the country who are in general, poor in knowledge and perception of production constraints, especially on diseases and insect pests of their crops, poor in capital, poor in capability to fulfill their needs for improving their crops. On the other hand, the spread and fast occurrence of a number of production constraints including diseases have increased from time to time.

Research Institute for Spice and Medicinal Crops (RISMC), a governmental institute, is responsible for doing research to help provide technological components to formulate an alternative integrated disease management. At present RISMC has been able to recommend some combination of compatible components to help farmers manage their pepper crops. However, its pratical success still has to be improved by imposing training and field demonstration to all farmers. Such activities are usually done in coordination with the Directorate General of Estate (DGE) through local extension service throughout Indonesia. Some of the controlling factors intensively improved are: agricultural practices, use of bioagents and reporting methods.

Three major diseases of black pepper namely foot rot disease, yellows disease and stunted growth disease are continuously causing severe problems to Indonesian farmers. Foot rot disease, caused by *Phytophthora capsici,* appears to be the most destructive, as it occurs in almost all parts of pepper plantations throughout the country. Yellows disease is caused by a complex of biotic and abiotic factors, such as parasitic nematodes (*Radopholus similis* and *Meloidogyne incognita*), parasitic fungus *(Fusarium solani),* nutrient deficiency and water stress. The stunted growth disease is suspected to be caused by a virus or a mycoplasma—like organism (MLO). These two diseases, in certain areas have also become serious problems. In some pepper gardens, the loss due to the major diseases may be as high as 55 per cent, depending on various factors affecting the whole system of pepper cultivation (Wahid and Sitepu 1992).

FOOT ROT DISEASE

This disease was first reported as a "sudden collapse" disease and was the cause of vine death in Sekampung, South Lampung, Sumatra in 1885. It was later called as foot rot disease in 1928 (Muller 1936). From Sekampung, the disease spread out to other places in South Sumatra. Soepartono (1953) reported that foot rot disease was then observed in many locations, namely, Bengkulu (in 1916), Palembang (in 1918), Aceh (in 1929), South and East Kalimantan (in 1930), West Java (in 1931), Central Java (in 1933) and Bangka (in 1933). At present the disease is found in almost all pepper plantations in Indonesia. Generally the disease incidence is prevalent during the rainy season, especially at the young plants of 2–3 years old. The pathogen infects all parts of the plant. However, leaf lesions occur on susceptible varieties such as *Petaling* I and *Bengkayang*. *Natar* I appears to be tolerant (Kasim 1990). Penetration of the pathogen into leaf tissues usually occurs 4–6 hours after inoculation.

Loss due to foot rot disease varies from time to time. In 1965, plant damage was reported to be as high as 52 per cent in Lampung, while in 1983, it was only about 20 per cent in Simpang Kates, Bangka (Sitepu *et al.* 1985). At the end of 1988, it caused damage to more than 110 ha (3%) of productive vines in West Kalimantan. Investigation revealed that the crops were of the susceptible variety, and they were planted in sloping areas (Manohara *et al.* 1989). Kasim (1990) calculated that about 10–15 per cent of the total crops in Indonesia are damaged by foot rot every year.

The causal agent of foot rot disease from Sekampung was first identified by Muller (1936) as *Phytophthora palmivora* var. *piperis*. In 1985, Tsao and his coworkers obtained some Indonesian isolates and identified them as *P. palmivora* MF4 (Tsao *et al.* 1985). Kasim (1978) identified the causal agent of foot rot from Lampung as *P. capsici* (Tsao and Alizadeh 1988). Seventy five isolates of *Phytophthora* from Indonesia were collected and studied from Bangka, Lampung, West and Central Kalimantan. Colony morphology on carrot agar (CA) and V8 juice agar (V8A) was highly variable, often with radiating striations or petalloid or floral pattern, or without any pattern. On PDA, the colonies were cottony with two types of margin: smooth and irregular. On oat meal agar (OMA), the colony of all isolates were plentifully cottony. Forty one isolates from Bangka, Lampung, West Kalimantan and West Java produced sporangia abundantly on the aerial mycelia. The sporangia were ellipsoid, markedly papillate and tapered at the base. The overall average sporangia length/breadth (L/B) ratio ranged from 1.54 to 2.37. Sporangium papilla was of conspicuous as well as semi-conspicuous type. Double septate sporangia were not found. All isolates were caducous, producing detachable sporangia, each with a long pedicel which is typical of *P. palmivora* MF4 type. The over-all average pedicel length ranged from 56.00 to 119.0 μm.

Sexual reproductive structures were produced when isolates were paired with the mating type. All isolates from Bangka and Pangkalanbun (Central Kalimantan) were A1 type. Almost all isolates from West Kalimantan were also A1 type, except one isolate from Sebopet which was A2 type. Two mating types, A1 and A2, were found in Lampung and West Java. The sexual organs were amphigynous. Younger oogonia had thin walls and hyaline. The walls became thick and amber to golden brown when mature. Antheridia also had thin walls and hyaline (Kasim and Prayitno 1979).

All *Phytophthora* isolates from Indonesia grew well on agar media at temperatures of 8°–32°C, but the optimum temperature for the growth varied depending on the medium, usually at 24°C (Manohara 1988). Thermal death point ranged from 45°–47.5°C (Kasim 1978). The number of germinated sporangia was relatively low at a temperature range of 8°–32°C, because most of the sporangia produced zoospores. The number of germinated zoospores was quite high at temperatures between 8°–36°C. The zoospores generally germinate 30 minutes after losing their motility. The length of the motility period increases with increase of temperature (8°–16°C). The motility period then decreases, until finally no motility at all is observed at 36°C. The period of zoospore motilty is 12 hours at 16°C (Manohara and Sato 1992).

Soil moisture is one of the most important environmental factors for the growth, sporulation and survival of *P. capsici*. The propagules of *P. capsici* (isolates from North Lampung) in latosol soil with 100 per cent field capacity, survive for more than 20 weeks. In podzolic soil, propagules survive for more than 20 weeks when they are kept at 60 per cent field capacity.

In latosol soil and field capacity of 60–100 per cent, the length of saprophytic stage of fungus on pepper leaves is 11 weeks, while on the stem, it is only 8 weeks. When the water content is 60 per cent of field capacity, in the podzolic soil, the saprophytic stage on stems was 10 weeks. The pathogen did not live saprophytically on roots.

YELLOWS DISEASE

Yellows disease of pepper has long been known to affect black pepper plantation in Indonesia, especially on the Island of Bangka, South Sumatra. The disease was first reported to occur on the island of Bangka (van der Vecht 1950), and later spread to West Kalimantan. Annual loss due to the disease may reach 10–32 per cent, and almost all plantations have been infested.

Typical symptoms of yellows disease are relatively thick yellow leaves with a stiff droop, and noticeable defoliation around the vines. These symptoms, may occur both in young and old vines. Usually the disease starts in scattered patches, which gradually increase in size. As the disease advances, the affected area is surrounded by a number of diseased plants in various stages of discoloration. Leaf discoloration usually starts at the bottom of the vines, and spreads to the top, although in many cases symptoms may occur throughout the vines. As the disease advances, the total number of leaves

Table 5.3.1 Parasitic nematodes associated with black pepper in Bangka, Lampung and West Kalimantan*.

No.	Nematode	Bangka	Lampung	West Kalimantan
1.	*Aphelenchus* sp.	+	+	–
2.	*Criconemella* sp.	+	+	+
3.	*Ditylenchus* sp.	+	+	–
4.	*Helicotylenchus*	+	+	+
5.	*Hemicriconemoides sp.*	–	+	+
6.	*Macrophostonia ornata*	+	–	–
7.	*Meloidogyne arenaria*	+	–	–
8.	*M. incognita*	+	+	+
9.	*M. javanica*	+	–	–
10.	*Meloidogyne* sp.	+	–	+
11.	*Pratylenchus coffeae*	+	–	–
12.	*Radopholus similis*	+	–	+
13.	*Tylenchus* sp.	+	+	–
14.	*Xiphinema insigne*	+	–	–
15.	*Xiphinema* sp.	–	–	–
16.	*Hoplolaimus* sp.	–	+	–
17.	*Dorylaimus* sp.	–	+	–

* Source: (Mustika and Zainuddin 1978; Bridge 1978; Djiwanti and Momota 1991).
+: present; –: absent.

on the infected plant become less due to defoliation. The main roots lose their feeder roots, so that dieback and eventually death of the vines usually follows. The symptoms are well pronounced when soil moisture is depleted. *Radopholus similis* was found consistently associated with roots of early affected or apparently healthy vines.

Results of experiments indicated that yellows disease in Bangka is caused by several factors such as infection by nematodes and fungus (Bridge 1978, Mustika 1984), soil nutrient deficiency (Wahid 1976, deWaard 1979), and low soil moisture (Mustika 1984). Studies in Bangka, Lampung, and West Kalimantan revealed that at least 14 genera of parasitic nematodes were associated with pepper (Table 5.3.1). Among them *Radopholus similis* and *Meloidogyne incognita* are often predominant in infecting pepper roots. The role of these two nematode species in association with "slow wilt disease" on pepper in India was also reported (Nambiar and Sarma 1977; Ramana and Mohandas 1987; Ramana *et al.* 1987). Bridge (1978) found several species of fungus associated with roots of diseased plant in Bangka such as *Fusarium oxysporum, F. solani, Cylindrocladium camelliae, Pestalotiopsis* sp. and *Curvularia affinis*. Among these fungi *F. solani* has been known as the cause of foot root disease of pepper in Brazil (Ichinohe 1980).

Further studies indicated that infection by *R. similis* appeared to induce the typical symptoms of yellows disease, and this was more pronounced when *M. incognita* and/ or *F. solani* were also present. *Meloidogyne incognita* appeared not to induce the typical symptoms of yellows disease. When the nematode was present in combination with *F. solani,* flaccid wilting and yellowing of the leaves was found (Mustika 1990). *Radopholus similis* penetrated the roots of black pepper within 24 hours after inoculation. Female nematodes laid eggs inside the roots, within five days of inoculation a clear destruction of tissues in the roots was found. Nematodes do not enter the stelar portion, but the xylem vessels appeared to be obstructed by "gumlike substances". In carrot disc culture, the nematodes complete life cycle within 20–30 days at a temperature ranging from 20 to 27°C (Mustika 1990).

When both *R. similis* and *M. incognita* were present concomitantly, they mutually inhibited reproduction. *Radopholus similis,* however, tended to be more dominant species than *M. incognita* (Mustika 1990). It was also found that the population of *R. similis* and *M. incognita* were suppressed by the presence of *F. oxysporum* (Mustika 1990).

On the basis of chemical analysis of soil and diseased plant parts, de Waard (1979) suggested that the cause of pepper yellows disease in the Bangka island is nutrient deficiency, especially of nitrogen and potassium. Indication that water stress may be associated with disease occurrence was also noted (de Waard 1986). The effect of nematode infection on plant nutrient status have been reported by many workers (Chitwood *et al.* 1952; Feldman *et al.* 1961; Nasr *et al.* 1980; Smith and Kaplan 1978). Jenkins and Malek (1966) suggested that nematodes in some way alter plant's mechanism of absorbtion, translocation, and accumulation of mineral constituents. Recent studies indicate that climatic conditions and soil moisture level appear not only to influence the growth of pepper plants, but also to affect the yellowing of the leaves. Plants grown at 60 per cent of field capacity when infected with *R. similis M. incognita* and *F. solani,* show less growth as compared to those grown at field capacity. Yellowing of the leaves was observed earlier under the drier condition (Mustika 1990).

STUNTED GROWTH DISEASE

Stunted growth disease is already observed in pepper plantations in Lampung, Bangka (South Sumatra), West Kalimantan and West Java. It is characterized by stunted growth at certain vines or the whole plant, leading to death. In Indonesia, Sitepu and Kasim (1976) found the disease in Lampung and classified it as a disease of unknown etiology. The disease is considered very dangerous to future pepper plantations in Indonesia. The symptoms of the disease in pepper are similar to those found in other crops caused by virus and MLO (Hibben *et al.* 1986). The prominent symptoms are: (1) abnormality of the growth of the plant such as: small leaves, flowers, fruits and roots, and short petioles and internodes and (2) mosaic pattern in the leaf. In the field, Kasim (1985) described infected plants as having leaves which are small, uneven in form, stiff and brittle, as well as yellowish in colour. In Lampung, Firdausil (1989) found that the infected vines possess stunted shoots, small, curling and yellow leaves with uneven surface and indicating mosaic pattern, short internodes, small spikes with less or no berries.

Many authors (Holliday 1959, Sitepu and Kasim 1976, Randombage and Bandara 1984) stated that the disease is caused by either virus or MLO. Holliday (*in* Kueh 1979) considered this stunting disease of pepper as being caused by virus, however, no occurrence of virus or MLO was observed in infected tissues. The same result was also reported by Randombage and Bandara (1984) dealing with little leaf disease in

Sri Lanka. They reported that the cause was MLO, but this was not proven satisfactorily. Firdausil (1989) using electron microscope, did not observe any virus particle in infected plants. However, a particle which is similar to MLO was found. This is partly supported by the unsuccessful mechanical transmission of the disease to other plants.

The disease has spread in almost all the pepper plantations in Indonesia. The disease can be transmitted through planting material. Holliday (1959) reported that pepper stunted disease can be transmitted by insect *Pseudococcus citri*. Field observation indicated that the insect *Aphis* sp. is also found in plants showing the symptoms of the disease.

Result of the experiment on mechanical transmission (inoculation with infected plant extract) indicated that the disease cannot be transmitted mechanically as there were no symptoms in the tested plants. This suggests that virus was not the causal agent of the disease. Result of the experiment on transmission through grafting, showed that the disease can be transmitted within a period of 30–90 days after grafting. This indicates that the disease is caused by a pathogen but it does not distinguish between a virus or an MLO. Diene Staining (Deeley *et al.* 1979) stains MLO infected phloem to dark blue, while it will be clear in healthy plant. When used in pepper the phloem of both infected and healthy plants exhibited the same dark blue color. However, there were differences in the size and the formation of phloem cells between infected and healthy plants. This method also could not provide information on whether the disease is caused by MLO or not.

Pepper plants grown in soil taken from spots before the plant got infection did not produce the expected symptoms. From the same soil, nematodes were also isolated to determine their role as vectors of the virus. Although nematodes were present, none of them was known to act as vector of virus. Further investigation was done by using electron microscope. No virus was detected, however particles similar to MLO were noticed.

The disease affected 23.3 per cent of black pepper plantations in Lampung in 1987. The incidence increased to 30–40 per cent in 1990. Field observations indicated that planting materials such as cv. *Jambangan* may facilitate the spread of the disease. It has been noted that by the end of rainy season, the cv. *Jambangan,* especially, the new shoots growing after pruning tend to show stunted disease. Also if less fertilizer is given to the plant, the plant becomes weak and this will increase the susceptibility of the crop to infection.

The role of insect should also be taken into account. At the onset of rainy season, the populations of insects are high, at the same time symptoms of the disease become evident. (See Chapter 5.1)

STRATEGY OF DISEASE MANAGEMENT

Foot rot disease

Research on biological control showed that some fungi and bacteria were able to suppress the growth of *P. capsici*. Among the fungal antagonists, *Tricboderma* spp.

are the most potential agents for biological control. This fungi caused lysis of mycelium and zoospore and inhibited the production of sporangia (Mulya and Manohara 1988).

Soil amendment with organic mixture comprising of rice straw, corn, soybean, peanut and mungbean, reduced foot rot disease by 20–50 per cent (Kasim 1985). Root exudates *of Allium fistulosum, A. ascalonicum, A. shoenoprasum* and *A. sativum* inhibited zoospore germination (Manohara *et al.* 1994). Observation on the rhizosphere of *Allium* spp. showed the presence of some microbial antagonists including *Trichoderma* and fluorescent bacteria. Based on the results it was concluded that *Allium* spp. have a good prospect for controlling *P. capsici*.

There were no pepper cultivars showing resistant response to *P. capsici*. However, some are tolerant: *Natar* I, *Bangka, Pulau Laut, Merapin, Banjarmasin* and *Daun Lebar* (Sitepu and Prayitno 1979; Kasim and Prayitno 1985).

To identify possible genetic sources of resistance, seven *Piper* species were tested. The results showed that *Piper colubrinum* green and pink, *P. hirsutum* and *P. arifolium* were resistant to *P. capsici* (Kasim 1985). These resistant species were used as root stocks for the susceptible cultivated pepper (Nuryani 1981). This method, however, was not successful because after two years, the graft combination was broken, possibly due to incompatibility.

Chemical control measures were effective in reducing propagules of the pathogen of foot rot disease in the field. Repeated applications do not automatically promise complete control, therefore fungicides are focused on preventive than curative measures. Screening of some fungicides done under *in vitro, in vivo* and field conditions, showed that systemic fungicides such as Metalaxyl 2 G at the rate of 50–100 g/plant at three months of interval, Fosetyl—A1 80 WP at the rate of 2–4 g/l with 14 days of interval (Sitepu *et al.* 1985), and Phosphoric acid 400 AS at the rate of 5 ml/l with 14 days of interval can be recommended for the control of foot rot disease. This component of technology should be applied in association with integrated pest management imposed on pepper cultivation in the country.

Recommended strategy for management of foot rot disease under specific conditions is as given below. In the national programme of disease management, regular and intensive training is an important part imposed on all people concerned.

Before planting condition

If the propagules of *P. capsici* are found in the location where pepper is being planted, appropriate actions should be taken to suppress growth rate of pathogen and inactivate their infection. Tolerant variety such as *Natar* I, one of the already released varieties, is recommended for particular areas. If the tolerant variety is not sufficient, the farmer has to eradicate the source of inoculum by preparing the land properly, followed by incorporating organic matter into the soils, using healthy plant materials and constructing good drainage systems.

After planting condition

Actions recommended for integrated management are:

- Construct and manage drainage systems, in the whole garden, in order to reduce excessive water logging
- Fertilize the crops at recommended dosage and time
- Prune regularly the dense branches of live support to improve micro environmental conditions
- Prune the lower branches of healthy vines up to 30 cm from the ground surface in the early part of rainy season
- Inspect the plantation regularly and eradicate infected plants, and at the same time report to local plant protection officer
- Do not replant diseased area with new pepper or other crops susceptible to the pathogen for at least 6 months
- Advise farmers on the use of chemical control
- Do not recommend clean weeding especially during rainy seasons
- Thoroughly wash and sterilise all farm tools with disinfectant after using in diseased area
- The farmer who works in diseased area should not enter a healthy area, before preventive treatments are taken
- Prevent any kind of animals from entering into the plantation.

Yellows disease

Considering the complexity of the causal factors of the disease, an integrated control measure seems to be the most promising method. This control measure should be based mainly on reducing the population of *R. similis, M. incognita* and *Fusarium* spp., as well as other fungi, and to create a condition favourable for the growth of black pepper. Some of the components for integrated control are: (1) cultural practices, (2) pesticides, (3) tolerant varieties, and (4) biological agents.

Cultural practices are primarily important for preventive control of the disease, aiming to obtain favourable conditions for the growth of black pepper plant, but unfavourable for nematodes and fungi to develop and to infect the roots. Wahid (1976) found that application of 4×400 g RBS (Rustica Blue Special) vine^{-1} year^{-1} prevents the development of yellows disease. De Waard (1979) suggested application of fertilizers at a dose of 400 kg N, 180 kg P, 480 kg K, 425 kg Ca and 112 kg Mg ha^{-1} year^{-1} in combination with mulch for effective control of yellows disease.

The usage of mulch consisting of plant debris of alang-alang *(Imperata cylindrica),* fern etc., is needed to improve soil physical conditions for stimulating pepper growth. Mulch creates a crumb structure of the soil, stabilizes the soil temperatures evenly to 25°C at day and night, tends to produce more K, creates a condition favourable for root development and adequate opportunity for uptake of minerals (De Waard 1979). Reduction of nematode populations by mulch, may be due to the increase of K available to the plant as found by Oteifa (1953), and Kirckpatrik *et al.* (1959). Wahid (1976) recorded about 18 per cent reduction of disease incidence in Bangka, after a 10–20 cm thick mulching with alang-alang. DeWaard (1979) found that under Bangka condition, the symptoms of yellows disease appeared earlier in plots without mulch than in plots with mulch. In plots with mulch, soil moisture was maintained at pF values, whereas in plots without mulch, pF values tended to rise towards wilting point.

A number of pesticides have been found effective in reducing nematodes on black pepper both in pot and field trials. Vapam, Nemagon, Temik, Furadan, Nemacur, Mocap, Hostathion, Dasanit and Basudin were found to reduce population of *Meloidogyne* spp. and *R. similis* in green house trials (Mustika and Zainuddin 1978). Under field conditions in Bangka, application of Aldicarb 4×50 g $vine^{-1}$ $year^{-1}$ to the soil in combination with Mancozeb 4×14 g $vine^{-1}$ $year^{-1}$ as soil drenching was able to reduce severity of yellows disease up to 15 per cent, and increased the production of green berries.

In Bangka conditions, where these two nematode species are found, cv. *Kuching* produced higher yield than did cv. *Jambi* and *Cunuk*. Mustika and Dhalimi (1986) reported that cvs. *Lampung Broad Leaf, Kuching* and *Bangka* were tolerant against *M. incognita,* as the berries production of these varieties was less affected. Further studies in “climate chamber conditions” revealed that cv. *Kuching* appeared to have tolerance to *M. incognita* and *R. similis* compared to other tested cvs. *Kalluvalli, Jambi* and *Cunuk* (Mustika 1990). These data indicated that *Kuching* is the most tolerant variety against *Meloidogyne* spp. and *R. similis*.

Plant parasitic nematodes can be controlled biologically by using natural enemies, such as fungi and bacteria. Several fungi have been known to reduce nematode populations such as *Arthrobotrys* spp., *Dactylaria* spp., *Verticillium* spp. and *Paecilomycess* spp. (Jatala 1986). Preliminary study in Bangka showed that juvenile of *Meloidogyne* spp. in the soil were infected by *Arthrobotrys* sp., *Monacrosporium* sp. and *Pasteuria penetrans*. However the prospect of controlling parasitic nematodes with such bioagents, and their application at economic scale of control have not been considered at present.

Present recommendation for control of yellows disease is the application of various compatible components to support the integrated strategy, as follows:

- Replace badly infected areas with tolerant varieties i.e. *Chunuk, Jambi* and *Kuching*
- Implement good and proper cultivation (weedings, fertilizations, mulchings etc.) to productive vines
- Inspect all crops regularly and treat infected vines or eradicate those which are damaged badly
- Allow infected areas to expose for six months before planting with new varieties
- Advice farmers in using pesticides either for preventive or for currative measure.

Stunted growth disease

Some control measures to combat the disease are:

- Apply appropriate cultural practices such as fertilization, pruning both support trees and pepper vines and weeding
- Due to experience that repeated use of pruning tools can induce (transmit) the disease, it is suggested to be strongly careful in using tools
- Advice farmers to apply insecticides regularly for controlling insect vectors
- Immediately eradicate plants indicating symptoms of the disease
- Use of bactericide containing tetracycline to combat MLO.

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6. INSECT PESTS OF BLACK PEPPER

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Infestation by insect pests is one of the main factors responsible for the low productivity of pepper in major pepper growing countries. Pepper is infested by 56 genera/species of insects in India damaging various parts of the vine such as roots, stems, shoots, leaves, spikes and berries. However, when the nature and extent of damage is taken into consideration, *pollu* beetle (*Longitarsus nigripennis* Mots.), top shoot borer (*Cydia hemidoxa* Meyr.), leaf gall thrips (*Liothrips karnyi* Bagn.) and scale insects (*Lepidosaphes piperis* Green and *Aspidiotus destructor* Sign.) could be considered as major pests. The other genera/species belonging to diverse groups are minor pests though some of them can cause severe damage to the crop sporadically in certain locations. Information on insect pests of pepper in India are available mainly from Devasahayam *et al.* (1988) and Premkumar *et al.* (1994). The major insects pests of pepper in Indonesia and Malaysia are pepper weevil/stem borer (*Lophobaris piperis* Marshl.), pepper bug (*Dasynus piperis* China) and tingid bug/blossom bug (*Diconocoris hewetti* Dist.). Information on various aspects of these pests are mainly available from Kueh (1979) and Deciyanto and Suprapto (1991). The information available on distribution, nature and extent of damage, life history, seasonal population, resistance, natural enemies, alternate hosts and management of these insect pests in India, Indonesia and Malaysia is reviewed here. A list of these insect pests and the plant parts affected by them is provided in Tables 6.1 and 6.2.

MAJOR INSECT PESTS OF PEPPER IN INDIA

Pollu Beetle *(Longitarsus nigripennis)*

Distribution

The *pollu* beetle is the most destructive pest of pepper in India and its incidence was reported to be higher (20–30 per cent) in the plains of Malabar (North Kerala) and low (5–10 per cent) in Wynad and Travancore (South Kerala) (Directorate of Agriculture, Madras 1954). Premkumar and Nair (1988) conducted comprehensive surveys in 128 locations covering most of the major pepper areas in Kerala and reported that the pest infestation was higher in Kannur (Cannanore), Kozhikode (Calicut) and Kottayam districts wherein 10–32 per cent of berries were damaged by

Table 6.1 List of insects recorded on pepper in India.

Genus/Species	*Plant part affected*
Order: Orthoptera	
Family: Acrididae	
Xenocatantops humilis (Serville)	Leaf
Order: Hemiptera	
Family: Cicadellidae	
Amrasca devastans (Dist.)	Shoot, Leaf
Family: Aleyrodidae	
Aleurocanthus piperis Mask.	Leaf
Aleurodicus dispersus Russell	Leaf
Bemisia tabaci (Genn.)	Leaf
Family: Aphididae	
Toxoptera aurantii (B. de F.)	Shoot, Leaf
Family: Pseudococcidae	
Ferrisia virgata (Ckll.)	Shoot, Leaf, Berry
Icerya sp.	Leaf, Berry
I. aegyptiaca (Dgl.)	Leaf
Planococcus sp.	Shoot, Leaf, Root
P. citri (Risso)	Shoot, Leaf, Berry
P. minor (Mask.)	Shoot, Leaf
Pseudococcus sp.	Shoot, Leaf
P. longispinus (Targioni)	Shoot, Leaf
P. orchidicola Takahashi	Shoot, Leaf
Family: Coccidae	
Coccus piperis Green	Leaf
Marsipococcus marsupialis (Green)	Leaf
Family: Diaspididae	
Aspidiotus destructor Sign.	Leaf, Berry
Anomalococcus indicus Ayyar	Stem
Chionaspis raricosa Green	Stem, Leaf, Berry
Lepidosaphes piperis Green	Stem, Leaf, Berry
Parlatoria pergandii Com.	Leaf
Pinnaspis aspidistrae Sign.	Stem, Leaf, Berry
P. marchali Ckll.	Stem, Leaf, Berry
P. strachani (Cooley)	Stem, Leaf, Berry
Protopulvinaria longivalvata Green	Leaf
Pseudaulacaspis sp.	Stem, Leaf
P. cockerelli (Cooley)	Stem, Leaf, Berry
Unaspis sp.	Leaf
Family: Miridae	
Disphinctus maesarum Kirk.	Shoot, Leaf
Helopeltis antonii Sign.	Shoot, Leaf
Family: Pentatomidae	
Cyclopelta siccifolia Westw.	Shoot, Leaf
Udonga montana (Dist.)	Shoot, Leaf

Table 6.1 (continued)

Genus/Species	*Plant part affected*
Order: Thysanoptera	
Family: Phlaeothripidae	
Liothrips chavicae Z.	Leaf
L. karnyi Bagn.	Leaf
L. pallipes Karny	Leaf
Order: Coleoptera	
Family: Scarabaedidae	
Holotrichia fissa Brenske	Root
Family: Cerambycidae	
Diboma procera Pasc.	Stem
Pterolophia annulata Chevr.	Stem
P. griseovaria Breuning	Stem
Family: Curculionidae	
Cylas formicarius F.	Stem
Eugnathus curvus Faust	Leaf
Myllocerus sp.	Leaf
Family: Chrysomelidae	
Hermaeophaga sp.	Leaf
Lanka sp.	Leaf
Longitarsus nigripennis Mots.	Shoot, Leaf, Spike, Berry
Neculla pollinaria Baly.	Leaf
Pagria costatipennis Jacoby	Leaf
Tegyrius sp.	Leaf
Order: Diptera	
Family: Cecidomyiidae	
Cecidomyia malabarensis Felt.	Shoot, Leaf, Berry
Unidentified cecidomyid	Leaf
Unidentified cecidomyid	Stem
Order: Lepidoptera	
Family: Limacodidae	
Latoia lepida Cram.	Leaf
Thosea sinensis Wlk.	Leaf
Family: Tortricidae	
Cydia hemidoxa Meyr.	Shoot
Family: Saturnidae	
Cricula trifenestrata Helf.	Leaf
Family: Noctuidae	
Spodoptera litura F.	Leaf
Family: Geometridae	
Synegia sp.	Leaf, Spike

Table 6.2 List of insects recorded on pepper in Indonesia and Malaysia.

Genus/Species	*Plant part affected*
Order: Orthoptera	
Family: Acrididae	
Cyrtanthacris varia	Leaf
Order: Isoptera	
Family: Rhinotermitidae	
Coptotermes curvignathus Holgmr.	Root, Stem
Order: Hemiptera	
Family: Membracidae	
Centrotus sp.	Leaf
Telingana flavipes Kby.	Leaf
Family: Cicadellidae	
Codusa sp.	Leaf
Jassus sp.	Leaf
Kana sp.	Leaf
Family: Aleyrodidae	
Aleurodicus destructor Quaint	Leaf
Family: Aphididae	
Aphis sp.	Shoot, Leaf
Toxoptera aurantii (B. de F.)	Shoot, Leaf
Family: Pseudococcidae	
Ferrisia virgata (Ckll.)	Shoot, Leaf, Berry
Planococcus citri (Risso)	Shoot, Leaf, Berry
Family: Coccidae	
Coccus sp.	Stem, Leaf, Spike
Ceroplastes sp.	Stem, Leaf
Paralecanium sp.	Stem, Leaf
Pulvinaria sp.	Stem, Leaf
Saissetia sp.	Stem, Leaf
Family: Diaspididae	
Aspidiotus sp.	Stem, Leaf
Chrysomphalus sp.	Stem, Leaf
Pinnaspis sp.	Stem, Leaf
Protopulvinaria sp.	Stem, Leaf
Pseudaonidia sp.	Stem, Leaf
Family: Tingidae	
Diconocoris hewetti Dist.	Spike
Diplogomphus hewetti Dist.	Spike
Elasmognathus greeni Kby.	Spike
E. hewetti Dist.	Spike

Table 6.2 (continued)

Family: Miridae	
Helopeltis antonii Sign.	Shoot, Leaf
Family: Coreidae	
Dasynus piperis China	Berry
Order: Thysanoptera	
Family: Phlaeothripidae	
Liothrips chavicae Z.	Leaf
L. crassipes	Leaf
L. pallipes Karny	Leaf
Order: Coleoptera	
Family: Scarabaeidae	
Lachnosterna bidentata Burm.	Leaf
Family: Cerambycidae	
Pelargoderus bipunctatus Dalm.	Leaf
Family: Chrysomelidae	
Aphthonmorpha collaris	Leaf
Family: Curculionidae	
Lophobaris sp.	Stem, Berry
L. piperis Marshl.	Stem, Berry
L. serratipes Marshl.	Stem, Berry
Order: Lepidoptera	
Family: Limacodidae	
Latoia darma Moore	Leaf
L. lepida Cram.	Leaf
Thosea sinensis Wlk.	Leaf
Family: Tortricidae	
Cydia hemidoxa Meyr.	Shoot, Leaf
Family: Geometridae	
Borbacha pardaria Guen.	Leaf

the pest. Plantations with more than 20 per cent damage were mainly seen in Kozhikode District. The pest infestation was higher in plains and in areas below 300 m MSL and there was no damage in areas above 900 m MSL. However, stray infestations of the pest have occasionally been noticed recently in Wynad, Idukki and Kodagu (Coorg) districts in Kerala and Karnataka above 900 m MSL (Devasahayam 1992a).

Estimates on loss in yield caused by *pollu* beetle infestations on pepper varied during different years and earlier reports indicated that the loss was 6–21 per cent (Thomas and Menon 1939) and 30–40 per cent (Rehiman and Nambiar 1967) in Kerala. Recent surveys conducted in Kannur District (a major pepper growing area in

Kerala) indicated that among all the causal factors contributing to yield loss, the most serious was infestation by *pollu* beetle which accounted for about 13 per cent loss (Prabhakaran 1994).

Damage

Adult beetles feed on tender shoots, leaves and spikes. On tender shoots and spikes the beetles scrape the tissues and feed on them resulting in black sunken patches. On tender leaves the feeding activity of beetles results in the formation of small irregular circular holes. Severely infested shoots, leaves and spikes often rot and drop due to the invasion of secondary microorganisms. However, the damage caused by grubs is more severe and striking. The grubs bore into tender berries and feed on the internal contents. The infested berries turn yellow initially and later black and crumble when pressed (the term *pollu* denotes the hollow nature of the infested berries in Malayalam—the local language of Kerala). The infested berries are generally found in groups of 2–4 and a single grub is responsible for damaging all the berries in the group. Sometimes the entire distal portion of the spike dries up when the grub, while tunnelling through from one berry to another, damages the main stem of the spike (Figure 6.1a–d). The pest infestation is generally more severe in shaded areas in the plantation. Vines trailed on standards (support trees) producing heavy shade also tend to have higher infestations (Premkumar and Nair 1988).

Life history and seasonal population

Adults are small beetles measuring about 2.5 mm×1.5 mm in size, the head and thorax being yellowish brown and the abdomen brown; the elytra is black. The femur of the hind pair of legs is considerably enlarged and the beetles jump away quickly when disturbed. The adults have been described in detail by Maulik (1926) and Premkumar (1980). An easy method for sexing live adults based on the presence of a sclerotized spine attached to the mid-ventral wall of the genital chamber and visible through the pale sternal plates in the abdomen of females has also been described (Vidyasagar *et al.* 1988). The morphometrics of various stages have been provided by Premkumar (1980) and Babu (1994).

Information on the life history of *pollu* beetle is available from many sources (Ayyar 1920; Ayyar *et al.* 1921; Rao and Ramaswamiah 1927; Babu 1994). The eggs are laid by the female beetles on the rind of tender berries in a shallow elliptical hole made by scraping the tissues. The eggs are laid singly or in groups of 2–3 in each hole which are covered with faecal matter after deposition. Sometimes the eggs are also laid on tender shoots and spikes. The eggs are oval and yellow when freshly laid and measure about 0.75 mm in size. The eggs hatch into creamy white grubs measuring about 1.5 mm in length in 3–8 days. There are three larval instars lasting for 20–40 days. Fully grown grubs are creamy yellow measuring about 5.5 mm in length. Pupation occur in the soil in earthen cocoons. The pupa measures about 3.0 mm×1.5 mm in size and lasts for 6–8 days. There are many overlapping generations in a year. Eggs laying

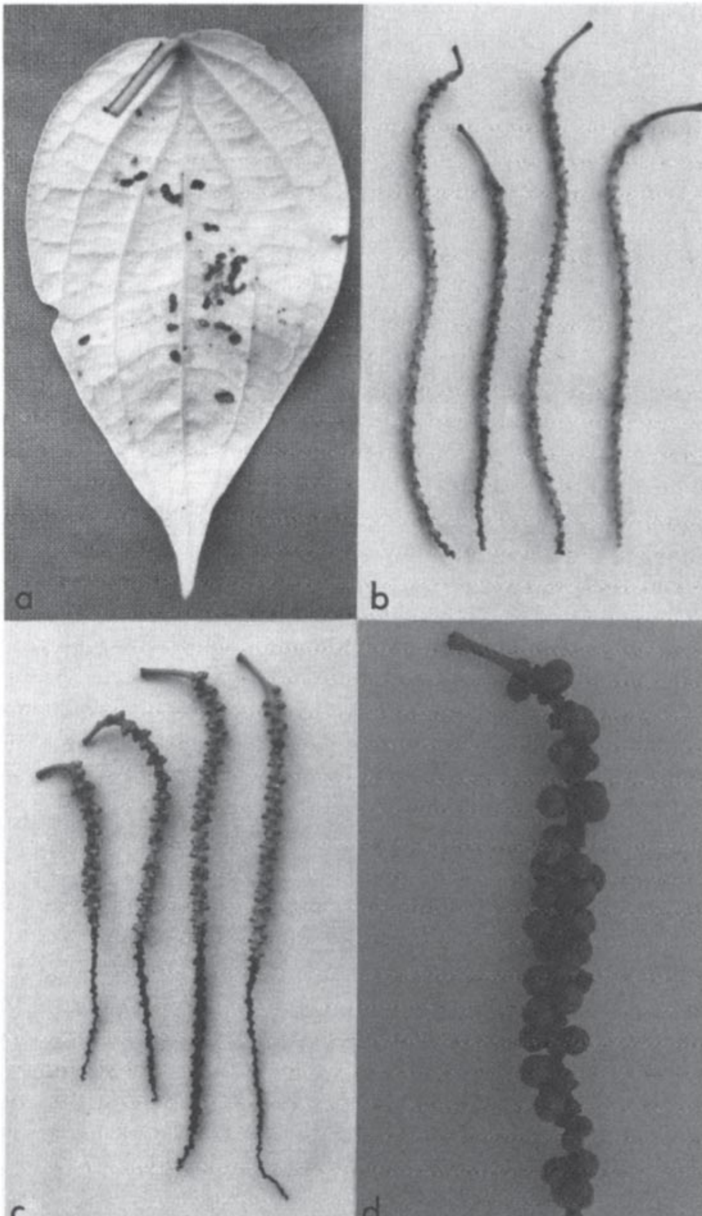

Figure 6.1 Infestation of *pollu* beetle on pepper.

a. Tender leaf damaged by adults

b. Tender spikes damaged by adults

c. Tender spikes damaged by grubs

d. Tender berries damaged by grubs

does not occur during December-May when the berries mature and are harvested. The adults are present in reduced numbers in the field during this period and they survive by nibbling mature leaves.

Studies on seasonal population of *pollu* beetle in Kerala indicated that the adult population was higher during July-January and May-September at Kozhikode and Kottayam districts, respectively. The pest population was positively and significantly correlated with rainfall. Rainfall probably has an indirect effect on the pest population, helping the plants to put forth new flushes and spikes, thus providing adequate feeding and breeding sites for the pest. The correlation between relative humidity and pest population was not significant. The correlation between temperature and pest population was negative and significant. Temperature probably has an indirect deleterious effect on the pest population since adequate feeding and breeding sites are not available during periods of high temperature (January-April) (Premkumar and Nair 1984).

Resistance

Wide variation in resistance/susceptibility of pepper cultivars to *pollu* beetle is observed in the field. Forty four cultivars of pepper maintained at Pepper Research Station, Panniyur (Kerala) were screened against *pollu* beetle and among them, *Uthirankotta* Types I and II, TMB V, *Shimoga* and *Kalluvally* Type II were less susceptible to the pest (Pillai and Abraham 1979). Among the four cultivars in which observations were recorded in the field, *Kalluvally* and *Karimunda* were least susceptible to the pest in North and South Kerala, respectively (Premkumar and Nair 1988). Four cultivars, relatively resistant to the pest under field conditions were identified among the 185 germplasm collections of pepper maintained at the Experimental Farm of the Indian Institute of Spices Research (IISR) at Peruvannamuzhi (Kozhikode District, Kerala). Six wild species of *Piper,* namely, *P. colubrinum* Link, *P. chaba* Hunter, *P. longum* L., *P. attenuatum* Ham. ex Miq., *P. barberi* Gamble and *P. hymenopkyllum* Miq. were also resistant to the pest.

Natural enemies

Very few natural enemies have been recorded on *pollu* beetle. These include an unidentified entomophagous nematode (Mermithidae), a predatory spider (Araneae) and *Oecophylla smaragdina* Fabr. (Formicidae). However, the level of parasitization/predation by these natural enemies was quite low and they may not be of much significance in the control of the pest in the field (Devasahayam and Koya 1994a).

Management

Application of insecticides is the only viable solution for the control of *pollu* beetle infestation. Various insecticides have been evaluated in the field for the control of the pest and only recent work are mentioned here. Evaluation of three promising insecticides at two locations (Kozhikode and Kottayam districts, Kerala) and seven insecticides in Kozhikode District indicated that spraying of endosulfan 0.05 per cent or quinalphos 0.05 per cent during July and October was more effective in controlling the pest infestation (Premkumar *et al.* 1986). In another series of trials, nine insecticides were evaluated in Kozhikode and Kottayam districts and endosulfan, quinalphos, methamidophos and methyl parathion (0.05% each) were more effective in controlling the pest infestation when sprayed during June and September (Premkumar and Nair 1987a). Three rounds of spraying endosulfan 0.05 per cent during May, July and September has also been suggested for the effective control of the pest infestation (Nandakumar *et al.* 1987).

Since use of insecticides could result in pesticide residues in the product, development of alternate methods of control has been receiving increasing attention in recent years. Laboratory bioassays conducted with entomopathogenic fungi such as *Beauvaria bassiana* Bals. (Vuill.) and *B. brongniartii* (Sacc.) Petch. gave promising results against grubs indicating their potential in the control of the pest. Leaf extracts of *Chromolaena odorata* L., neem (*Azadiracbta indica* A. Juss.) and nuxvomica (*Strychnos nux-vomica* L.) and neem oil, neem seed kernel extract and custard apple (*Annona squamosa* L.) seed extract possessed appreciable antifeedant activity against *pollu* beetle in laboratory bioassays (Devasahayam and Leela 1997). Some of the commercial neem products were also effective in reducing the pest damage in the field indicating their potential in the development of ecofriendly pest management schedules (Devasahayam and Anandaraj 1997).

Top Shoot Borer *(Cydia hemidoxa)*

Distribution

Top shoot borer is a serious pest of pepper in young plantations (up to 2–3 years old) and is widely distributed throughout Kerala in the plains and also at higher altitudes. In South Kerala, up to 48 per cent of shoots were damaged in a 1 year old plantation (Pillai 1978); however, even up to 100 per cent infestation of new shoots has also been observed in young plantations in some areas.

Damage

Larvae of top shoot borer infest tender, terminal orthotropic shoots especially those that adhere to the standards. The earlier instar larvae scrape and feed on the epidermis of tender terminal shoots and sometimes on tender leaves also. The later instars bore into tender stems and feed on the internal contents resulting in decay and drying up of infested shoots (Figure 6.2). Generally a single inter nodal region is sufficient for a larva to complete its development. Consequent to the death of the terminal shoot, new shoots arise from the axillary buds which may also get attacked subsequently. Repeated infestation of tender terminal shoots affects the growth of vine and its establishment especially during early stages. Up to 57 per cent reduction in growth was observed on 1 year old vines when there were three repeated infestations on the same vine during a year (Devasahayam and Koya 1993a).

Figure 6.2 Tender terminal shoot of pepper damaged by top shoot borer.

Life history and seasonal population

The adults are small moths with a wing span of 10–15 mm, the forewings being crimson red and yellow and the hind wings grey. The adults have been described by Meyrick (1931). Eggs are yet to be observed in the field. There are five larval instars. Fully grown larvae are greyish green and measure 12–14 mm in length. The larval period lasts for a maximum of 14 days. Pupation generally occurs either within the infested shoot or just outside it. The pupae are elongated and measure about 2 mm in length; pupal period lasts for 8–10 days (Visalakshi and Joseph 1965).

The pest infestation is observed in the field throughout the year but is higher during the monsoon period (August–December) when young vines actively grow and numerous succulent shoots are available on them (Visalakshi and Joseph 1965).

Natural enemies

A few natural enemies including five genera/species of hymenopterous parasitoids, an entomophagous nematode and a mite have been recorded on top shoot borer (Devasahayam and Koya 1994a). At Peruvannamuzhi, among the natural enemies, *Hexamermis* sp. (Mermithidae) and *Apanteles cypris* Nixon (Braconidae) were more common parasitizing up to 76.7 and 20.0 per cent of larvae during August and September, respectively (Devasahayam and Koya 1993b, 1994b).

Management

In spite of the serious nature of the pest infestation in younger plantations, very few insecticides have been evaluated for their effectiveness in controlling the pest. In areas infested with *pollu* beetle, it has been suggested that the insecticide spray (endosulfan 0.05%) given for this pest is adequate to control top shoot borer also (Banerjee *et al.* 1981b). Spraying of monocrotophos 0.05 per cent twice a year during June and September has also been suggested for controlling the pest (NRCS 1990).

Leaf Gall Thrips *(Liothrips karnyi)*

Distribution

Leaf gall thrips are persistent pests of pepper and are more serious on younger vines especially at high altitudes. The pest is also very common in nurseries in the plains. In South Wynad, a major pepper area in Kerala, leaf gall thrips are the most important pest of the crop in that region (Banerjee *et al.* 198la). Surveys conducted in major pepper areas in Kerala, Karnataka and Tamil Nadu indicated that the pest infestation was more serious in Wynad, Idukki, Thiruvananthapuram (Trivandrum) (Kerala), Shimoga, Kodagu (Karnataka) and Nilgiris (Tamil Nadu) districts; a positive and significant correlation was observed between pest incidence and altitude (Devasahayam 1992b).

Damage

Leaf gall thrips initially infest tender leaves causing the leaf margins to curl downwards and inwards resulting in the formation of marginal, tubular, hypophyllous galls. As the infested leaves grow they become crinkled, malformed and reduced in size; the leaf margins also turn chlorotic later (Figure 6.3). The developmental and comparative morphology of leaf galls have been studied. Gall development involves marginal infolding, rolling of the folded region, thickening of gall lamina and maturation of the gall. The process of maturation involves epidermal hypertrophy and proliferation and formation of sclereid bands and vascular proliferation (Raman and Ananthakrishnan 1983). Since the pest infestation is generally more serious on younger vines, the growth of the vine may be affected in severe cases of infestation.

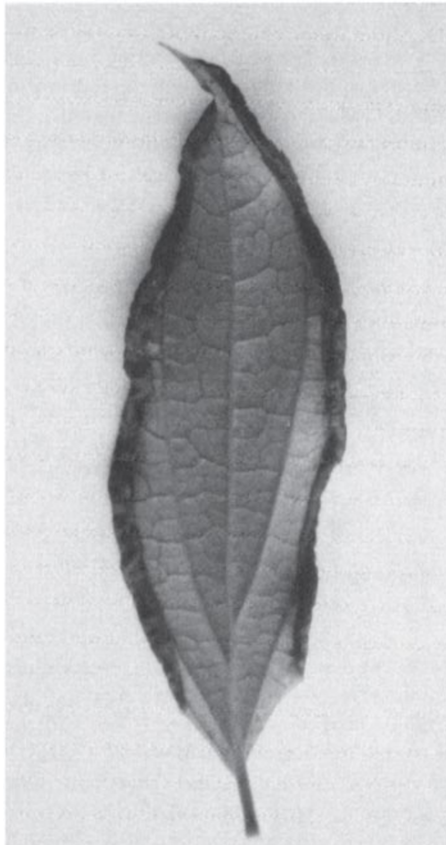

Figure 6.3 Tender leaf of pepper damaged by leaf gall thrips.

Life history and seasonal population

Adult thrips have been described by Ananthakrishnan (1960). The adults are black with the tibiae and tarsi and distal segments of the antenna light lemon yellow, and measure 2.5–3.0 mm in length; the larvae and pupae are creamy white. The morphometrics of various stages have been provided by Visalakshi and Joseph (1967). The eggs are laid within the leaf galls in small clusters and they are creamy white and hatch in 6–8 days. The two larval stages, pre-pupal stage and two pupal stages last for 4–7, 4–7, 2, 2–3 and 2–3 days, respectively (Visalakshi and Joseph 1967).

Leaf gall thrips initially infest tender leaves and remain in them till the leaves are partly mature. At Kalpetta (Wynad District, Kerala), the pest population was higher in the field during June-September during the monsoon period (Devasahayam 1992b).

Natural enemies

A number of predators have been recorded on leaf gall thrips in the field. Among them, *Montandoniola moraguesi* (Puton) (Anthocoridae) and *Andothrips flavipes* Schmutz (Phlaeothripidae) are widely distributed and play a significant role in the control of the pest in the field. The predatory potential, life cycle and seasonal population of these predators have been studied (Devasahayam 1992b). The other predators reported on the pest include an unidentified anthocorid and a mite (Visalakshi and Joseph 1967), *Geogarypus* sp. (Geogarypidae), *Lestodiplosis* sp. (Cecidomyiidae) and *Rhodesiella* sp. (Chloropidae) (Devasahayam 1992b) predaceous on juvenile stages.

Resistance

Among the five cultivars in which observations were undertaken in the field at South Wynad, *Kalluvally* was least susceptible to the pest (Banerjee *et al.* 198la).

Management

Evaluation of six insecticides in Wynad (Kerala) for the control of leaf gall thrips indicated that monocrotophos 0.05 per cent and dimethoate 0.05 per cent were more effective when sprayed during emergence of new flushes during June/July (Devasahayam 1990). Experiments conducted under green house conditions with nine insecticides indicated that residual toxicity was maximum in monocrotophos 0.05 per cent followed by malathion 0.1 per cent (Devasahayam 1989). At Thadiyankudisai (Dindigul Anna District, Tamil Nadu) among the six insecticides evaluated for the control of the pest, fenvalerate and methamidophos (2 g ai/vine) were more effective (Vivekanandan *et al.* 1981). Monocrotophos 0.02 per cent, dimethoate 0.03 per cent and phosphamidon 0.05 per cent were also more effective in controlling the pest in earlier studies at Vellayani (Thiruvananthapuram District) (Nair and Christudas 1976).

Scale Insects-Mussel Scale *(Lepidosaphes piperis)* and Coconut Scale *(Aspidiotus destructor)*

Distribution

Scale insects are major pests of pepper at high altitudes. Among the various species recorded on the crop in India, the mussel scale L. *piperis* and coconut scale *A. destructor* are more important. In Shevroy hills (Salem District, Tamil Nadu), 47.5 per cent of vines in six pepper gardens surveyed were infested with *A. destructor* (Venkatesan *et al.* 1992). In Idukki District (Kerala), *A. destructor* was the most destructive pest of pepper infesting up to 34.9 per cent of leaves in some locations; *L. piperis* caused serious damage in certain locations only (Selvan *et al.* 1996). Comprehensive surveys on the distribution of scale insects were conducted by Koya *et al.* (1996) in 162 locations in Kerala, Karnataka and Tamil Nadu. Among the various species of scale insects recorded by them on pepper, *L. piperis* and *A. destructor* were the most common and were widely distributed at higher altitudes (above 600 m MSL). The incidence (mean percentage of infested vines) of *L. piperis* and *A. destructor* was highest in Idukki District (27 per cent) and Nilgiris District (24 per cent), respectively. A highly significant and positive correlation was observed between the incidence of these two species of scale insects and altitude.

Damage

Mussel scales encrust the main stems of younger vines, stems of lateral branches, mature leaves and berries. The pest infestation results in chlorotic spots/patches, yellowing and drying of leaves subsequently (Figure 6.4a,b). Younger vines succumb to the pest during the course of 1–2 years especially when the infestation occurs on the main stems. On older vines the infested lateral branches wilt and dry resulting in vacant spaces in the canopy. *L. piperis* also infests older cuttings in the nursery in the plains. Coconut scales infest leaves and very rarely stems of lateral branches and berries. The pest infestation results in chlorotic spots/patches on the leaves and their yellowing subsequently (Figure 6.4c).

Life history and seasonal population

Adult females of *L. piperis* are elongated and dark brown measuring 3–4 mm in length. The eggs are white and are found under the scale cover of mature females. The I and II larval stages last for 9–12 and 9–10 days, respectively. In males the prepupal and pupal stages last for 2–3 days each. Adult female scales of *A. destructor*

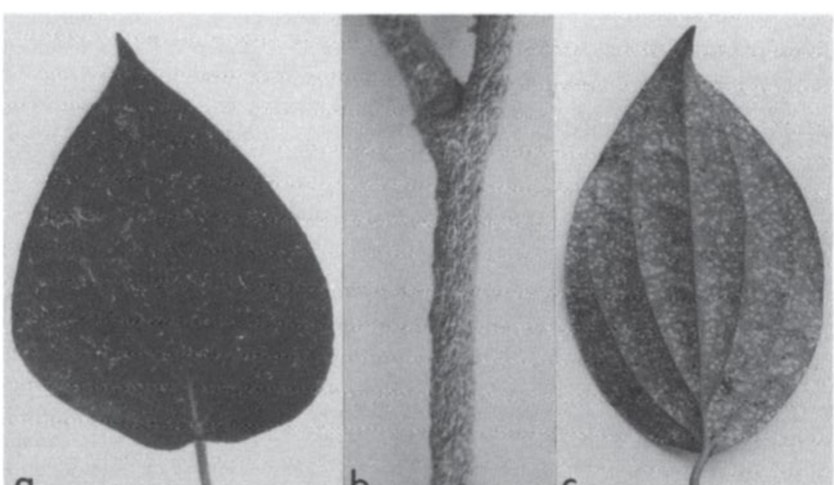

Figure 6.4 Infestation of scale insects on pepper
a. Infestation of mussel scale on leaf
b. Infestation of mussel scale on stem
c. Infestation of coconut scale on leaf

are circular and light yellow measuring 1.5–2.0 mm in length. The eggs are creamy yellow and the I and II larval stages last for 6–7 and 4–5 days, respectively. In males the prepupal and pupal stages lasts for 6–7 and 4–5 days, respectively. Males of both the species are produced in large numbers during certain periods. Males are weak bodied with a pair of wings and superficially resemble cecidomyiids. Males do not live long and die after mating. Both the species reproduce parthenogenically leading to a tremendous increase in population within a short period (Koya and Devasahayam 1995).

A. destructor is highly polyphagous and has been recorded on more than 20 economically important host plants in India. *L. piperis* also occasionally infests cassava (*Manihot esculenta* Crantz) stems in the field and storage (Pillai 1994) and also *P. attenuatum* in the nursery.

Rainfall has a deleterious effect on the population of both the species of scale insects. At Kalpetta (Wynad District, Kerala), populations of *L. piperis* were higher during summer (February-May); populations of *A. destructor* were higher during the post monsoon and summer months (September-February) (Koya and Devasahayam 1995).

Natural enemies

A number of natural enemies have been recorded on *L. piperis* and *A. destructor*. These include 21 genera/species of predatory mites, thrips, mirids, coleopterans and hymenopteran parasitoids (Devasahayam and Koya 1994a; Selvakumaran *et al.* 1997). Among them, *Aphytis* sp. (Aphelinidae), *Pseudoscymnus* sp. and *Chilocorus circumdatus* (Gyllenhall) (Coccinellidae) were more common and widely distributed.

Management

Application of insecticides is essential for the control of scale insects. Six insecticides were evaluated in the field (in Wynad District) for the control of mussel scale and among them malathion, dimethoate and monocrotophos (0.1% each) were effective when sprayed twice at 30 day intervals during January/February (Devasahayam and Koya 1994a). At Idukki, spraying of dimethoate 0.05 per cent and monocrotophos 0.05 per cent were effective for the management of coconut scales on pepper. Neemgold (a commercial formulation of neem) caused 58 per cent reduction in scale population compared to 83–100 per cent reduction in monocrotophos 0.05 per cent and dimethoate 0.05 per cent (Selvan *et al.* 1996).

Since scale insects are generally serious during early summer when berries are about to be harvested, application of insecticides has to be done judiciously to avoid residues in the product. A number of potential biocontrol agents have been identified against scale insects and methods have been standardised for the mass rearing of some of these species at IISR, Calicut. Evaluation of these biocontrol agents for the control of scale insects infesting pepper is in progress in the field at Wynad.

MINOR INSECT PESTS

Grasshoppers

Grasshoppers such as *Xenocatantops humilis* (Serville) have been observed to feed on older leaves of pepper vines at Peruvannamuzhi. The grasshoppers generally feed on many species of weeds present in pepper plantations. On pepper they feed on the leaf lamina causing irregular shaped large feeding holes.

Leafhoppers

The cotton leaf hopper *Amrasca devastans* (Dist.) has been listed as a pest of pepper infesting the foliage (Hill 1983).

Whiteflies

Pepper whitefly, *Aleurocanthus piperis* Mask., has been listed as a pest of pepper (Nair 1975). A heavy incidence of the tobacco whitefly *Bemisia tabaci* (Genn.) was observed at many locations in Kasaragod District (Kerala) during 1989. The whitefly infested very young leaves causing light yellowish discolouration on them; these spots became larger and turned brown later under severe attack. Pepper was only a feeding host of the whitefly and attempts to rear the insect on the plant were not successful (Ranjith *et al.* 1992a). Recently, the mealy whitefly (*Aleurodicus dispersus* Russell) has also been observed to infest pepper in Kerala (Ranjith *et al.* 1996).

Aphids

Colonies of the black citrus aphid (*Toxoptera aurantii* B. de F.) infest tender shoots and leaves causing yellowing symptoms in severe cases of infestation (Gautam 1980). The aphids infest both grown up vines in the field and also younger vines in the nursery.

Mealybugs

Nine genera/species of mealybugs, namely, *Icerya* sp., *I. aegyptiaca* (Dgl.), *Planococcus* sp., *P. citri* (Risso), *P. minor* (Mask.), *Ferrisia virgata* (Ckll.), *Pseudococcus* sp., *P. longispinus* (Targioni) and *P. orchidicola* Takahashi have been reported to infest pepper (Devasahayam *et al.* 1988; Koya *et al.* 1996). The mealybugs generally infest tender portions of the vines such as shoots, leaves and berries. Generally no visible symptom of damage is observed in the field; however, severe infestations of *P. longispinus* on tender shoots result in wilting of young plants in the nursery. Colonies of *Planococcus* sp. are also observed at the basal portion of the stem under the soil and also on roots causing yellowing, wilting and mortality of younger vines in the field and in the nursery. The mealybugs are sometimes encrusted in a crust of fungal tissue (unidentified) especially in severe cases of infestation.

Scale Insects

Apart from *L. piperis* and *A. destructor,* 12 genera/species of scale insects, namely, *Coccus piperis* Green, *Marsipococcus marsupialis* Green, *Protopulvinaria longivalvata* Green, *Parlatoria pergandii* Com., *Pinnaspis aspidistrae* Sign., *P. marchali* Ckll., *P. strachani* (Cooley), *Chionaspis raricosa* Green, *Pseudaulacaspis* sp., *P. cockerelli* (Cooley), *Unaspis* sp. and *Anomalococcus indicus* Ayyar have been recorded on pepper (Devasahayam *et al.* 1988; Koya *et al.* 1996; Suresh and Mohanasundaram 1996). Among them, *M. marsupiale* is reported to be serious in Idukki District. *P. longivalvata* is more serious on older cuttings in the nursery and the pest infestation results in subsequent attack by sooty moulds which accelerates the deterioration of the infested plants. The other species of scale insects occur either on stems and/or on mature leaves causing localised chlorotic patches/spots on them.

Mirid Bugs

The tea mosquito bug, *Helopeltis antonii* Sign., is occasionally observed on young pepper vines in the field and also in the nursery. The pest infestation results in the formation of necrotic lesions on tender stems and angular necrotic spots on tender leaves. When very young shoots are attacked they dry up completely (Devasahayam *et al.* 1986). *Disphinctus maesarum* Kirk, has also been included under the list of insects infesting pepper (Hill 1983).

Pentatomid Bugs

The stink bug, *Cyclopelta siccifolia* Westw., has been included under the list of insects infesting pepper (Nayar *et al.* 1976). However Ranjith *et al.* (1992b) reported that though the bugs are serious pests of *Erythrina indica* Lamk. (a popular standard of pepper) in certain areas of Kannur District, they did not attack pepper. An outbreak of *Udonga montana* (Dist.) was observed in many plants including pepper in Wynad District during May 1991. The feeding activity of the pest caused defoliation and spike shedding (Mathew and Sudheendrakumar 1991).

Thrips

Two other species of *Liothrips* apart from *L. karyni* have also been reported on pepper. *L. pallipes* Karny and *L. chavicae* (Z.) were collected from leaf roll galls of tender pepper leaves from Wynad (Karny 1926). *L. chavicae* was also later collected from the hilly tracts of the former Travancore-Cochin State which now forms part of Kerala (Mani 1973).

Root Grubs

Grubs of *Holotrichia fissa* Brenske have been occasionally observed to feed on roots of young vines causing their mortality at Peruvannamuzhi. The pest infestation is generally observed in gardens where numerous other crops are also grown.

Stem Borers

Grubs of *Diboma procera* Pasc. and *Pterolophia annulata* Chevr. were observed to tunnel into and feed on the inner portions of the stems of pepper vines around the collar region. The incidence of the pest was as high as 50 per cent in some gardens in Kannur and Kozhikode districts. Though the grubs were observed on older live vines, they had a preference for dead and drying tissues (Dubey *et al.* 1976). *P. griseovaria* Breuning has also been observed to attack pepper in many parts of Kerala and Karnataka; the pest infestation was more severe in Kasaragod and Kannur districts (Ranjith *et al.* 1991). The sweet potato weevil *Cylas formicarius* F. has been reported to bore into orthotropic shoots of pepper vines resulting in yellowing and drying of leaves and subsequently the whole vine dries up leaving only the basal portions about a foot from the ground free of attack (Ranjith 1985).

Leaf Feeding Beetles

The leaf feeding beetles recorded on pepper include *Neculla pollinaria* Baly., *Pagria costatipennis* Jacoby (Nair 1975), *Hermaeophaga* sp. and *Lanka* sp. (Premkumar and Nair 1987b) in Kerala and *Tegyrius* sp. in Karnataka. All these species generally feed on tender leaves making small holes. The weevils feeding on the foliage include *Eugnathus curvus* Faust. (Nair 1975) and *Myllocerus* sp. (Pillai 1978).

Gall Midges

Maggots of the gall midge, *Cecidomyia malabarensis* Felt, develop within berries, leaf stalks, leaf veins and shoots of pepper vines resulting in swelling of infested tissues. The pest infestation is more common in the nursery. Two unidentified species of cecidomyiids causing hypophyllous globose solitary pellet shaped galls on the leaf and minute irregular rinden galls on the stem have also been reported on pepper (Mani 1973).

Leaf Feeding Caterpillars

The army worm, *Spodoptera litura* F., damages young pepper vines and also young cuttings in the nursery by feeding on the leaves. About 53 per cent of leaves were found to be damaged in a sample of 50 vines during May 1979 at Peruvannamuzhi (Gautam 1980). The semilooper *Synegia* sp. damages tender shoots, leaves and spikes especially in young vines. In a sample of 100 vines at Peruvannamuzhi, 52 per cent of leaves and 17 per cent of spikes were damaged (Premkumar and Devasahayam 1989). The other leaf feeding caterpillars recorded on pepper include *Latoia lepida* Cram. (Fletcher 1914), *Cricula trifenestrata* Helf. (Ayyar 1940) and *Thosea sinensis* Walk. (Hill 1983).

MAJOR INSECT PESTS OF PEPPER IN INDONESIA AND MALAYSIA

Pepper Weevil *(Lophobaris piperis)*

Damage

The pepper weevil is the most serious pest of pepper in Indonesia and Malaysia. The grubs bore into the nodal region of the climbing (orthotropic) and flowering (plagiotropic) shoots resulting in wilting of infested shoots. The entire upper portion of the vine collapses and dies eventually. The pest infestation on the lower, middle and upper parts of the climbing shoots resulted in 43.5, 12.1 and 5.8 per cent yield loss, respectively (Deciyanto and Suprapto 1992). The adults feed on flowers, fruits, shoots and young stems. When the berries are damaged, they either fall prematurely or do not attain their normal size.

Life history

The adults are small black weevils measuring 3–5 mm in length. The eggs are laid singly at the nodes of the climbing and flowering shoots. The life cycle from egg to adult is completed in 68–167 days, the larval stage lasting for 40–120 days. Females oviposited for about 14 months, laying 1–3 eggs per day with an average of 377 eggs during its life period. Adult longevity averaged 12 and 16 months for males and females, respectively (Vecht 1940). Little information is available on the population dynamics of the pest.

Resistance

Studies on host range of the pepper weevil on 19 plant species belonging to 7 families indicated that the preferred host plants belonged to the genus *Piper,* the most preferred being *P. nigrum* and *P. sarmtenosum* Roxb. ex Hunt. (Suprapto 1986). Studies on the food and oviposition preferences of the weevil on common varieties namely, *Jambi, Bangka, Kuching, Uthirancotta* and *Belantung* indicated that *Jambi* was the most preferred (Anuar 1993; Deciyanto *et al.* 1984).

Natural enemies

A number of natural enemies have been recorded on the pepper weevil in Indonesia and Malaysia. These include *Euderus* sp. (Euloplidae), *Dinarmus coimbatorensis* Ferriere (Pteromalidae), *Eupelmus* sp., *E. curculionis* Ferriere (Eupelmidae), *Rhaconotus* sp., *Spathius apicalis* and *S. piperis* Walker (Braconidae) (Vecht 1940; Anuar 1986). Brief descriptions of the adults with notes on the biology and distribution of these parasitoids in Indonesia have been provided by the former. Recent trials in Indonesia on the efficacy of *S. piperis* in controlling the pest indicated that the parasitoid could control up to 40 and 37 per cent of pepper weevil population in the laboratory and field conditions, respectively (Deciyanto and Suprapto 1992).

Management

A number of insecticides have been recommended for the control of pepper weevil. These include spraying of endosulfan 0.2 per cent, permethrin 0.2 per cent, fenitrothion 0.2 per cent, parathion 0.2 per cent, dimethoate 0.05 per cent or diazinon 0.2 per cent or application of granular insecticides such as aldicarb 10 G or carbofuran 3 G. Use of granular insecticides at the beginning and end of the rainy season and spraying with insecticides 1½ to 2 months after granular insecticide application and repeated every 1½ to 2 months intervals has been suggested to obtain an effective control of the pest. Removal of affected branches and stems would also help in reducing the level of pest infestation in the field (Kueh 1979; Deciyanto and Suprapto 1992).

Pepper Bug *(Dasynus piperis)*

Damage

The nymphs and adults of the pepper bug feed on the sap of pepper berries; when immature berries are attacked, they turn black and drop prematurely. When mature berries are attacked, black spots are developed on the pericarp. The infested berries are often subsequently infected by pathogens resulting in berry rot.

Life history and seasonal population

The adults are green and measure about 1 cm in length. The eggs are laid on the leaves and berries. The egg and nymphal stages last for 7–9 and 19–35 days, respectively. Adult longevity lasts for 25–85 days and females lay up to 132 eggs (Vecht 1933).

Studies on fluctuation in population of the pepper bug at Bangka, Indonesia indicated that the pest population was higher during November to June and lower during July to September when rainfall was low and less number of berries were available (Deciyanto 1991). Karnawati (1988) analysed the distribution of eggs and nymphs on various parts of the vine in South Sumatra (Indonesia) and developed a sequential sampling strategy for predicting the population of the pest.

Resistance

Suprapto *et al.* (1987) reported that among the six varieties of pepper namely, *Jambi, Kerinci, Lampung Daun Lebar, Belantung, Bangka* and *Chunuk,* maximum number of eggs were oviposited in *Lampung Daun Lebar* and the minimum in *Kerinci.* However, the maximum and minimum damages were observed in *Belantung* or *Chunuk* and *Lampung Daun Lebar,* respectively.

Natural enemies

A number of egg parasitoids have been recorded on green bug in the field. These include *Gryon* sp. (*Hadronotus* sp.) (Scelionidae), *Anastus* sp. (Eupelmidae), *Ooencyrtus malayensis* Ferriere (Encyrtidae) and an unnamed species (Vecht 1933; Deciyanto and Ellyda 1989). Vecht (1933) notes that in Bangka (Indonesia), 80 per cent of the eggs were parasitized by these parasitoids. Notes on the description and distribution of these parasitoids have also been given.

Management

Various insecticides have been recommended for the control of the pepper bug. These include malathion 0.125 per cent, nicotine 0.15 per cent, carbaryl 0.2 per cent, BHC 0.02 per cent, azinophos-ethyl 0.1 per cent, deltamethrin 0.2 per cent, diazinon 0.2 per cent and carbofuran 3G (Kueh 1979; Deciyanto and Suprapto 1992).

Tingid Bug *(Diconocoris hewetti)*

Damage

The adults and nymphs of the tingid bug feed on the sap of inflorescences before the berries are set resulting in their browning and drying. The pest was estimated to cause about 30 per cent yield loss in Sarawak (Malaysia). In Bangka, 9–37 per cent of the inflorescences were estimated to be damaged by the pest.

Life history and seasonal population

The adult tingid bugs are black with lace like wings and measure about 4.5× 3.0 mm in size. The adults can be recognized by the presence of a pair of humps on the thorax. The eggs are laid singly on the spikes. The egg and nymphal periods last for an average of 10 and 19 days, respectively and the adult life for 27 days (Rothschild 1968).

The pest population is higher in the field during October to February and lower during July to September and is affected to a great extent by the presence of inflorescences on the vines (Deciyanto 1988).

Management

The insecticides that are effective against the pepper bug have also been recommended for the control of the tingid bug.

MINOR INSECT PESTS

In addition to the major insect pests, many other insects such as termites, flea beetles, leaf hoppers, mealybugs, scale insects and nettle caterpillars occur sporadically on pepper. These pests infest roots, stems, branches, leaves, flowers and fruits and cause serious damage to the crop in certain locations. A list of these insects in addition to the major insect pests and the plant parts affected by them is given in Table 6.2.

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7.1. ON FARM PROCESSING OF BLACK PEPPER

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In India, pepper plants start flowering during May-June with the onset of South west monsoon, and the harvesting is usually done in December-January; while in Malaysia and Indonesia the flowering is in September-October and the crops come to harvest in March-April. Variation in maturity pattern depends on factors such as variety, rainfall, altitude, ambient temperature etc. In the plains of Kerala, the early maturity cultivars reach harvesting stage by November and the late ones by December-January. At higher altitudes, the fruit growth and maturity get delayed due to the low winter temperature. Under such conditions the early cultivars reach maturity by December but the late ones comes to harvest only by February-March and may even go up to April.

Pepper has three components that are important in an Industrial point of view, viz., (i) volatiles, which are recovered as volatile oils (ii) Non volatile resins, waxes etc. which are recovered as oleoresin and (iii) cellulose and fibre which add bulk to the spice. The pepper harvesting has to be regulated for various end uses as given below (Govindarajan 1979).

Products	Maturity at harvest
White pepper	Fully ripe
Black pepper	Fully mature and near ripe.
Canned pepper	4–5 months
Dehydrated green pepper	10–15 days before full maturity
Oleoresin	15–20 days before maturity
Pepper oil	15–20 days before maturity
Pepper powder	Fully mature with maximum starch

Pepper fruits undergo many maturity related changes (Table 7.1.1). Length, width, thickness, bulk density, total surface area and specific heat value increase as moisture content increases, while apparent density, inter particle space ratio and specific surface area decreases as the moisture content increase. The best shape of pepper berries from Belantung was described as spherical with sphericity 0.94 to 0.97 (Mulyono *et al.* 1994). The shape of pepper fruits is also important because in a competitive market visual appeal influences the decision making of consumers.

Table 7.1.1 Changes in the chemical composition of two cultivars during maturation.

Cultivar	*Karimunda*					*Panniyur-1*				
Stage of maturation	*Months after fruit setting*					*Months after fruit setting*				
	3.0	*4.5*	*5.5*	*6.5*	*7.0*	*3.0*	*4.5*	*5.5*	*6.5*	*7.5*
Volatile oil (%)	6.8	10.4	8.2	4.4	3.6	6.4	7.6	6.3	2.8	2.0
N.V.E.E.	10.3	9.7	8.6	7.5	7.4	8.7	8.8	8.7	8.1	7.8
Piperine content (%)	1.9	2.4	2.4	3.1	3.1	1.9	2.6	2.7	3.1	3.5
Starch content (%)	2.6	4.9	6.2	15.3	15.3	2.5	3.7	5.1	10.2	16.8

HARVESTING

Generally harvesting is done when one or two berries in a few spikes turn orange or red. Care should be taken to harvest only the mature spikes. Immature fruits on drying tend to shrivel up and will reduce the quality of the produce. In countries like Sri Lanka, due to the threat from thieves many farmers harvest pepper much early and such half mature pepper on drying gives a product having light weight, often called "light pepper" (Purseglove *et al.* 1981). Light pepper has higher percentage of oil and oleoresin and many oleoresin extracting companies in India import light pepper from Sri Lanka. Indian farmers are unwilling to do early harvesting as there is no premium price for the early harvested produce.

Harvesting is done using single pole ladder kept leaned on to the support tree (Fig. 7.1.1). The harvested spikes are collected in clean sacs or bags tied at the back of the worker. Drastic pulling may break the plant from the standard and care is essential to safe guard the vine. Height adjustable mechanical ladders attached to trolleys will not disturb the vine during harvesting. But in India, the plantations are mostly on hill slopes and mechanical devices cannot reach the site. Ladders with twin leg system also safeguard the vine (Purseglove *et al.* 1981).

POST HARVEST HANDLING

Decorning (Threshing)

Post harvest handling is very crucial to get a high quality product. Harvested spikes are spread on a clean floor and then threshed manually by trampling with legs or by using mechanical thresher. The small scale farmers use only manual decorning while mechanical threshing is much faster and useful in large plantations. In spite of this advantage such threshers are not popular in India but they are commonly used in other countries like Indonesia and Malaysia. One type of mechanical thresher used in certain estates is given in Fig. 7.1.2 and Fig. 7.1.3. The capacity of this unit is 1.5 ton/hr. Here the green spikes are fed slowly to the thresher in which a rotating drum with aluminium blades removes the berries from stalk. The speed of rotation is adjusted in such a manner that it should not be too slow or too fast. A three HP motor is used as

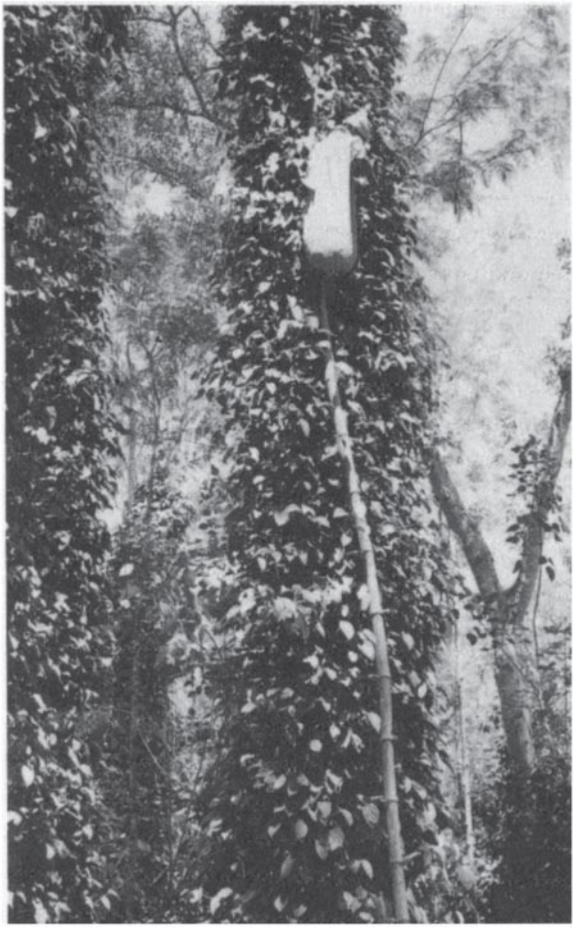

Figure 7.1.1 Harvesting of pepper, using tall ladder. The harvester uses a gunny bag tied to his back for collecting the harvested spikes.

the power source. The spikes are fed between a moving drum with aluminium plate with suitably adjusted gaps. Due to the mild stretching action berries are separated from spikes. A modified version of this uses a large drum to hold the spikes, a conveyor belt and the decorning unit. The spikes from the storage drum moves through the conveyor belt at a fixed speed and fed into the decorning unit. Units with a capacity of three tons an hour are used in certain plantations. Mechanical threshers having different capacities can be developed without much capital investment, to reduce the cost of production. A pedal operated small unit will be useful to the small scale farmers. Such a small scale thresher has been developed in Indonesia (Risfaheri, this volume.)

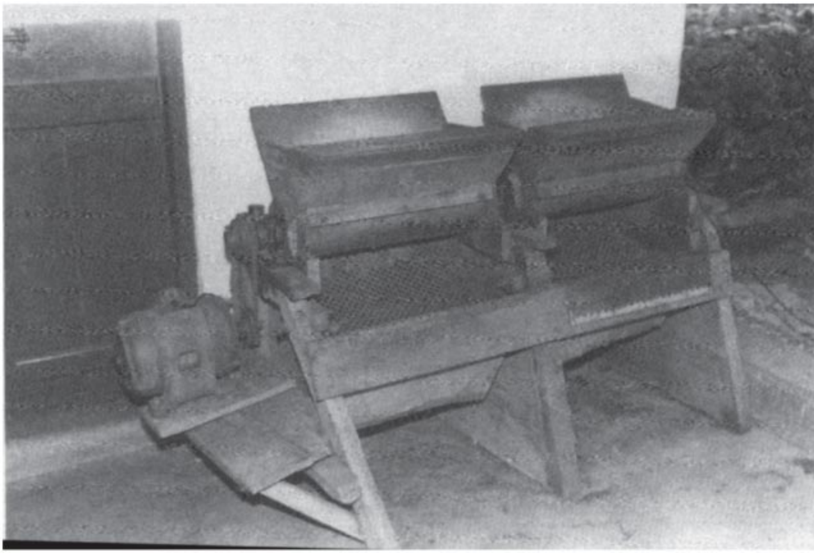

Figure 7.1.2 A locally fabricated pepper thresher installed in a local plantation.

Washing of Spikes

Mechanical washing of the harvested spikes or even simple dipping of the spikes in a tank or big vessel with clean water will remove the adhering particles of dust and dirt. Spikes from pepper gardens near highways and village roads have to be washed properly before threshing.

Grading Before Drying

It is ideal to grade the green berries using a mesh to remove the light berries and pin heads. The popular cultivars can be classified based on the size of the berries. There are three major groups viz., >4.25 mm, 3.25 to 4.25 mm and <3.25 mm. Some of the popular cultivars which belong to these three groups are listed below (Gopalam *et al.* 1991).

Large size (>4.25mm)	Medium size (3.25–4.25)	Small size (<3.25mm)
Panniyur-1	Karimunda	Kurialmundi
Valiakaniakkadan	Arakulammunda	Narayakodi
Vadakkan	Ottaplackal	
Karuvilanchi	Kuthiravally	
	Kaniakkadan	
	Neelamundi	
	Balankotta	

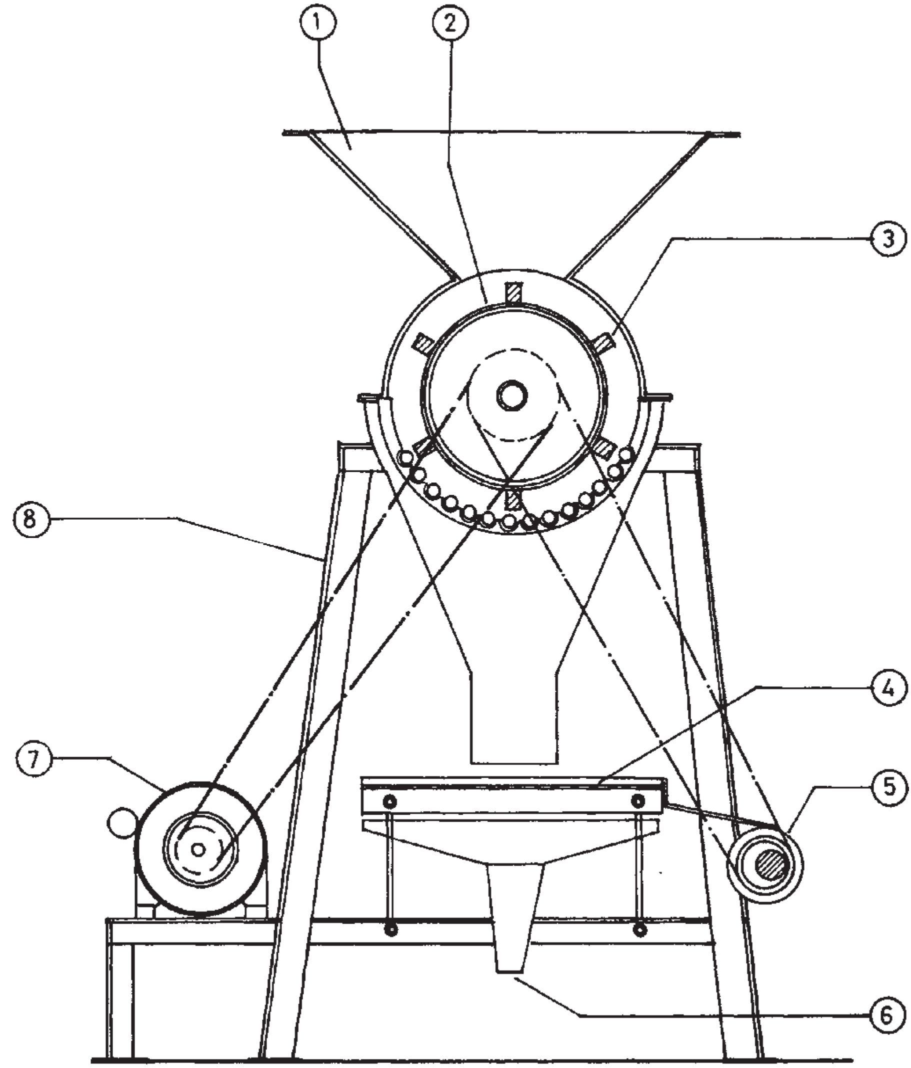

Figure 7.1.3 Sketch of a pepper thresher designed by the College of Agricultural Engineering, Kerala Agricultural University.
1. Feed hopper, 2. Rotating drum, 3. Aluminium strip, 4. Oscillating sieve, 5. Eccentric, 6. Pepper outlet, 7. Motor, 8. Stand.

Blanching

Blanching of the threshed fruits are carried out by taking them in bamboo baskets or a perforated vessel and dipping in boiling water for one minute. This process cleans the produce thoroughly from all the adhering dust particles, birds excreta and other extraneous particles and gives shining black colour to the produce and enhance the drying process. After blanching the produce can be dried to a uniform moisture level (8–10%) within three days in full sunlight. The produce will have a shining black colour. Studies have indicated that volatiles and other chemical loss is minimum by this treatments (NRCS 1987). In Papua New Guinea, Indonesia, Micronesia, etc blanching is done at 82°C for two minutes (Pruthi 1992).

A combined washing-cum-blanching cum-grading-operation is possible by spraying boiling water on to pepper fruits as they move in a conveyor belt fitted with mechanical brushes, and the blanching time can be adjusted through the speed of the conveyor belt. At the end of the conveyor belt the blanched and washed berries pass through sieves of various dimensions to separate pin head and light pepper. The graded pepper is then flushed with dry air to remove surface moisture and then is transported to the drying yard or to artificial driers.

Blanching is known to activate the phenolase enzyme which is responsible for producing the black colour. It also ruptures the cells and thereby accelerates the escape of moisture from the inner core and simultaneously enhances the black colour with the help of resinoids inside the berry. Hence blanched pepper will have more shining black colour and it dries at a faster rate.

The black colour that pepper acquires on drying is due to the oxidation of colourless phenolic compounds present in the skin. Polyphenolase (0-diphenol oxidase) present in the fruit wall converts colourless phenolic substrates (3,4 dihydroxy phenyl ethanol glycoside) present in the cells to black polymeric compounds (Variyar *et al.* 1988).

Sun Drying of Pepper

Pepper fruits after threshing are generally dried in sun, when the moisture content is reduced from about 65 per cent to within about 10 per cent. Sun drying is the process used in most of the pepper growing countries. Pepper put for sun drying has to be turned over periodically to facilitate uniform drying, without that, the produce may attract mould infestation and this will affect the general appearance of the produce. The main disadvantage of sun drying is the lack of uniformity and the possibility of contamination by micro-organisms. The general recovery is about 33 per cent of the green berries, but varies from 29 to 38 per cent among cultivars. Cultivars like *Kalluvally, Uthirankotta, Kottanadan, Karimunda, Kaniakkadan,* etc. yield about 34 to 38 per cent dry pepper. The fresh and dry yield is influenced by many factors such as temperature and humidity during flowering, general soil moisture if rain fed, fertiliser availability, standards, timely rain etc. (Govindarajan 1979). To get good quality product, it is essential to use proper drying surface. Pepper can accumulate lot of dust and dirt from the drying surface and the surroundings. The following are the common drying surfaces used in India.

Bamboo mat

The common material used by small scale farmers for sun drying pepper is bamboo mat. Coating bamboo mat with cowdung was a practice prevalent in Kerala in earlier times, but now this has been completely discontinued mainly because of the quality standards imposed by importing countries. Spices Board of India has introduced a fenugreek paste to coat bamboo mat. This is very popular among farmers now and same mats are used by them for sun drying other agricultural produces also.

Cement floor

Another very common surface used for drying pepper is the cement floor and this is used in all plantations. The size of the floor varies depending on the quantity of the produce each plantations have. The floor is about two feet elevated from the ground level. This prevents contamination of the produce with dust and the encroachment of domestic animals. A wire or nylon net is provided on the sides and also above the floor at a height of about 10 ft to prevent any bird excreta. Drying pepper on cement floor reduces drying time by about 18 to 24 hrs and ensure a clean product. Except for the initial cost it is very convenient too (Pruthi 1992). Black oxide coated cement floor is more suitable as the heat absorbing and radiating capacity will be more and this in turn speed up the drying process.

Polyethylene fabric

Black, Low Density Polyethylene (LDPE) or Reinforced High Density Polyethylene fabric (HDPE) or synthetic tarpaulin are becoming popular among farmers and traders. Studies carried out at IISR have shown that drying pepper on this material reduce the drying time considerably and it is very convenient to use. During the process of drying it is necessary to make heaps of the pepper fruits and keep them covered by poly ethylene or better by tarpaulin in the evening, and the heaps are again spread out the next day morning. This collection and heaping become easier when polyethylene fabrics are used as they can be folded along with the pepper fruits in the evening and again spread out in the next morning. A combination of cement floor and a synthetic tarpaulin is ideal for sun drying. Black surface is better as it gives faster drying due to higher heat absorption (Krishnamoorthy and Zachariah 1992).

Wynad method of sun drying

In Wynad area of Kerala state the farmers adopt a slightly different practice of sun drying. The despiked fruits are spread out on bamboo mats or cement floor and are left under sun for two days. The second day afternoon the fruits, when it is still warm, are gathered in gunny bags and are stacked in a room for two days. During this time a process of fermentation sets in, and this leads to uniformly black product and improved flavour. The pepper berries after two days of storage are again spread out on the floor and dried in the conventional way. The Wynadan pepper is traditionally regarded as high quality, may be due to the particular drying process adopted.

Solar Drying and Solar Driers

Solar drier

Institute of Agricultural Engineering for the Tropics and Subtropics, University of Hohenheim, Germany has developed a solar tunnel drier for Agricultural products. This drier consists of a plastic foil covered flat plate solar air heater, a drying tunnel and small axial flow fans. The floor of the drier consists of plastic foam sandwiched between two metal sheets with a groove and tongue system. Solar air heater and drier are covered with transparent UV-stabilized PE plastic foil 0.2 mm in thickness with a transmissibility of 92 per cent for visible radiation. To convert solar radiation into heat top surface of the solar air heater is painted black, showing an absorption of about 90 per cent (Esper and Muhlbaur 1996).

In solar tunnel drier the crop is spread on a wire mesh placed 20 mm above the floor, which is covered with a plastic net. Axial fans are incorporated to suck ambient air into the collector depending on the available solar radiation. In the solar air heater the drying air is heated to a maximum temperature of about 60°C which is the optimum temperature for drying pepper. The crops spread in a thin layer in the drier itself acts as an absorber enabling the drying air to gain additional heat when passing through the drier. The heat loss caused by evaporation of the moisture during drying are compensated by this additional energy gain resulting in an almost uniform drying. The air inlet and outlet are covered with plastic nets or mesh wire to prevent insects from entering the solar tunnel drier (Esper and Muhlbaur 1996). The authors claim that compared to natural sun drying, in the solar drier change occurs mainly in the final drying phase where sun drying require several days to reach the final desired moisture level, while solar drying accelerates the drying process which leads to considerable reduction in drying time. In addition, almost constant temperature throughout the drying process ensures a clean product free from microbial contamination and other extraneous matter. The cost of the unit can be reduced by using locally available materials for fabrication.

The Central Institute for Agricultural Engineering (CIAE) Bhopal, India had developed solar driers (Fig. 7.1.4) to dry a variety of agricultural produces (Kachru and Gupta 1993). Tamil Nadu Agricultural University Coimbatore, India has developed a solar drier that can be used for pepper also. The solar cardamom drier, developed at Central Plantation Crops Research Institute at Kasaragod, is a cheap and simple device useful for drying pepper (Fig. 7.1.5). This drier can be adapted for large scale drying also (Patil 1989).

Mechanical Driers

Various mechanical driers using other sources of energy like electricity or other fuels are also employed to dry pepper.

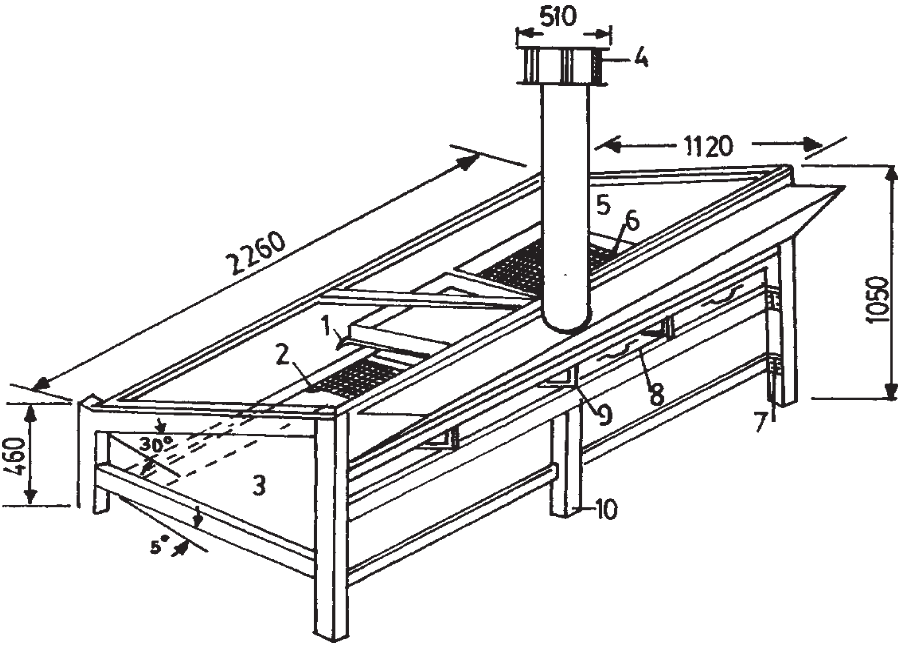

Figure 7.1.4 A solar cabinet drier designed by the Central Institute of Agricultural Engineering (Dimensions in mm).
1. "-" type guide for rack, 2. Air inlet, 3. Drier bottom—built in solar reflector, 4. Chimney with aspirator, 5. Top glass seating, 6. Rack bottom built in wire mesh, 7. Fastening plate for frame, 8. Sliding rack, 9. Vertical support for glass seating, 10. Wooden frame.

a) *Copra drier*

Using agricultural waste as fuel like coconut shell, husk etc. pepper can be dried in a copra drier. Studies carried out at Central Plantation Crops Research Institute, Kasaragod, Kerala indicate that in this drier about 60 kg green pepper can be dried in about 30 hrs by using 28–30 kg of agricultural waste at a temperature ranging from 50 to 60°C (Personal communication).

b) *Convection driers*

Mechanical driers are very essential to overcome the vagaries of weather. Natural convection driers or forced draft driers can be used to get better quality product. The Natural Resource Institute, London, U.K. has developed an improved version of a convection solar drier (Pruthi 1992). Regional Research Laboratory,

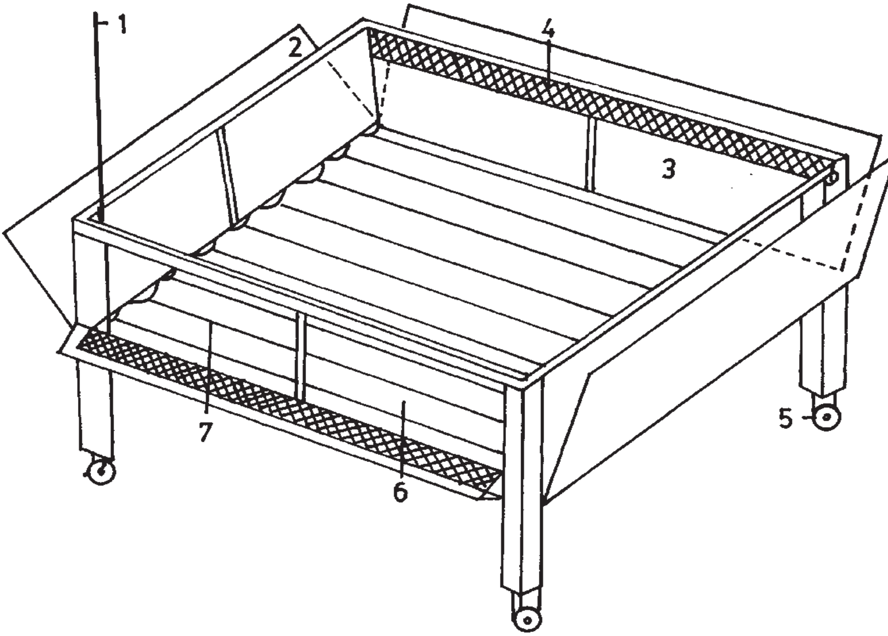

Figure 7.1.5 A low cost solar drier designed by the Central Plantation Crop Research Institute. 1. Sun tracking rod, 2. 24G. Commercial grade aluminium foil reflector, 3. 3 mm plastic sheet, 4. Wire mesh covered exhaust, 5. Coster wheel, 6. 3 mm window glass, 7. 22G corrugated GI sheet (Black painted).

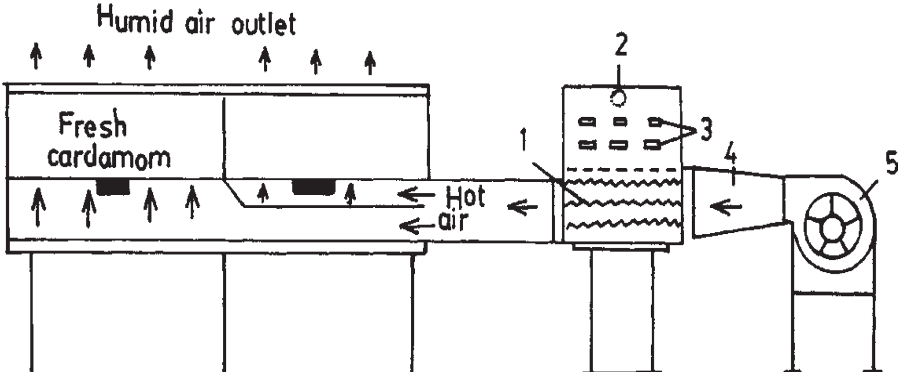

Figure 7.1.6 Mechanical drier for drying pepper/cardamom, developed at Regional Research Laboratory, Trivandrum.
1. Electric heating system, 2. Thermostat, 3. Control switch, 4. Cold air, 5. Blower.

Thiruvananthapuram, Kerala (India) has developed a drier that consists of a centrifugal blower, electric furnace, ducting management for uniform hot air flow and a drying chamber (Fig. 7.1.6). The model can dry 120 kg pepper or cardamom per batch and the drying time is around 20 hrs., and final product is reported to be of a superior quality (Kachru and Gupta 1993).

c) *Cascade type driers*

Cascade type driers using indirect heating from kerosene or gas is used in many countries. By using hot air oven by counter—current technique the moisture is reduced to 10 per cent at a fast rate. In this system the hot air is introduced through bottom and they can reduce the moisture content to 12 per cent from 70 per cent in about 8–10 hrs. However, mechanical drying using electrical energy is very expensive. Hence partial mechanical drying up to a certain moisture level and the remaining by adopting sun drying fetches a reasonably good product (Pruthi 1992). Under Indian condition, good sunlight throughout the day is assured during the harvesting season and hence sun drying is the cheapest and if properly done can give a good product. Infrared driers are also becoming popular for drying spices. In this case, the temperature of cardamom is raised to about 40°C by pad heaters and infrared lamps. To remove moisture vacuum pump is used. The heating sources are thermostatically controlled and it takes about 8–10 hrs for complete drying (Kachru and Gupta 1993).

Recovery of Pepper

A reduction of about 70 per cent in weight is observed when pepper is dried. The dry recovery may vary from 29 to 38 per cent depending on the variety. Bulk density of pepper ranges from 426 to 850g/litre. Tellicherry types generally show high values and Coorg (Karnataka) types show low values (Pruthi 1980), but with the spread of the improved cultivars in all region such differences no longer exist.

Pepper dried as per any one of the methods mentioned gives an average percentage composition as follows (Pruthi 1993).

Constituent	Percentage composition
Moisture	8.7–14
Total nitrogen	1.5–2.6
Volatile ether extract	0.3–4.2
Non volatile ether extract	3.9–11.5
Alcohol extract	4.4–12.0
Starch (by acid hydrolysis)	28.0–49.0
Crude Fibre	8.7–18.0
Crude piperine	2.8–9.0
Piperine	1.7–7.4
Total ash	3.6–5.7
Acid insoluble ash	0.03–0.55

Garbling, Cleaning and Fractionation

Before packing, dried pepper is cleaned to get rid of extraneous matters like, dirt, grit, stones, stalks, leaves etc and berries are graded according to size or density. Pneumatic separators equipped with magnetic separators are used to remove metallic contamination such as iron filings and stray nails.

Combination of air-classification and vibratory conveying using inclined docks is very efficient for destoning of spices (Ramanathan and Rao 1974). This kind of mechanical separators are employed mostly by corporate farmers and exporters. Small scale farmers generally clean the spices by winnowing or by use of air blowers so that heavier and bolder berries of pepper separate out from dust, stalk and pinheads which being lighter are blown away.

Some of the well established processing houses clean and grade pepper with the help of multiple sieve-cum-air classifier type of machines whereby dust, stalks, pinheads, hollows, immature pepper, red pepper and extra-bold pepper are removed (Pruthi 1992, 1993). Separated pepper is then washed and dried to make it free of adhering fungus and other extraneous matter.

Hence to obtain good quality pepper of international standard, the steps involved in processing are (a) drying (b) separation of various fractions (c) size segregation or grading (d) physical cleaning (washing and drying) and (e) packaging.

In countries like India, farmers as well as middle men bring the produce to the market usually in an ungraded form and generally garbling and grading are done at

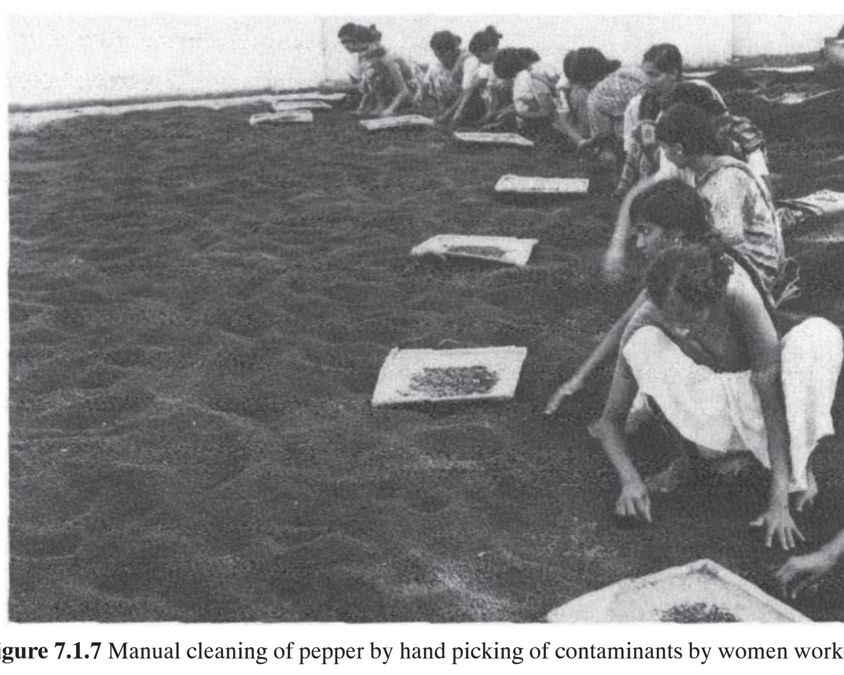

Figure 7.1.7 Manual cleaning of pepper by hand picking of contaminants by women workers.

Figure 7.1.8 Garbling or grading is done manually by using sieves of specific sizes.

the exporters' premises. Most of the exporters do cleaning and grading operations using garbling machines which remove dust, chaff and grade the pepper according to densities. However most of these machines do not remove iron filings and heavy metals. These are generally hand picked. Usually the pepper collected by the whole salers are first cleaned manually by hand picking the contaminants such as plant debris and other extraneous matter. This operation is mostly done by women workers (Fig. 7.1.7). After this the pepper goes for garbling. Many whole salers and exporters still use manual grading using sieves of specified sizes to separate extra bold, bold, medium, light and pin heads (Fig. 7.1.8). This is also an operation were mostly women workers are employed.

Madasamy and Gothandapani (1995) developed a spiral separator for cleaning pepper. This is ideal to remove foreign materials like rodent excreta from the dried pepper. The parameters which generally affect the effectiveness of separators are material of the spiral, helix angle, maximum friction angle of pepper, radius at which the grain lies, length of path, height of the unit, feed rate etc. The efficiency was found to be 97.5 per cent at the feed rate of 60 kg/hr. The increase in efficiency upto 98.68 per cent was achieved by this machine at a speed rate of 90 kg/hr. But at 120 kg/h, the efficiency has decreased to 81.77 per cent (Madasamy and Gothandapani 1996).

Traditionally pepper is manually cleaned by winnowing and then packed in gunny bags. In certain plantations cleaning is done through a funnel like arrangement in which the dried pepper is fed and cleaned using a blower at the outlet point, when the pin heads and light berries are blown away (Fig. 7.1.9).

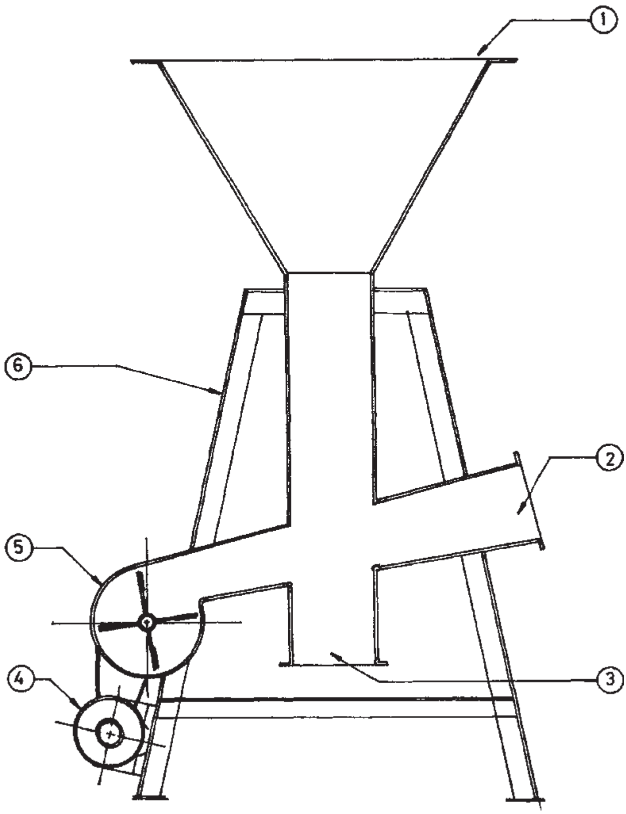

Figure 7.1.9 Design of a locally fabricated pepper winnower.
1. Feed hopper, 2. Dust outlet, 3. pepper outlet, 4. Motor, 5. Blower, 6. Stand.

CFTRI, Mysore, has developed a machine which can continuously clean and grade pepper having a capacity of 100 kg per hr. It consists of aspirator, destoner, rotary washer and continuous fluidised dryer, air classifier and size grader. Processed product is free from dust, extraneous matter and has an improved appearance.

Grades and Grading

Directorate of Marketing and Inspection (DMI), Govt. Of India (1971) formulated the following grades of pepper.

Malabar Garbled (MG Grades 1 and 2)
Malabar Ungarbled (MUG Grades 1 and 2)

Tellicherry Garbled Black pepper Special Extra Bold (TGSEB)
Tellicherry Garbled Extra Bold (TGEB)
Tellicherry Garbled (TG)
Garbled Light pepper (GL special, GL grades 1 and 2)
Ungarbled Light pepper (UGL special, UGL Grades 1 and 2)
Pin heads (PH Grade Special and PH Grade 1)
Black pepper (Non-specified) (NS Grade X)

The advantage of grading are:

i) Securing higher prices of pepper
ii) Increase in export of superior qualities of pepper like TGSEB
iii) Considerable reduction in international trade disputes and rejection of consignments
iv) Increase in farmers' returns.

Good garbled pepper should have a bulk density of 500–600 gm per litre. Light berries should be less than 10 per cent and pin heads (unfertilised) less than 4 per cent. Low bulk density indicate more light berries (less starch content) which results in poor milling quality of the pepper. Pepper should have good aroma and a biting taste. It should contain at least 1.5 per cent volatile oil and 3 per cent piperine. (Lewis 1984). Chemical composition of different grades of pepper is given in Table 7.1.2.

A certain percentage of pepper berries will become hollow due to attack by insects. These berries generally are less dense and can be separated by winnowing. This grade (light pepper) has less of carbohydrate and protein, but is rich in volatile oil cells. It is

Table 7.1.2 Composition of black pepper grades.

Grades	*Moisture* %	*Vol.oil* %	*Piperine* %	*NVEE* %	*Starch* %	*Crude Fibre* %
Pin heads	13.0	0.6	0.8	7.1	11.5	27.4
Light pepper	13.0	2.9	4.1	13.5	14.6	27.8
Malabar garbled	13.0	3.7	5.0	12.3	39.7	11.8
Tellicherry garbled EB*	13.0	2.2	4.4	9.1	39.7	11.8
Tellicherry garbled special Extra Bold	10.0	3.2	4.9	10.3	40.9	9.20
Malabar ungarbled	12.0	2.8	5.0	11.4	41.8	12.5
Tellicherry ungarbled	12.0	4.0	6.3	13.5	39.3	11.0
High range ungarbled	12.0	2.6	4.0	11.1	41.8	10.5

* EB=Extra bold.

very good for extracting oil. Another grade know as "half pepper" comes in between normal pepper and light pepper. The berries are slightly under mature and therefore contain more of the active principle "piperine'. The berries may appear slightly wrinkled due to its immaturity and this is ideal for oleoresin extraction. The concentration of piperine in oleoresin is very important, than its aroma which is represented by oil.

The size grading is done by using appropriate sieves. Very small and undeveloped berries are classified as pin heads. Bulk of the pepper belongs to the average size known as "Malabar garbled". The larger sized ones are classified as "Tellicherry bold', "Tellicherry extra bold", "Tellicherry special extra bold" and "Giant" (Mathew 1992, Kachru *et al.* 1990).

Starch accounts for about 34 per cent in pepper, 56.5 per cent in white pepper and 63.2 per cent in decorticated white pepper. Of the 12 per cent water-soluble nitrogen present in berries, non-protein nitrogen constitutes about 82 per cent and of this more than half is made up of simple amino acids which can be readily utilised by human system.

Adulteration

Other than dust, dirt, stems, chaff or similar organic extraneous matter, pepper berries are adulterated with papaya seeds (Sen and Roy 1974, Hartman *et al.* 1973).

Figure 7.1.10 Packing of the cleaned and graded pepper in gunny bags.

Packaging

Pepper is hygroscopic in nature and its nature of absorbing moisture during rainy season result in mould attack and insect infestation as it has good amount of starch. Mould and insect damage can lead to loss of aroma, caking and hydrolytic rancidity. Efficient packaging and proper storage is essential to ward off this problem. Whole pepper is generally packed and transported in gunny bags (burlap bags) and polyethylene lined double burlap bags. Dried pepper having a moisture level of 10–11 per cent can be stored without any mould growth in jute gunny bags with polyethylene lining of 0.003 inch or more thick or in laminated HP bags or similar containers (Balasubramanyam *et al.* 1978). The small scale wholesalers generally use polyethylene lined gunny bags for packing (Fig. 7.1.10) and transporting to exporters' premises or warehouses.

Storing

Spices are to be stored with utmost care as they deteriorate rapidly. The precautions are based on the following observations.

i) Moisture level in pepper is to be in the range of 10–11 per cent before it is stored
ii) Store houses to be constructed scientifically and it should be damp-proof, rat-proof and bird-proof. The room should have controlled ventilation and devices for control of humidity and temperature
iii) The room should be properly fumigated before storage
iv) The walls should be white washed regularly
v) Proper drainage should be provided
vi) Polyethylene-lined gunny bags or laminated HDPE are ideal for storing pepper.
vii) Rooms used for storing pepper shouldn't be used for other items like cereals or other spices like chillies, turmeric etc. The strong pungent odour of other spices may spoil the aroma of pepper. A good dehumidifier fitted in the storage rooms can eliminate mould and insect attacks by keeping the atmosphere always dry.

Chemical Quality

Pepper is exploited industrially for its pungency and aroma. The pungency is broadly contributed by oleoresin and specifically by piperine. The aroma is contributed by its essential oil which consists of a wide variety of chemical constituents viz. terpenes, hydrocarbons and oxygenated compounds. The oleoresin or the solvent extract represents the total pungency and flavour of pepper. Volatile oil is commercially extracted by steam distillation and the oleoresin using solvents like ethylene dichloride/acetone. The alkaloid piperine, $C_{17} H_{19} O_3 N$ (m.p. 129–130°C), is the major constituent which imparts the biting taste. The other alkaloid, chavicine, is a resinous isomer of piperine, which on hydrolysis yields piperidine and iso-chavicinic acid (Govindarajan 1979, Bandhopadhyay *et al.* 1990). Besides these, chlorophyll and other colouring matters, resins, sugars, fixed oils etc, are also found (Mathew 1992, Govindarajan *et al.* 1973).

It was found that the yield of oleoresin and its quality are dependent on the raw material extracted. Hence it is essential to use the right quality material for extraction. Even within a cultivar, variability has been observed in chemical quality (Gopalam and Ravindran 1987). Cultivars like *Kottanadan, Kumbhakodi* and *Kuthiravally* are high in piperine while *Balankotta, Malligesara* etc. are low in piperine. The quality components are also reported to depend on maturity stage (Mathai 1981, Pruthi 1980, Sumathykutty *et al.* 1989). Maturity—the stage at which pepper is harvested-influences the chemical contents as high lighted in Table 7.1.1. The chemical composition of different commercial grades are given in Table 7.1.2.

Microbiological Aspects

The studies conducted in Malaysia (Apun *et al.* 1993) have indicated that pepper fruits collected from various farms had Total Viable Counts (TVC) between 10^5–10^7/g sample. The spore formers were in the range of 10^4–10^6/g sample. The same authors have carried out microbiological analysis of pepper during the process of drying. It was observed that at the initial drying stage all samples had TVC between 10^7–10^8/g. As the drying process proceeded (after the third day) a ten fold drop was reported (10^6–10^7/g). A further increase in TVC was noted (10^7–10^8/g sample) on storing (Kasing *et al.* 1993). During white pepper preparation a twenty fold decrease in TVC was noted, and for the stored samples of white pepper, the TVC was around 10^5/g sample; but no coliform types were detected. The TVC was found to be less where a pepper threshing machine was employed compared to manual threshing by trampling with feet (Kasing *et al.* 1993). Washing the spikes before threshing and blanching in boiling water are useful practices for minimizing the microbial load. Unfortunately not much studies have been carried out on the microbiological aspects of pepper drying in India.

Wide range of insects and other arthropods are found to be associated with whole pepper transported by ship. It was found that at 27°C and 77 per cent RH these insects failed to multiply. However at 30–32°C and 77–81 per cent RH, cigarette beetle, dug store beetle, larger cabinet beetle and flat grains beetle have access to grow in whole or coarsely broken pepper. Washing the produce before drying make the product cleaner. The various steps suggested to eliminate microbial contamination are: (1) cold sterilisation by irradiation (2) vacuum fumigation with or without heat treatment and (3) thermal inactivation. Fumigation with ethylene di bromide, methyl bromide, ethylene oxide and propylene oxide are found to be useful for long term storage of pepper in ware houses. The degree of decontamination achieved by this method depends on concentration of the gas, temperature, length of time allowed and also on the water content of spice. However due to fear of residues fumigation is no more practiced (Pruthi 1980, 1991, 1992).

A process of thermal sterilization of herbs and spices known as "steri spice" has been developed in Denmark. This is achieved by steam injection at temperature above

100°C. The full sterilization cycle is different for various spices and takes account of the heat stability of the flavour components. To limit the loss of flavour components, a coating system based on protein extracts from food grade bones is added to the spices during the process. Only unground spices can be treated by this process (Pruthi 1992). Reports from importing countries indicate that contamination with *Salmonella* has not been found in pepper. (See also the chapter on Industrial Processing).

Processing for White Pepper

One of the major pepper products consumed world over is white pepper. It is generally prepared by retting ripe berries in running water for about seven to ten days. The skin undergoes bacterial degradation and the softened skin is removed by trampling with leg or by decortication (Pruthi 1993). A study from Sarawak indicated that pepper fruits having specific gravity of >1.12 are the best for conversion to white pepper, and those having less than 1.12 are good for making pepper (Anon. 1995) (For details see the chapter on Industrial Processing).

CONCLUSIONS

Harvesting and of farm processing are important operations, on which the quality of the final product depends. Cleanliness should be ensured at every stage of post harvest handling. Harvesting at the correct stage, processing and drying under hygienic conditions are essential prerequisites for producing attractive clean products. Mechanization of the various operations are helpful in producing high quality product and popularization of mechanized post harvest handling and drying can surely go a long way in achieving the final goal of high quality.

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7.2. PEPPER PROCESSING—THE INDONESIAN SCENARIO

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The two major primary products of *Piper nigrum* which are internationally traded are black pepper and white pepper. There are several other products which are also internationally traded but in small amounts (less than 2%), such as green pepper, pepper oil and oleoresin. Among the producing countries (Indonesia, India, Malaysia, Brazil, Thailand, Vietnam, China and Sri Lanka) only India and Thailand export the other pepper products but in a very small volume. In 1994, the export of Indonesian pepper products can be seen from the table below.

Table 7.2.1. Export of pepper and pepper products.

Product	*Volume (mt)*	*Value ('000 US $)*
White pepper	18,575	50,287
Black pepper	16,842	26,903
Green pepper	166	226
Ground pepper	453	1189
Pepper oil	9	31

Source: Ministry of Agriculture (1996).

Pepper is widely used all over the world. In Europe and America in particular, pepper is an important item on dining tables, without some flavouring with pepper most dishes would be unappetizing. Another usage of pepper is in medicine and cosmetics, although only in very small quantities compared to the consumption in the food and beverage industries.

The majority of pepper cultivation in Indonesia is conducted by subsistent farmers in small holdings which provide a vital source of their income. This condition leads to low adoption of innovative technology to improve the pepper processing at the farm level. Moreover, little attention is given to the hygienic aspect and quality of the pepper products. To improve the pepper processing technology, the Research Institute for Spice and Medicinal Crops (RISMC) has carried out researches on equipment design for black and white pepper processing that can be applied at the farm level.

BLACK PEPPER

Black pepper is prepared from whole mature pepper berries. The harvesting is carried out when the green berries commence to acquire a yellow coloration, the age of the pepper berries is usually 6–7 months. The spikes are picked at weekly or fortnightly intervals over a period of 1 to 2 months.

The black pepper processing method in several producing countries varies especially the treatment prior to drying process. In Indonesia, after harvesting the pepper berries are removed from the spikes by trampling, beating with stick or by hand. In the next stage the pepper berries are spread out on bamboo mats, or concrete platform in the sunlight. Sometimes, after harvesting the pepper berries are piled up for 2–4 days to let the browning fermentation occur and the berries are easier to be removed from spikes. The sun drying for the black pepper processing in Indonesia takes between 5 and 7 days depending on the thickness of berries and weather condition until moisture is reduced to between 12–13 per cent. After drying the pinhead and light berries are separated by winnowing. The yield of dried black pepper is around 30 per cent of the fresh berries.

In Indonesia, pepper is predominantly produced by small holders and the final cleaning, grading and packing of the dried pepper is carried out by exporting firms. Most of pepper exporters have a complete sortation units which consist of: (1) combination of winnowing and shaking machine, (2) washing machine, (3) hot air dryer and (4) screw type separation machine. The capacity of this sortation unit is about 5 tons of black pepper per hour. Grading is normally done according to overseas buyer requirement, and double-lined gunny bags are used for packing. The bags are usually stored in godowns prior to shipment.

The quality of black pepper is determined more by organoleptic factor than the results of constituent analysis. For black pepper which is used as spice in the whole or ground form, the appearance is of primary importance to buyer. Bold sized pepper corns with a uniform dark-brown to black colour fetches the best price. The aroma and flavour imparted by the volatile oil is of greater significance than the absolute pungency level when the spice is sold for domestic culinary purpose.

The blanching treatment for several minutes prior to sun drying can improve black pepper quality. The advantages of blanching treatment on the black pepper processing are: (1) to accelerate drying time and it requires only 3 days for drying in the sun, (2) the black pepper has an attractive uniform colour and (3) the blanching in the hot water will minimize dust, foreign matter and microbial contamination. Risfaheri and Hidayat (1993), suggested to blanch the pepper berries in 80°C of water for 1.5–5 minutes prior to sun drying. Prolonged blanching in 80°C and blanching in the boiling water can deactivate the enzymes responsible for browning reaction which causes colour deterioration of the black pepper. The prolonged thermal treatments may damage the flavour profile of the pepper and loose part of volatile oil. Effects of treatments prior to sun drying on black pepper quality can be seen on Table 7.2.2.

Table 7.2.2 Effect of treatments prior to sun drying on pepper qualitya.

Treatment	*Drying time (hours)*	*Water content (%)*	*Colour*	*Aroma*	*Oil content (%)*	*Piperine content (%)*
Directl sun* drying/control	31	11.70	brownish black, less uniform	less strong	2.76	2.99
Piled up for* 4 days	28	11.48	brownish black, uniform	less strong, fermentation odour	2.71	3.32
Blanching in 80° C* of water (1.5 minutes)	21	11.60	black-shiny, uniform	strong	2.73	3.20
Blanching in 80° C*) of water (2.5 minutes)	21	11.10	black-shiny, uniform	strong	2.75	3.07
Blanching in 80° C**) of water (5 minutes)	21	11.30	black-shiny, uniform	strong	2.80	–
Blanching in boiling**) water (2.5 minutes)	21	11.30	greenish black	strong	2.54	–

Note:-
* cv. Belantung.
** cv. Chunuk.
– Thickness of berries spread on bamboo mat was 3.5 cm.

[a] Source: Risfaheri and Hidayat (1993).

WHITE PEPPER

White pepper is prepared from the fully ripe reddish berries which are decorticated and dried. The white pepper can be sold in whole or ground form. Until now, the white pepper is still prepared with traditional method.

After harvesting, the ripe berries are tightly packed into gunny bags. The bags are then soaked in slow running water, usually a stream for 10–14 days. During this operation, microbial retting process occurs which loosens the pericarp from the core of the fruit. After removal of the bags from water the berries are placed in a tank of water and are trampled to remove any remaining adhering pericarp. Finally, the smooth buff coloured cores are thoroughly washed in running water. Then the berries are dried under the sun. Drying is carried out by spreading out the berries on bamboo mats or gunny sacks for several days depending upon the brightness of weather until the moisture content is about 13–14 per cent. The yield of white pepper from fresh fruit is about 25 per cent. The dried product are graded and packed in gunny bags. White pepper is sorted by exporting firms prior to shipment using a machine with a capacity of 20–30 tons per day before being packed into gunny bags.

The hygienic aspect and quality of white pepper products are main problems in the traditional preparation of white pepper. Usually, the berries are soaked in rivers or ponds with poor quality water. Contamination of the product is caused by microorganisms or waste, and the product gets a swampy odour which is difficult to eliminate. Beside the contamination problem, soaking in water for a long time would result in volatile oil loss and aroma and flavour deterioration. The quality of white pepper in the whole and ground form is imparted by appearance, aroma and pungency. Decorticating pepper berries using steaming or blanching the fresh green berries for 10–15 minutes, and then removing the rind in fruit-pulping machine has been tried (Purseglove *et al.* 1981). Risfaheri and Hidayat (1996) had also carried out experiments on decorticating by soaking and the boiling water method. The pepper berries used in the experiment were cv. Chunuk. The white pepper resulted by soaking in boiling water method for 15–25 minutes had stronger aroma than those resulted by traditional method (Table 7.2.3). The prolonged soaking in boiling water will lead to volatile oil loss and affects the aroma of white pepper, as prolonged thermal treatment is known to damage the flavour profile of pepper (Pruthi 1992). Soaking in boiling water softens the pepper fruit wall, so that decortication becomes easy. The use of machine for decorti

Table 7.2.3 Comparison of decorticating of pepper by conventional and boiling water method*.

Treatment	*Decorticating**	*Colour***	*Aroma*	*Oil content*** ml/100g (%)*	*Piperine ontent*** (%)*
Traditional method (control)	difficult	white, uniform (10YR8/2)	less strong and swamp odour	2.55[a]	3.59[a]
Soaking in boiling water (100 °C), 15 min.	less difficult	darkish-white, uniform (10YR7/4)	stronger	2.72[a]	3.50[a]
Soaking in boiling water (100 °C), 20 min.	easy	darkish-white, uniform (10YR7/4)	strong	2.63[a]	3.53[a]
Soaking in boiling water (100 °C), 25 min.	easy	darkish-white, uniform (10YR7/4)	strong	2.44[a]	3.02[a]
Soaking in boiling water (100 °C), 30 min.	easier	darkish-white, uniform (10YR7/4)	less stronger	2.30a	3.35[a]

Note: *) The skin of berries was rubbed off by hand.
**) The value based on Munsell Soil Colour Chart.
***) Numbers followed by the same letter within each coloumn are not significantly different at 5 percent level.

[x] Source: Risfaheri and Hidayat (1996).

Table 7.2.4 Appearance and aroma of ground white pepper.

Treatment	*Colour**	*Aroma*
Traditional method (control)	darkish-white, uniform (10 YR 8/3)	swampy odour
Soaking in boiling water (100° C), 15 min.	darkish-white, uniform (10 YR 8/4)	strong
Soaking in boiling water (100° C), 20 min.	darkish-white, uniform (10 YR 8/4)	strong
Soaking in boiling water (100° C), 25 min.	darkish-white, uniform (10 YR 8/4)	strong
Soaking in boiling water (100° C), 30 min	darkish-white, uniform (10 YR 8/4)	less strong

* The value based on Munsell Soil Colour Chart.

cating process may save the soaking time in boiling water. The prolonged soaking in boiling water can lead to oil loss, but had no effect on piperine content. The white pepper made by soaking in boiling water has poorer colour than the one resulted from traditional method. This may be due to the effect on pepper phenol and chlorophyl in the skin which dissolve in boiling water. In the ground form, the colour was not significantly different (Table 7.2.4). Another opinion is colour deterioration was caused by gelatinization of starch (Purseglove *et al.* 1981).

PEPPER PROCESSING EQUIPMENT

Research Institute for Spice and Medicinal Crops (RISMC) has been trying to develop appropriate and low cost technologies/machineries for black and white pepper processing. Several prototypes of the equipment have been designed to be applied at the farm level. Scheme of mechanical black and white pepper processing are given below. With the mechanical white pepper processing the soaking process is not necessary. Furthermore, the pericarp of the berries can be directly removed from the cores by pepper decorticator.

Harvesting
↓
Removal of the pepper berries from the spikes (using pepper thresher)
↓
Blanching in 80° C water (2.5 minutes)
↓
Drying (Sun drying or artificial drying 50–60° C
↓
Black pepper

Harvesting
↓
Removal of the ripe berries from the spikes (using pepper thresher)
↓
Removal of pericarp from the berries (Using pepper decorticator)
↓
Washing
↓
Drying (sun drying or artificial drying)
↓
White pepper

Table 7.2.5 Specification and performance of pepper thresher designed in RISMC.

Specification/ performance	*Pepper thresher with pedal**	*Peper thresher with electric motor***
Spesification		
Type	throw-in	throw-in
Power	pedal	electric motor (1.5 HP)
Dimension (mm)		
– length	1030	1130
– width	590	850
– height	990	550
Performance		
Capacity (kg/hour)	170–185	425–450
Threshing efficiency (%)	94.13	92.21
Separation efficiency (%)	94.27	93.16
Pepper berries damage (%)	3.78	6.13

Source: * Risfaheri *et al.* (1992b).
** Hidayat and Risfaheri (1992).

Pepper Thresher

RIMSC has designed two types of pepper threshers i.e. pedal man powered thresher and electric motor powered thresher. The first prototype was designed by Rusli (1990b). The test result of this equipment showed that the threshing efficiency is low. The thresher also needs to be equipped with a suitable component to separate berries from spikes and such a machine was designed and developed by Risfaheri *et al.* (1992b) and Hidayat and Risfaheri (1992). This machine is based on the principle of friction and impact mechanism. The specification and performance of the pepper thresher are shown in Table 7.2.5.

The pedal powered thresher can be applied at the smallholder farming level, whereas the electric motor powered thresher is more effective at farmers groups or large farming level. This pepper thresher consist of five main parts i.e threshing part, hopper, separation part, outlet (spikes and cores) and power source (Fig. 7.2.1 and Fig. 7.2.2).

Pepper Decorticator

The first prototype of fin type decorticator was designed by Iskandar (1986). Rusli (1990a) has developed a cylinder type to replace the fin type. Both prototypes have similarity in mechanism of decorticating, but there is still weakness due to occurrence of defection on surface of the cores. This weakness has been minimized by using disk type which was designed and developed by Tamrin (1990) and Risfaheri *et al.* (1992a),

The decorticating mechanism of disk type based on the principle of pressure and friction as well as combination of these principles. The objective of the mechanism is

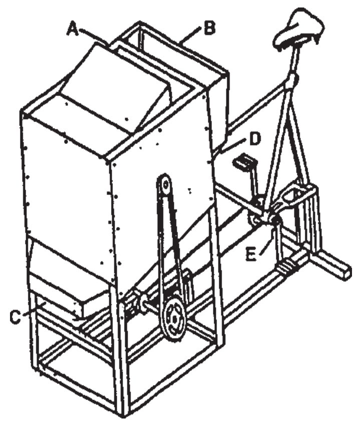

Figure 7.2.1 Pedal powered thresher: A—inlet hole; B—table for the placement of the material; C—outlet of berries; D—outlet of pepper spikes; E—source of power

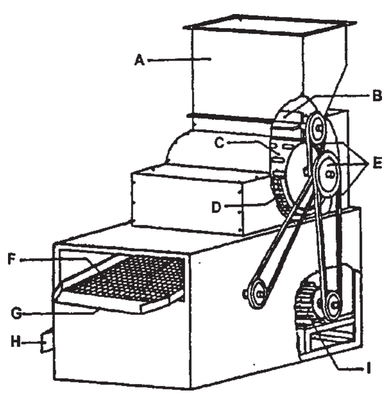

Figure 7.2.2 Electric motor powered pepper thresher: A—hopper; B—feeder; C—threshing cylinder; D—concave; E—transmission compressor; F—vibrant sieve; H—berry outlet; I—source of power

to crush or damage the structure of the skin of berries without damaging the inner core. The pepper decorticator consists of four main parts i.e., decorticating part, hopper, outlet and power source. The specifications and performance of pepper decorticator designed in RISMC are shown in Table 7.2.6.

Table 7.2.6 Specifications and performance of pepper decorticator designed in RISMC.

Specifications/ performance	*Pedal powered decorticator**	*Electric motor powered decorticator***
Specification		
Type	throw-in	throw-in
Power	pedal	electric motor (1 HP)
Dimension (mm)		
– length	1130	750
– width	590	550
– height	1160	1250
Performance		
Capacity (kg/hours)	23–26	55–60
Decorticating efficiency (%)	97.52	99.69
Broken pepper (%)	0.31	3.28
Surface damage of white pepper (%)	4.77	3.19

Source: * Risfaheri *et al.* (1992a).
** Hidayat and Risfaheri (1994).

The white pepper produced by machines has higher oil content, better and stronger aroma than the product of the traditional method (Table 7.2.7). The risk of contamination by micro-organism and odour is very little, because the processing by machine does not require soaking in the water.

The processing by machines using excessive pressure in the operation to remove the pericarp leads to damage of the surface of the cores. Besides, discolouration of the core is caused by the occurrence of phenol in the pericarp. If the cores are processed in the form of ground pepper, the appearance problem can be eliminated.

Black Pepper Oil

Pepper oil is produced by steam distillation of pepper berries. It lacks piperine that gives pungency to the pepper, hence is valued for its aroma in the fragrance industry

Table 7.2.7 The quality of white pepper—a comparison*.

Characteristic	*Traditional method*	*Processing by machine*
Colour		
– cores	Yellowish white	White and slightly brown
– ground	White and slightly brown	White and slightly brown
Aroma	Pepper specific, less strong, swampy odour	Pepper specific, strong
Moisture content (%)	11.9	11.7
Oil content (%)	2.5	3.2

* Source: Hidayat and Risfaheri (1994).

as well as in the flavour industry. Its fragrance outlets are mainly toiletries and a few high grade perfumes. In the flavour industry, it is used principally in foodstuff which requires a high pepper aroma, often in conjunction with the pepper spice or with pepper oleoresin. The volatile oil derived from steam distillation of pepper is almost colourless to slightly greenish liquid with the characteristic odor of pepper, reminiscent also of phellandrene, one of the principal constituents of the oil. The taste of the oil is mild, not at all pungent. In the past few years, the export of Indonesian black pepper oil has increased sharply and exporters are giving more emphasis to value addition.

In Indonesia, most pepper berries have been processed as white pepper and black pepper. The processing of products is usually done at the farmer level, and then reprocessed by the exporters to get better and cleaner products. From the white pepper are obtained aval (white pepper light berries), hulls, stems and dust as by product and wastes. The by-products and wastes could be used as raw materials to get pepper oil, because most oil in pepper berries is in the hull. However, pepper oil could also be produced from the low quality (less attractive) black pepper or broken white pepper. During pepper season (the age of the berries is between 6–7 months), especially on the dry season, there are some berries which are not fully developed and fallen before they get ripe. Such berries would make an excellent distillation material. The yield and quality of pepper oil depend on some factors, i.e., plant variety, age of berries, material handling prior to distillation and distillation method. Depending on variety and kind of material, variations do exist in pepper oil yield (Tables 7.2.8 and 7.2.9).

Table 7.2.8 Essential oil content of four pepper cultivars*.

Variety	*Oil content (% v/w)*
Lampung daun lebar (Petaling 1)	3.10
Jambi (Petaling 2)	2.83
Kerinci (Natar 2)	3.19
Belantung (Natar 1)	2.81

* Source: Rusli and Wahid (1988).

Table 7.2.9 Essential oil content of different raw material for pepper*.

Material	*Essential oil content (% v/w)*
Black pepper:	
– light berries	2.12–4.42
– pinhead	1.76–2.03
– fallen berries	3.80–5.30
White pepper:	
– steam	0.30–0.50
– light berries (aval)	3.30–5.15
– hull (skin) and dust	0.80–1.52

* Source: Rusli and Wahid (1988) and Nurdjanah (1988).

Table 7.2.10 The yield and physico-chemical properties of pepper oils derived from aval, light and fallen berries.

Characteristic	*Aval*	*Light*	*Fallen*
Yield (% v/w)	4.3	3.4	3.4
Specific gravity, 25° C	0.872	–	–
Refractive index, 25/25° C	1.459	–	–
Optical rotation	−1° 21′	−5° 48′	−9°
Solubility in 95 per cent alcohol	1:2.5 soluble	1:2 soluble	1:2 soluble

Light berries from black pepper and fallen berries are the best to be used because of their high oil content and low price. Besides, the oil derived from by product of white pepper has an unpleasant odour. On storage or during transport, the material loss is particularly noticeable in the hulls (skin) of the berries. Damaged or broken berries form the most economical raw material for distillation.

Distillation methods suitable to get pepper oil are water and steam distillation or direct steam distillation. Prior to distillation the berries should be crushed, then distilled immediately. To get better steam circulation, the pepper stem could be mixed into the berries and placed in two separate trays in the distillation tank (Risfaheri 1990). RISMC has designed and made an energy saving distillation apparatus for essential oil which could also be used for pepper oil. For small scale industry or a group of farmers appropriate method is water and steam distillation with 300 liter tank capacity. Bigger industry or an estate could use the direct steam distillation method with more than 2500 liter tank capacity. Depending on the kind of raw material used, the 300 liter tank capacity could produce 0.5–4 liter of pepper oil for each time of operation with 5 hours of distillation. Table 7.2.10 shows the yield and physico-chemical properties of pepper oils produce by the 300 liter tank capacity of equipment mentioned above.

Black Pepper Oleoresin

Extraction of black pepper or its by products with organic solvent provides an oleoresin possessing odour, flavour and pungent principles of the spice. The organoleptic properties of the oleoresin are determined by its volatile oil and piperine contents, and the abundance of the components is principally depending upon the raw material used for extraction. The pepper may be comminuted in flakes or ground into coarse powder and is extracted with a suitably purified solvent. This is usually acetone, ethanol or dichloroethane, but other solvents may be used.

The extraction may be conducted by one of several methods. It could be done by circulation of hot or cold solvent through a bed of ground spice, or a method based on the soxhlet extraction or by a countercurrent process employing several extractions. In this last process pepper remains in the small extractors, but the solvent is transferred from one extractor to the next, during which time the concentration of the material extracted progressively increases, until the solvent meets fresh pepper, after which it is conveyed into a steel vessel where most of the solvent is removed (for re-use). The concentrated extract is than subjected to carefully controlled vacuum distillation in which the solvent in the extract is reduced to trace levels.

When freshly made, the pepper oleoresin is a dark green, viscous, heavy liquid with a strong aroma but, on standing, crystals of piperine appear and the oleoresin requires mixing before use to ensure uniformity and consistency. The components and the quality of the extract depend on the raw material used, method and condition of the processing and handling of the products. The experiment conducted at RISMC proved that as the raw material for oleoresin, black light berries is better than pinhead because of high oil content, Non Volatile Ether Extract (NVEE) and piperine (Mapiliandri 1989). The oleoresin produced is influenced by the solubility of the solvent used. The experiment conducted at RISMC showed that acetone, ethanol and isopropanol give same amount of oleoresin. Hexane gives very low yield, because of low solubility of piperine in hexane. From the four solvents used, ethanol is the best one because it gives the highest yield at the solvent recovery process, and also the price is lower than the others, less poisoned and easy to get. The oleoresin offered by some of the principal manufacturers contained 15–20 per cent volatile oil and 35–55 per cent piperine; and claims have been made that 1 kg of oleoresin obtained from 8 kg of black pepper (Purseglove *et al.* 1981). The oleoresin yield and the oil content of the oleoresin obtained from the experiment conducted at RISMC is given below (Mapiliandri 1989).

Solvent	Oleoresin(%)	Oilcontent(%)
Ethanol	10.70	17.92
Acetone	10.62	14.96
Isopropanol	10.62	13.48

However, further research is needed to fine tune the extraction technology, to minimise oil loss, and to fractionate oil for further blending to produce oil and oleoresin with specific quality characteristics.

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7.3. INDUSTRIAL PROCESSING AND PRODUCTS OF BLACK PEPPER

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Pepper, before being made available for human consumption, have to go through several processing steps. The initial processing (onfarm processing) like removing the fruits from the stalk and sun drying them, etc. are done in a decentralised way in the farms. Although the process is very simple many factors like maturity play an important role in the appearance and colour of the final product. Dipping the despiked fruits in boiling water for a minute prior to drying produces pepper with uniform black colour. During the sun drying operation it is very important to turn over the material periodically for uniform drying. Otherwise a poor product with greyish, unattractive appearance and heavy mould growth could result.

At plantation level, the sun drying operation is being replaced by artificial drying. The specifications for pepper have been made more stringent, incorporating maximum tolerance level for various extraneous matters and this made it essential to go in for machine processing for cleaning and drying of pepper.

In modern spice processing plants, pepper which has been dried at the farm level and graded to different standards, further undergoes processing before being sent for human consumption. The dried pepper is passed through mechanical sifters for removal of pinheads, vegetable seeds, fine dust, sand etc. before winnowing and destoning for removal of dust, stalks, light foreign matter and stones. Now all these operations are being carried out with the help of multiple-sieve-cum-air-classifier type of machines and gravity separators. The separated pepper is then washed in mechanical washers fitted with brushes for the removal of any mould growth, or dust on the surface. The mechanical brushes impart a nice shine to the final product. It is then centrifuged to remove water and then dried in electric or diesel fired indirect dryers. The dried pepper is sent through spirals for final cleaning followed by sterilization either by steam or gamma irradiation before being packed. By using pneumatic conveyer-cum-dryer-cum-grader it is possible to complete the operation of drying and grading quickly in sequential steps.

GRADES OF PEPPER

Pepper is classified into several grades depending on the size and shape of the berries. International Standards Organization (ISO) has classified pepper into non processed (NP), semiprocessed (SP) and processed (P). The ISO have set limits for extraneous matter, light berries, pin heads or broken berries and bulk density for these grades (ISO/DIS 958–1, 1996). Pepper growing countries have their own national standards and the most popular grades in India are Tellichery Garbled Special Extra Bold (TGSEB), Tellichery Garbled Extra Bold (TGEB), Malabar Garbled (MG), Malabar Ungarbled (MUG), Garbled Light (GL), Unspecific and Pinheads(PH)-based on the size, shape and colour.(see Annexure II at the end for details of ISO standards).

STERILIZATION OF PEPPER

In order to ensure high quality and freedom from microbial contamination, cleaned and dried pepper is subjected to sterilization. For this, several methods are available including hydrostatic/pressure sterilization, ozone sterilization, compressed carbon dioxide treatment, irradiation, microwave heating, alcohol vapour treatment, extrusion, steam treatment and fumigation.

Hot Air/Steam Sterilization

The spice is preheated to a temperature of 50–55°C and then sterilised by a combination of indirect heating and direct steam injection. It was found that the total counts, yeast, moulds, coliform counts etc. were considerably reduced. The sensory quality as well as volatile oil content remained unaffected (Schneider 1993).

Another process involves exposure to elevated pressures and temperatures for a predetermined time in a series of chambers. The material to be sterilised is placed in the first chamber and pressurised, then transferred to subsequent chambers and exposed to respective sterilization regimes for set times. The sterilised material is subsequently depressurised in a chamber (Dudek 1996).

A modified steam sterilization process consists of steam jacketed pressurised vessel with three temperature envelopes (50, 100 or 120°C) for different products. The pressurised system ensures no loss of oil or moisture and the product appearance is unchanged. Steam, compressed air and nitrogen gas may be used depending on the end product (Daarington 1991).

A continuous steam sterilization method developed involve subjecting the spice to a rapid flow of superheated steam for a predetermined period of time followed by drying, rehumidification and packaging. Microbial levels as well as enzyme activity are considerably reduced to low levels and no significant oil or flavour loss was reported (Uijil 1992). There are reports about the use of pulsed steam for the sterilization of pepper where the spice is subjected to rapid pulses of steam. The steam condenses on the surface of the spice and the contaminants are removed (Leife 1992). In countries where sterilization by radiation as well as by chemical methods are not permitted, steam sterilization is the best alternative.

Gamma Irradiation

Gamma irradiation is considered to be a superior method for sterilization and insect disinfestation due to its ability to treat items which have been prepacked. This irradiation treatment is a cold process and hence the loss of volatile or flavour components are practically absent (Nair 1993). Low dose of 1 kGy (KiloGray) is effective in controlling insect infestation whereas a dose of 10 kGy is required to reduce the microbial load to acceptable levels. Unlike fumigation, this process does not leave any harmful residues. The size and shape of containers have to be selected depending on the source geometry as well as the conveyor system employed. Codex General Standards for irradiated foods and recommendations of the International Code of practices for the operation of irradiation facilities gives guidelines for irradiation procedures. It is essential to follow Codex Standards to facilitate international trade.

The sensory evaluation of the irradiated pepper showed that the sensory attributes are not affected in pepper subjected to 10 kGy of radiation dose. No significant change in the pepper oil content or piperine was observed in the irradiated spice. Studies have indicated that 30 kGy of radiation was required for heavily contaminated pepper because 10 kGy of radiation produced product with aerobic bacterial count of 2–4 log cycles.

Several countries including USA, France etc. have approved irradiation as a sterilization process and have started the commercial application of this technology. Over 95 per cent of the gamma irradiation facilities operating in the world use cobalt-60 sources. These are highly suited for treating bulk materials. The radiation energy emitted by cobalt-60 continuously decreases at the rate of about 13 per cent per year. The source have to replenished regularly to maintain the throughput of the process. A gamma irradiation facility generally consists of four main parts- a source for radiation, a shielded room to expose and store the sources, product conveyer with control mechanisms and safety devices. Among this the product conveyer and control system is the most critical component. The speed of the conveyer is the only parameter for control of the process and hence an accuracy of 99 per cent is insisted upon. Gamma irradiation facilities are capital intensive and the unit cost of processing is highly sensitive to the scale of operation. The best way of achieving a minimum unit cost of processing is to operate round the clock at the maximum rated throughput that the facility is designed for. A gamma irradiator is simple to operate and maintain and a plant availability factor as high as 95–97 per cent can easily be attained. Efforts should be made to utilise the full rated capacity of the gamma irradiator for economic operation.

Chemiluminescence, thermoluminescence and free radial dosimetry are employed as routine methods for the detection of irradiated pepper. Other methods include use of coloured indicators on the containers to be exposed to radiation, viscosity measurements of gelatinised pepper and intensity measurements of reflected signals of Electron Spin Resonance (ESR) spectrum.

Chemical Sterilization

Fumigation with ethylene dibromide for insect disinfestation followed by ethylene oxide or propylene oxide for destroying microbes are the most common chemical processes employed for the sterilisation of pepper. The effectiveness of sterilisation depends on the moisture content of the pepper, concentration of the gas, temperature and time of contact. The volatile and non-volatile contents of pepper are reported to be reduced on fumigation.

The major problem associated with the use of these fumigants are their explosive, toxic and irritant nature. They are unsafe for the workers and packaged items cannot be subjected to fumigation. Further it leaves behind harmful residues and affects the organoleptic properties. Because of all these, many countries have banned the use of fumigants.

Microwave Sterilization

Laboratory and industrial scale trials conducted on sterilization of pepper by microwave heating (2450 MHz) or high frequency heating (27.12 MHz) indicated that microbial counts were reduced by a factor of 10–103 which is sufficient for moderately contaminated spices. Microbicidal efficiency increased with increasing moisture content of the samples but resulted in loss of some of the essential oil constituents. Both the above methods of sterilization are comparable in all aspects.

VALUE ADDED PRODUCTS

Green Pepper Products

Dehydrated green pepper

This product is prepared from immature green pepper fruits of suitable varieties by processing under controlled conditions. The fruits should be reasonably uniform in size having characteristic pungency, flavour and colour of green pepper. Pepper fruits are blanched in boiling water for a few minutes, drained, cooled and then soaked in sulphur dioxide solution to fix the green colour followed by drying in a cabinet drier at 50°C. Upon rehydration, this product will reconstitute to a good quality product possessing the characteristic pungent, spicy taste, colour and flavour of green pepper, when one part by mass of dehydrated green pepper is cooked for 20 minutes in presence of ten parts by mass of 1 per cent sodium chloride solution. To conform to international standards (ISO/DIS 10621, 1996), the product should have a moisture content of less than 8 per cent. Efforts are underway at various research institutions (Sankarikutty *et al.* 1994) to find an alternative for sulphur dioxide which is being phased out due to health hazards.

Canned green pepper

There has been lot of demand for canned green pepper. The pepper fruits after the removal from the spikes are washed in running water and are then kept soaked in water containing 20 ppm residual chlorine for about an hour. They are then covered with 2 per cent hot brine containing 0.2 per cent citric acid, exhausted at 80°C, sealed properly and processed in boiling water for 20 minutes. It is cooled immediately in a stream of running cold water. The addition of 2 per cent acetic acid instead of citric acid gave a product with better colour. However as per international standard, the only substance that may be added to the covering brine is a small quantity of citric acid not exceeding 0.6 per cent by mass of the packing medium and the covering brine must be 1–2 per cent by mass of edible common salt. It has been observed that pepper harvested one month prior to maturity is the best for the manufacture of green canned pepper.

Bottled green pepper

The manufacturing process consists of despiking the fresh green pepper fruits of uniform size and maturity immediately after harvest followed by cleaning, washing and steeping in 20 per cent brine solution containing citric acid. This is allowed to cure for three to four weeks. The liquid is drained off and fresh brine of 16 per cent concentration together with 100 ppm sulphur dioxide and 0.2 per cent citric acid is added. The resulting product is stored in container well protected from sun and rain. As per international standards (ISO/DIS 11162, 1996), the product shall have the characteristic odour and flavour of fresh green pepper, the colour varying from pale green to green.

Dry packed green pepper

This product is prepared just like the bottled green pepper except that the liquid at the final stage is drained off and packed in flexible pouches. Dry packed green pepper which has the same qualities of canned and bottled green pepper can partly replace these products.

Freeze dried pepper

Now-a-days good quality freeze dried pepper are available in the market at premium prices. This pepper retains the original green colour and shape. The details of the process of freeze drying is kept as a guarded secret by the manufacturers.

White Pepper

White pepper is prepared from ripe fruits by removing the outer pericarp either before or after drying. This product is mainly used in food products in which dark particles are undesirable such as in light coloured sauces, salad dressings, mayonnaise and soups. In certain countries white pepper is traditionally used and preferred to black pepper.

White pepper is manufactured by one of the following techniques: (1) water steeping and retting technique—either from ripened fresh berries or from dry berries (2) steaming or boiling technique (3) chemical technique and (4) decortication technique.

Water steeping technique or retting process

When one or two fruits in a spike start yellowing the crop is harvested, thrushed and heaped in tanks through which water is allowed to run for 7 to 10 days. The light fractions of the pepper like pin heads and light berries which come to the surface are removed and the remaining mass is rolled over at least thrice a day during the retting stage. On the eleventh day the outer skin is removed by gentle rubbing and the deskinned fruits(seeds) are put in another tank containing bleaching solution. It is then allowed to stay in the bleaching solution for two days after which they are drained, washed and sun dried.

Boiling technique

This technique, developed at the Central Food Technology Research Institute (CSIR), Mysore, India involve steaming or boiling the mature green fruits for 10–15 minutes. The outer skin of the fruits gets softened during the steaming process and is removed by passing through a pulping machine. The deskinned fruits (seeds) are washed and treated with sulphur dioxide or bleaching powder solution after which they are washed and dried in the sun. The skin recovered from this process may be used for the recovery of pepper oil by steam distillation though it may not be economical.

Chemical process

There are several chemical methods reported for the preparation of white pepper by treatment with acid or alkali, but no commercially viable operation exists. Recently studies have been undertaken for the removal of the outer skin of dried black as well as fresh pepper by microbial decortication and the process is being optimised (Manilal *et al.* 1995).

Decortication process

Whole dried black pepper fruits can be processed to white pepper by employing decorticating machines. The loss of pepper due to breakage will result in reduced yield and hence the white pepper obtained by this method is expensive. Also the characteristic flavour associated with the traditional product is lacking in the white pepper obtained by decortication technique and hence not preferred.

Of the several processes described, the traditional retting process is the most popular and the product obtained by this process is preferred by the consumers. As per international standards (ISO/DIS 959–2, 1996) the product should have only 1 per cent maximum of extraneous matter, 4 per cent maximum of broken berries and 15 per cent maximum of black berries. Also the minimum bulk density should be 600 g/l.

Economics of white pepper production

On drying 100 kg of mature green pepper the yield of black pepper will be approximately 33 kg where as the white pepper obtained by the retting process will yield only 25 kg. Thus it is evident that the cost of white pepper should be atleast 35 per cent above that of the black pepper. The world demand for white pepper is about 38,000 MT which is almost 25 per cent of the black pepper produced world wide.

Ground Pepper

Black and white pepper powder

Ground pepper is obtained by grinding pepper without adding any foreign matter to the pepper. Grinding can be accomplished by employing equipments like hammer mill or plate mill. It has been observed that the silica content in the ground material obtained from a plate mill is above the permissible level and hence hammer mills with copper tipped hammers are employed for the grinding. The ground product is further sieved and material possessing the required size are packed. The overflow is sent back to the grinding zone for further size reduction.

In modern spice grinding units, pepper is first fluidised for the removal of extraneous matter and then passed through a magnetic separator for the removal of metal particles. It is then passed through a vibrating screen for further removal of extraneous matter and then sent to the hammer mill. The ground product coming out of the hammer mill is fed into a cyclone separator for the recovery of pepper powder. It is further sieved using appropriate sieves and the overflow is recycled. Bag filters are employed after the cyclone separator to prevent the escape of fines into the atmosphere. The ground spice matching the customer's specification in terms of particle size, ash content, pungency, moisture, crude fibre, volatile oil etc. are packed in air tight containers prior to shipping.

Processing for white pepper powder is similar to the above operation except that the starting raw material is white pepper. The flavour of ground white pepper is characteristic, slightly sharp, very aromatic, must be free from extraneous odours and flavours including mouldy and rancid odours (ISO/DIS 959–2, 1996).

White pepper powder can also be produced from black pepper by selective grinding followed by sieving. Before the pepper is subjected to grinding it is conditioned by adjusting the moisture content. The skin fraction which is a by-product of the process can be a feed stock for essential oil or oleoresin extraction.

Cryoground pepper

This new technique of grinding the spice at temperatures much below 100°F will cut down the oxidation of the oils present in the pepper during the grinding operation besides it will assist in the fine grinding of the spice by making the raw spice brittle at low temperatures employed. The cryoground spices disperse more uniformly in spice formulations and the loss of the volatile oil and flavour are very much reduced during the grinding operation.

The usual practice during the cryogrinding is to inject liquid nitrogen into the grinding zone. A temperature controller maintains the desired product temperature by suitably adjusting the liquid nitrogen flow rate. The exhausted gas is recirculated for the precooling of the spice.

Pepper Oil

The aroma of black pepper is attributed to the essential oil present in the spice, which can be recovered by steam distillation or water distillation. The essential oil contains mainly a mixture of terpenic hydrocarbons and their oxygenated compounds with boiling points in the range of 80 to 200°C. The composition of the oil has shown wide variation depending on the cultivar, agroclimatic conditions, region of origin, grades etc with pin heads having the least amount of oil and graded pepper having the highest. With respect to the variation in composition of the oil with different grades, the pin heads (PH) was found to contain the highest amount of sesquiterpenes. It is thus possible to make essential oils to meet different flavour requirements by suitable blending of oil from different grades of pepper.

Industrial process for the recovery of essential oil involves flaking of the black pepper using roller mills and conducting steam distillation in a stainless steel extractor. The material to be distilled is dumped into the distillation unit and compacted near the walls to avoid any channelling of the steam. Dry steam is passed through the bottom of the still. The still will also be heated through the jacket provided for the purpose. The steam comes in contact with the ground pepper particles rising its temperature. The oil present in the oil cells gets vaporised and will rise along with the steam through the still. It is then condensed and the oil being lighter than water, will float on the surface of the condensing water. The oil is recovered using an oil/ water separator.

Several studies have been conducted regarding the flow rate of steam, the direction of passage of steam—whether it should percolate up or down, and the particle size of the ground pepper. It has been observed that by keeping the steam flow rate at half the weight of the charge per hour, economical recoveries of the oil could be achieved in a short span of time. The steam, while rising up through the bed of the spice will condense on its surface and additional energy is required for the evaporation of this condensed water. Other wise there is a likelihood of some oil remaining in the bed itself along with this condensed water. To avoid this problem, a new method called hydrodiffusion is employed in which steam is passed from the top of the bed and the oil rich vapours are condensed and recovered from the stream coming out of the condenser. It is quite uncertain whether hydrodiffusion is being practised for the recovery of pepper oil even though hydrodiffusion is the preferred practice for the recovery of essential oil from flowers.

The oil recovered by steam distillation is allowed to stand over anhydrous sodium sulphate for the removal of traces of moisture. The hydrocarbons as well as the sesquiterpenes present in the pepper oil can undergo oxidation during long storage under the influence of air and light. Hence they are stored in airtight containers before being shipped.

Oleoresin

Oleoresin represents the total pungency and flavour constituents of pepper obtained by the extraction of ground pepper using solvents like ethanol, acetone, ethylene dichloride, ethyl acetate etc. Oleoresin offers considerable advantages over whole or ground spices in that they are uniform in composition as well as strength. Contaminants like mould and fungus are absent in the oleoresin and hence can be directly added to any food material after adjusting the flavour concentration. The extractives are usually made available in both oil soluble and water dispersible forms and also in dry forms of the extractives.

The process for the recovery of the flavour constituents involves size reduction prior to solvent extraction which is done in stainless steel extractors. At present oleoresins are recovered by a single stage or a two stage process. In the single stage process the oil is recovered along with the resins by solvent extraction whereas in the two stage process the ground pepper is first subjected to steam distillation for the recovery of the essential oil followed by drying and powdering the oil extracted spice before solvent extraction. The extract obtained in the two stage process is blended with the oil recovered by steam distillation to meet the specification laid down by the consumer. The oleoresin obtained by the two processes differ slightly in their quality in terms of the composition of the oil and the yield of the oleoresin. In the two stage process, there is a possibility of the yield of oleoresin to be low and this is attributed to the presence of moisture in the wet cake obtained after steam distillation. To prevent such a loss, drying is resorted to prior to solvent extraction.

For the single stage process, pepper is flaked to a thickness of 1–1.5 mm and packed in stainless steel extractors for extraction with the organic solvent. Normally a solid to solvent ratio of 1:3 is employed and an extraction temperature of 55–60°C is maintained. The solvent is continuously kept recirculated to ensure efficient solid to solvent contact and after three hours of extraction the miscella is filtered and sent for evaporation. The solids are further contacted with lean solvents from other extractors and the entire extraction process is completed after 6 or 7 stages of extraction.

The miscella sent from the extractors are evaporated in a shell and tube evaporator or a tubular evaporator at a temperature not exceeding 80°C and a vacuum of 250 mmHg. When the temperature start rising and no further solvent is recovered from the concentrated miscella, it is pumped into a high vacuum stripper or a wiped film evaporator through a filter. The final desolventization is done at a vacuum of less than 20 mm of Hg and at no stage of operation the temperature is allowed to rise above 100°C. In the initial stages of this vacuum distillation, the condensate recovered will mostly be the organic solvent and towards the end of distillation the essential oil will also start coming out along with the organic solvent. At this stage some entrainer like alcohol or the monoterpene fraction of the essential oil is added to the desolventiser. This is done to remove the final traces of the organic solvent as well as to supplement the monoterpene fraction of the pepper oil which might have been lost during the final desolventization. The product is pumped into storage tanks after confirming that the residual solvent levels are within limits. Suitable blending is resorted to meet the customer requirements in terms of piperine content as well as oil content.

Certain consumers specify the homogeneity of the oleoresin as well as the colour of the resin. This is achieved by passing the oleoresin through a homogeniser which may be a colloid mill or a sand mill. The oleoresin which is dark green in colour is bleached using activated carbon to obtain decolourised oleoresin. The bleaching operation can be done either at the extraction stage itself or prior to the evaporation of the miscella.

In the two stage process, the cake obtained after steam distillation is further dried and ground to 40 mesh size and packed in stainless steel percolators. One volume of solvent is added to the extractor and it is allowed to stand overnight. The concentrated miscella is drained off and equal volume of fresh solvent is added. The resulting miscella is drained off immediately and then fed to the adjacent extractor filled with fresh charge. This operation is repeated so as to effect counter current extraction. The extraction is done in four or five stages. The concentrated miscella obtained from each of the extractors are pooled and distilled for the recovery of oleoresin.

As is evident, the quantity of miscella from the two stage process is less than that from single stage process. This will reduce the energy consumption in the processing plant. Further as the flavour imparting essential oil is recovered prior to extraction, the flavour of the oleoresin, which is very heat sensitive, is superior.

In both types of extractions the final adhering solvent is recovered from the extractors by sparging steam. The solvent rich steam is condensed and the solvent is recovered. The entire operation is done in such away that the solvent losses are kept as low as possible. The total loss of solvent by the industry is estimated to be about 50 kg per ton of spice processed.

The chlorinated solvents which are presently employed for oleoresin recovery are slowly being replaced by other solvents or solvent mixtures. Ethyl acetate and acetone are good competitors for the chlorinated solvents but the miscibility with water, flammability and low boiling point are major drawbacks. Hexane-acetone mixture in the ratio 2:3 is a good alternative for the presently employed solvents. Research work is underway at the Regional Research Laboratory, Thiruvananthapuram, India to find an alternate solvent system by a suitable blending of certain fractions of a naturally occurring essential oil with permitted organic solvents so as to match the polarity and other favourable characteristics of the organic solvent presently employed.

Oleoresin extraction, all over the world, is done mostly in batch extractors. A recent investigation conducted at Regional Research Laboratory, Trivandrum (Sreekumar *et al.* 1993) on the kinetics of extraction has revealed the possibility of extraction being done at ambient conditions and with very low residence time. The present day extractions, which take more than 18 hours for processing one batch, can be dispensed with by employing continuous countercurrent extraction. Also the quantity of solvent required for extraction as well as its loss can be reduced.

Extraction of pepper has been done at laboratory level by enzymatic breakdown of spice cell walls. Spice is mixed with water, pH adjusted by the addition of citric acid, treated with enzymes individually as well as in combination followed by centrifugation. The enzymes used were commercially available cellulase, pectinase, hemicellulase and liquefaction enzyme preparations. Pepper extracts with good sensory and compositional properties were obtained with some of the enzyme combinations. Optimum results were obtained using a combination of cellulase and pectinase preparations. The addition of hemicellulase did not show any improve ment in flavour.

This solvent-free extraction route offers an alternate process for the recovery of flavour compounds which however is not commercially viable at present.

Another solvent-free extraction which has shown promising results is the super-critical carbondioxide extraction. The major advantages of the process include low energy consumption for solvent recovery, high purity of the extracts, ecofriendly and the possibility of fractional separation of the components present in the spice. The prohibitive cost of machinery is to be compared to the benefits derived like selectivity of extraction, no residual solvent, no bacterial contamination and standardisation of flavour strength.

Now a days, the demand for piperine is on the increase. Piperine in the concentrated form can be produced from the oleoresin by centrifuging the oleoresin in a basket centrifuge. Part of oil along with some resin will come out of the centrifuge and the centrifuged cake containing as high as 60 per cent piperine is obtained. The piperine concentration can further be increased by washing the cake obtained with fresh pepper oil and further centrifuging it.

From pepper oleoresin, numerous secondary products have been developed to improve the solubility in food substances and are marketed under various trade names by the manufacturers with their flavour strength indicated on the respective label. These include standardised seasonings compatible with and are able to withstand almost all processing conditions. Products such as emulsions, solubilised spices, dry soluble spices, encapsulated spices, heat resistant spices, fat based spices etc. are a few of them.

Emulsions are liquid seasonings prepared by emulsifying blended pepper oil or oleoresins with gum acacia or other permitted emulsifying agents. A stabiliser is added to prevent creaming and the products have only a very limited shelf life. Solubilised pepper is blended pepper oil and/or oleoresin mixed with one of the polysorbate esters in such a concentration as to give a clear solution when mixed with water. Dry soluble pepper is prepared by dispersing the standardised oleoresin onto an edible carrier like salt, dextrose, rusk etc. to give a product having a flavour strength equal to that of a good average quality ground pepper.

OTHER VALUE ADDED PRODUCTS

Microencapsulated Flavours

Microencapsulation is the technique by which the flavour material is entrapped in a solid matrix and is ready for release as and when required. Encapsulation can be achieved by a number of techniques-spray drying, coacervation, polymerization etc. Of this, spray drying appears to be the most popular method employed. The process involves homogenisation of the oil/water mixture in presence of the wall material and removing the water under controlled conditions in a spray drier. The advantage of spray drying over other types of drying is that the product, even though in contact with exiting gas, which is at a higher temperature, will never reach this high temperature within the short residence time. During spray drying the oil/ water emulsion is atomised using an atomiser in the spray drier. The atomisation can be achieved either by the use of a pressure nozzle or a rotary nozzle or by a pneumatic nozzle. The fine droplets of the emulsion come in contact with the hot gas in the spray chamber and a semipermeable membrane is formed which will selectively permit the water molecules to diffuse out where as the flavour imparting essential oil is left behind. The residence time of the emulsion droplets are controlled in such a way that it is separated from the hot stream of gases as soon as the moisture level reaches below the accepted value for the product using a cyclone separator.

The commonly used wall materials for the purpose of encapsulation are selected from among vegetable gums, starches, dextrins, proteins, sugars and cellulose esters. The wall material is selected so as to meet as closely as possible the properties like low viscosity at high solids, ability to disperse or emulsify the active material, non reactivity with the material to be encapsulated both during processing and on prolonged storage, uniform film forming property, ready availability etc.

It has been observed from studies (Anon. 1989) that the addition of surfactants during the emulsification step prior to spray drying will reduce the volatile oil loss. This has been attributed to the ability of the surfactant to reduce the internal rotation within the droplet during the drying step.

Another process developed for microencapsulation is the CR-100 process (Anon. 1995, Findlay Wilson 1995, Mos 1995) and this overcomes the limitations of the spray drying process like reduction in flavour quality and the yield. Another advantage claimed is that the carrier substance can be tailored to suit the processing conditions. Carriers used in this process include hydrogenated fats and fat based emulsions.

Heat Resistant Pepper

These are double encapsulated products in which the capsules are rendered water insoluble by a suitable coating and the contained flavour is released only at high temperatures such as in baking.

Fat Based Pepper

Fat based pepper is a blend of pepper oil and/or oleoresin in a liquid edible oil or hydrogenated fat base formulated for use in such products as mayonaisse etc.

Extruded Spices

Spices can be sterilised, ground and encapsulated in a single step by this technique. The process involves a combination effecting pressure changes, temperature shock and shear. This three-in-one process using a twin screw extruder retains the colour and flavour principles in the original form due to the very short processing time involved. The fresh spice when fed into the twin screw extruder, the starchy materials get gelatinised and forms an encapsulated product. This will drastically reduce the bacterial, yeast and mould contamination. The product emerges as a spice “rope” from the extruder which is cut to pellet size. Lucas Ingredients, U.K (Scott 1992) are marketing this product under trade name “Master Spice”.

Pepper being the most important spice used by humankind, there is further scope for its product diversification.

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8.1. THE WORLD PEPPER ECONOMY— DEVELOPMENTS AND OUTLOOK

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This chapter focuses on analyzing and forecasting supply and demand of pepper. The first three sections deal with a description of the pepper economy and the model applied to analyze the pepper economy. Second and third sections concentrate on supply and demand respectively, while the fourth focuses on prices and equilibrium in the market. The model used for the current paper is a somewhat revised, extended and updated version of the model described in Bade and Smit (1992). At that time it was the first detailed model for the pepper economy. Data and time constraints did not allow a further and more in-depth analysis. Such an analysis is clearly called for when more sound policy conclusions are to be drawn up. Projections for the pepper economy are presented in the subsequent section. The model in mathematical terms is described in the Appendix A. Appendix B gives the outlook for the world economy which is a basis for the outlook for the world pepper economy.

ANALYSIS OF THE PEPPER ECONOMY—THE SUPPLY SIDE

In this section the model of the pepper economy is presented and discussed as far as the supply side is concerned. Limitations of data are the major hurdle in model building. Therefore many comments in this section point to restricted data availability or the dubious quality of data. Nevertheless this section will also provide insight in the ways that can be exploited to estimate relationships. The large number of assumptions provide an equal amount of challenges to check their validity. All quantities of pepper mentioned in this report are in metric tons unless stated otherwise.

The study of supply of pepper is mostly approached on a country basis, looking at area, production and exports. The best approach would be to base the analysis on the number of productive vines, to be multiplied by the average yield of a vine to receive what may be called normal production. Although measurement by vines must be considered much better, the same line of reasoning can be applied with area and average yield per hectare. The major draw-back of this method in comparison to using vines is that it adds a source of variation. Not only does the yield per vine fluctuates, but of course also the number of vines per hectare. In some countries, like India this variation is very strong, while in others (e.g. Thailand) the number of vines per hectare is almost the same all over the country. If there is no significant change in cultivation patterns and the intensity of cultivation is relatively constant it is possible to estimate a nation-wide normal average yield per hectare. If the average number of vines per hectare cannot be expected to be constant an assumption is needed about the change. If intensification takes place or superior varieties are introduced, it can be assumed for e.g. that there will be an upward trend in the normal yield per hectare some two years after the start of the intensification, when the planted vines become productive. This subject is investigated again when discussing Indian yields.

If normal yield can be used as a basis for forecasting, the actual yield will deviate from it because of weather influences, amount of fertilizer applied and time spent on maintenance. Regretfully, these effects are not confined to one year. In the occurrence of a very wet year, there will be a smaller crop, but perhaps even more important is that there will be more foot-rot and other diseases. These diseases also influence next year's crop. Also the effects of neglect or exceptionally good maintenance will spread over more than one year.

This illustrates that, even when data on productive vines and average yields were available and absolutely reliable, there would be enough scope for simulation and expert interpretation. Unfortunately in this world information is costly. Gathering data on agricultural activities is even very costly, because it is time consuming. As a matter of fact it is not one of the priorities of developing countries. Planning however depends largely on information and a model cannot compensate for lack of quality of data. As far as quality of information is concerned it can only interpret and detect inconsistencies. The conclusion of this paragraph is therefore that the modelling of production and supply presented in this section must be seen as a step on the road towards a more sophisticated modelling analysis based on superior data.

Brazil

Although there are different systems of cultivation in Brazil, there are no time series on area by cultivation system. In fact it is not fully clear how the Brazilian Pepper Exporters Association gets the data that are presented at IPC meetings. The relevant data are shown in Figure 8.1.1. The assumption on which the area equation is based is that the data are on productive area. That means that the price of pepper as of last year

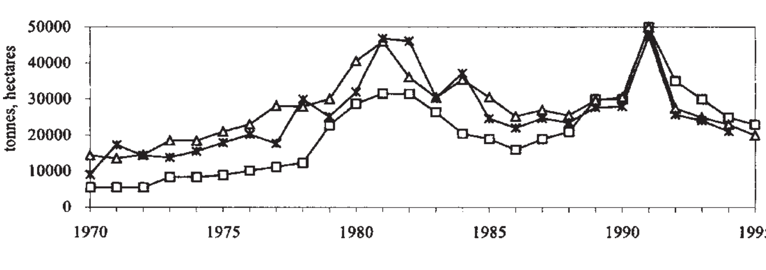

Figure 8.1.1 Area production and export of pepper in Brazil.

has been an incentive or disincentive to plant or replant. That price will be a good explanatory variable for the change in the current productive area under pepper: the price elasticity with a lag of three years was estimated at 0.30. The years 1979 and 1991 were found to be outliers. The low prices in the early 1990s combined with high production costs and diseases resulted in a decline in area and thus in production.

When looking at area and production one would expect that yields have gone up over time. Unfortunately the opposite is true. If production is divided by area the result is a decreasing function over time. There is even a strong fall in yield from 1978 to 1979 when area increased rapidly, suggesting that in those years data on area did also include area with immature new planting. After 1979 the correlation between area and production is strong although 1984 was extraordinary, with a much higher yield than could be explained. Obviously there should be a positive price correlation; the price elasticity being 0.27.

Finally exports are analyzed. As pepper consumption in Brazil is negligible compared to production and presumably kept out of production statistics as there are some other small pepper producing region outside Para state, it can be expected that total production will virtually be exported, as represented by a coefficient of 0.98. However, there is rather constant amount apparently not exported of just over 1.5 thousand tonnes. The resulting equations are given in Appendix A.

India

Indian data are shown in Figure 8.1.2. Area under pepper in India was enough to supply the whole world with pepper if yields were only in the order of one third of what they are in Sarawak. Plenty of reason to take a close look and ask some questions about the way these data are collected. Pepper is mostly grown as an intercrop in small and marginal holdings along with crops like coconut, arecanut, coffee and cardamom. Up to 1986 a survey among extension workers was held in

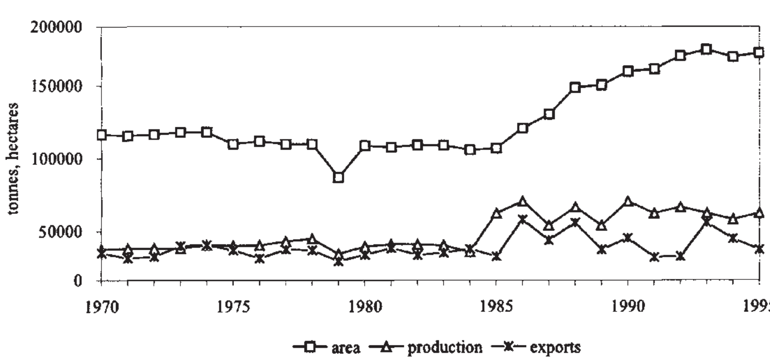

Figure 8.1.2 Area, production and export of pepper in India.

randomly chosen parts of Kerala State, in such a way that within five years every part was visited once. The total area under pepper from the population was then multiplied by the inverse of the (sample area/state area) ratio. The question asked was to estimate area on the basis of 560 vines per hectare. The method was applied, asking the same people, to get production estimates. Since 1987 the Department for Economics and Statistics is trying to introduce a more sophisticated system, especially to estimate production. The reason that this method of data gathering is described here is that it gives a plain indication of the quality of data available. Especially when it is considered that India is a country with a long history where it comes to organized collection of statistical information. Probably the data on area and production of other countries are not collected in a better way. Consistency of data of other countries could on the other hand even be interpreted as an indication that they were calculated backwards with export figures as a starting point.

Returning to Indian area, the equation that was estimated does not differ from the one for Brazil. Again, the change in area (in logarithms) is explained from the price of one year ago. While the data for the first part of the sample period are rather poor in quality still the full sample period of 1971–1993 has been used, while applying a dummy for the period 1971–1981 in particular. Comparing the coefficients with Brazil it is noteworthy that the price-elasticity is much lower: 0.09. Recently the situation for pepper is quite favourable with development programmes under way, leading to an increase in area and possibly in production when the weather is good.

When modelling production in terms of the ratio between production and area, one finds an increasing trend, contrary to the case of Brazil, especially in the second half of the 1980s. This implies that recent extension to the area are more productive. The fact that the price of last year significantly influences production per hectare illustrates probably two things. Firstly, that the use of manure and better maintenance and perhaps more picking rounds are effective. The higher the last year's price, the greater the incentive, the elasticity being 0.17. Secondly farmers keep pepper in stock. If stocks at farm level are not part of production figures it is obvious that when the price goes up and farmers release their stocks, it will seem as if production has gone up. The opposite will happen if the price goes down and farmers are reluctant to sell. If this latter explanation would be the most important one it would have been better to take the current year's price as explanatory variable. The years 1985 and 1986 are exceptionally high, while 1984 was very low.

Indian exports depend largely on this year's crop. The other factor is the influence of price changes on stocks of traders. Note that if there is a sudden increase in price the total amount of exports may even exceed production. Again 1985 is exceptional. The same applies for 1991 and 1992 because of the restructuring of the Indian economy. The resulting equations are shown in Appendix A.

Indonesia

Data on aggregate area under pepper in Indonesia are very poor. They are shown in Figure 8.1.3. Official records claim that total area did not change from 1983 until

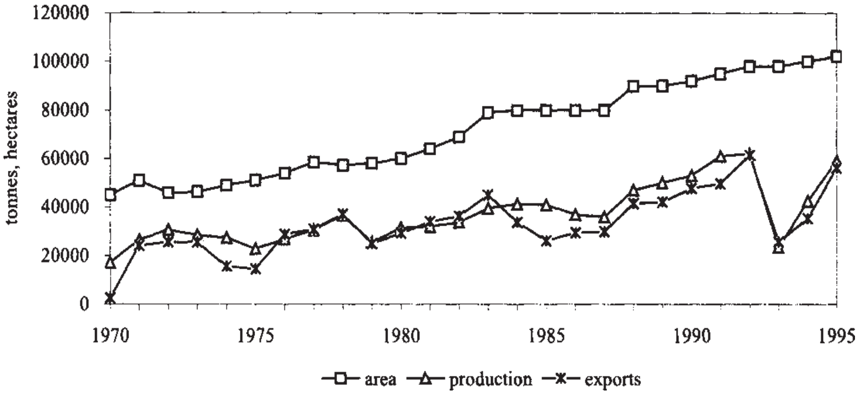

Figure 8.1.3 Area, production and export of pepper in Indonesia.

1987. Records for Lampung and Bangka show considerable changes over these years. Unfortunately the time series on area of Lampung and Bangka are still too short. Furthermore there is hardly any information on area in Kalimantan. Regional disaggregation of supply of Indonesia is one of the important items for future modelling research. Especially because of the special position of Bangka where only white pepper is produced.

The area equation is again familiar, with prices of three years playing a small role: an elasticity of 0.01. Other price influences could not be demonstrated. This may partly be a reflection of the reality, partly an indication of the poor quality of the data. Clearing of new land has been important and will continue to be important. Nowadays this clearing of new land predominantly takes place in Kalimantan and Sulawesi.

When looking at production per hectare, the price of 4 years ago (price elasticity of 0.15) performed better than other prices, indicating that for Indonesia the influence of the price on stocks is far less important than on maintenance. This is the same as the conclusion drawn in the case of India. The year 1993 shows a serious set-back in production and thus in exports reflecting the bad situation of white pepper in Bangka.

A very straightforward relation was superimposed on exports. Regression of exports with only production as explanatory variable gave an elasticity of 0.88. No positive influence of price could be detected. The years 1974, 1975 and 1985 registered unexpectedly low levels of exports. The resulting equations are presented in Appendix A.

Malaysia

When looking at data on area and production in Malaysia (nowadays 98 per cent on Sarawak) one immediately becomes aware of the fact that either the data are wrong or yields are extremely volatile (Figure 8.1.4). Sources claim that both is true.

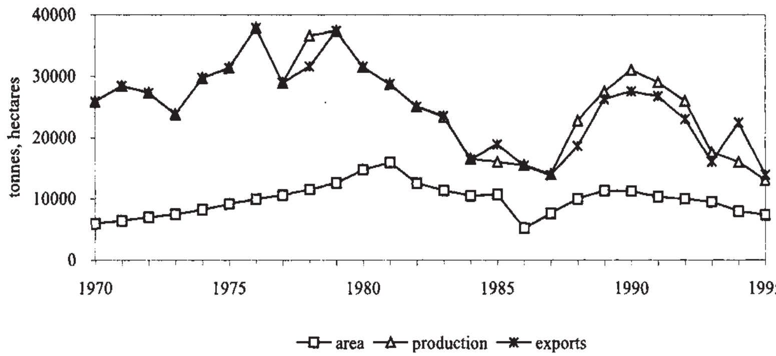

Figure 8.1.4 Area, production and export of pepper in Malaysia.

Yields are strongly influenced by footrot and data are unreliable as production used to be estimated on the basis of exports, whereas it is well known that the farmers in Sarawak are relatively rich and speculate with pepper as is also done by exporters. So there may be large differences between production and exports from time to time.

The area equation performed very well except for 1982 and 1986. A one year lagged price has a very significant influence, as represented by the elasticity of 0.22. Since 1989 there is a clear downward trend reflecting the high cost of production in Malaysia due to lack of labour and high wages, which does not allow for profitable pepper production to the extent as was the case in the past.

The price of pepper two years ago as independent variable was very significant (elasticity of 0.28) in explaining production per hectare, although it is clear that this influence should largely materialize through new planting of vines. Of course one would also still expect the one year lagged price to have effect on maintenance and the current price or price change to affect stocks. Speculation was taken into account by taking current and last year's production as variables in the export equation next to price changes, resulting in an elasticity of 0.15. Again, 1985 was found to be an outlier. For the equations see Appendix A.

Thailand

Thailand is a relative newcomer in pepper (Figure 8.1.5). Area was quite steady until 1986, increased strongly afterwards, but dropped again during 1991 to 1993 when prices were low. Government encouraged farmers to diversify away from pepper. Changes in area were found to be influenced by prices of last year with an elasticity of 0.16. Area is still rather stable.

Productivity per hectare is very high, while production is also strongly influenced by last year's change in prices: elasticity is 0.66. The production figures for 1987 could not be satisfactorily explained by the model. Recently, however, production is

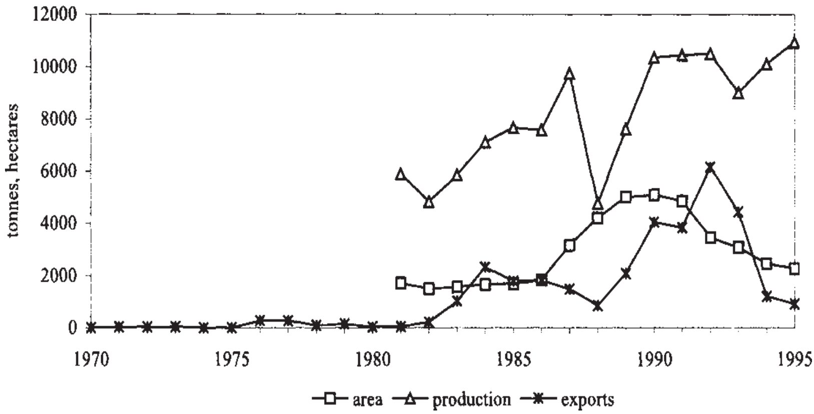

Figure 8.1.5 Area, production and export of pepper in Thailand.

on a declining trend. Domestic consumption in Thailand is substantial: around 5000 tonnes per year. Exports take a rather fixed share of production, while being affected by a relative surplus or shortage in the previous year (Appendix A).

Sri Lanka

Sri Lanka is a traditional producer of pepper. Area data show a slight increase over time. The figures for 1986 and 1987 have been adjusted, as they were around one million hectare too high. Productivity is very low and production does not show a significant increase, which is surprising because area is on the increase, requiring new more productive area.

Area in Sri Lanka has been explained in the model in a straightforward way from a trend term and one-year lagged and two-year lagged prices: the elasticity of the price ratio is 0.06, while production per hectare can to some extent be seen as a function of three-year lagged prices with an elasticity of 0.18. The year 1993 showed a pattern which is quite opposite to Indonesia: an incredibly high level of production and exports. Export could be well explained from production, the change in production and the domestic price level, as represented by an elasticity of 0.07. Export in the year 1990 was unexpectedly high, exceeding production (Figure 8.1.6).

Other Countries

For the other producing countries, i.e. Madagascar and other Africa, Vietnam and China and other Asia, graphs on exports are shown in Figures 8.1.7 to 8.1.9 Only an export equation was estimated or some crude assumption was made. To improve on this, longer time series and information on area and production as well as on internal markets and export possibilities are needed.

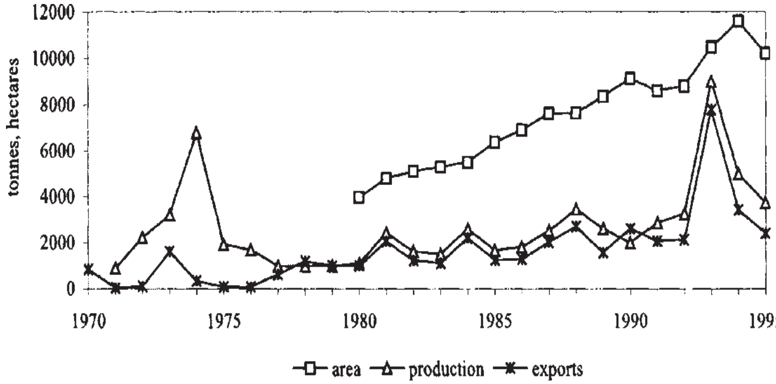

Figure 8.1.6 Area, production and export of pepper in Sri Lanka.

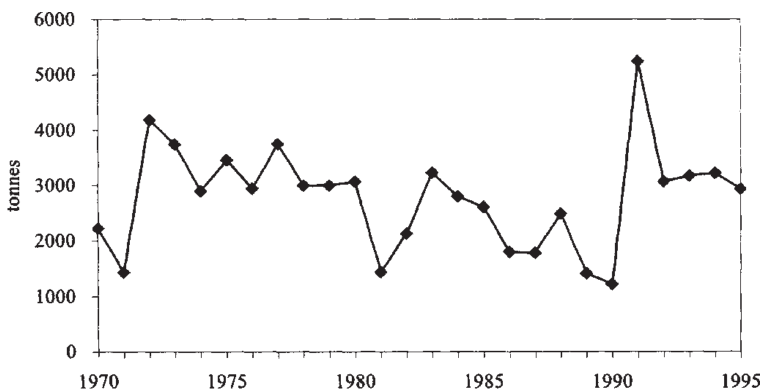

Figure 8.1.7 Exports—Madagascar and other Africa.

International Distribution of Exports

Graphs are shown in Figures 8.1.10 and 8.1.11 for the years 1970 and 1980. There has been a considerable change in the geographical composition of exports during the 1970s with Brazil and Indonesia taking a large share away from India and Malaysia. The year 1990 shows a slightly different picture compared to 1980: Indonesia easily takes the largest share, with India, Brazil and Malaysia all around 20 per cent. Other countries have little to contribute.

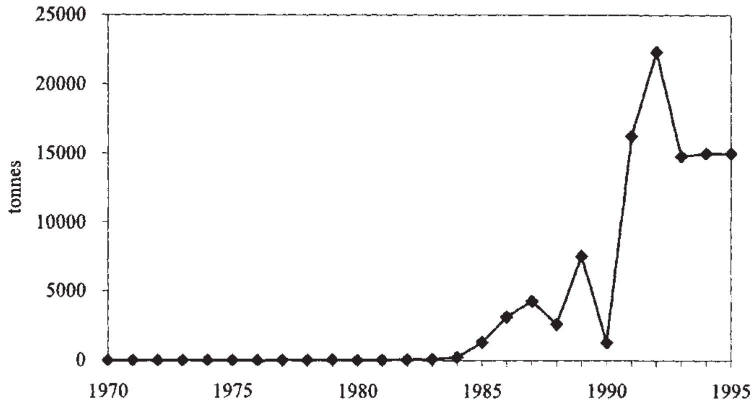

Figure 8.1.8 Exports—Vietnam.

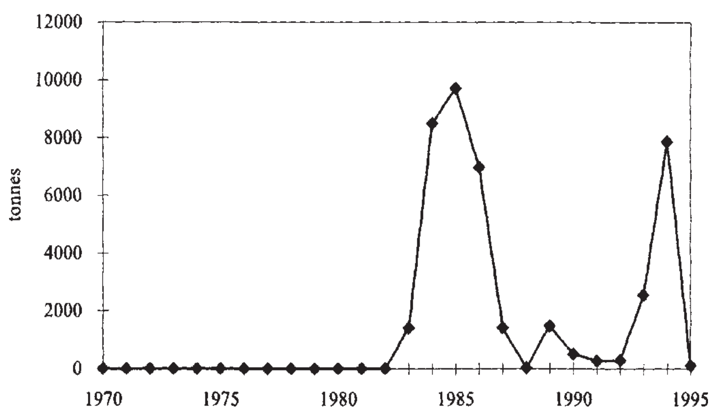

Figure 8.1.9 Exports—China and other Asian countries.

ANALYSIS OF THE PEPPER ECONOMY—THE DEMAND SIDE

Modelling demand for pepper is proposed to be based on imports consisting of consumption and changes in stocks. Lack of data on end-use of pepper forced us to use general variables as income and/or population as explanatory variables for consumption. A more sophisticated modelling approach of demand, including a

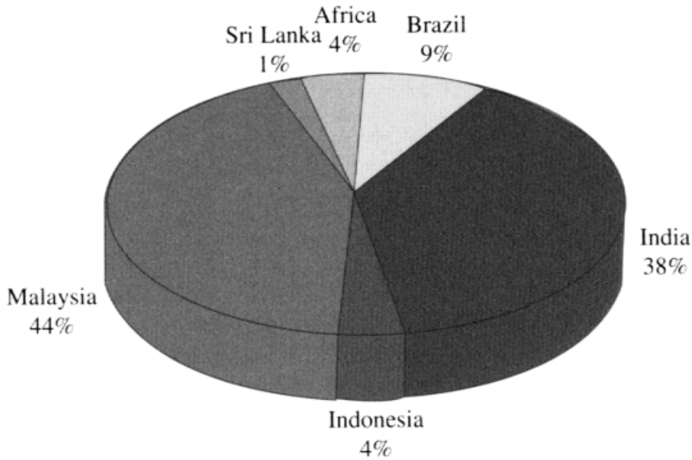

Figure 8.1.10 Exports 1970.

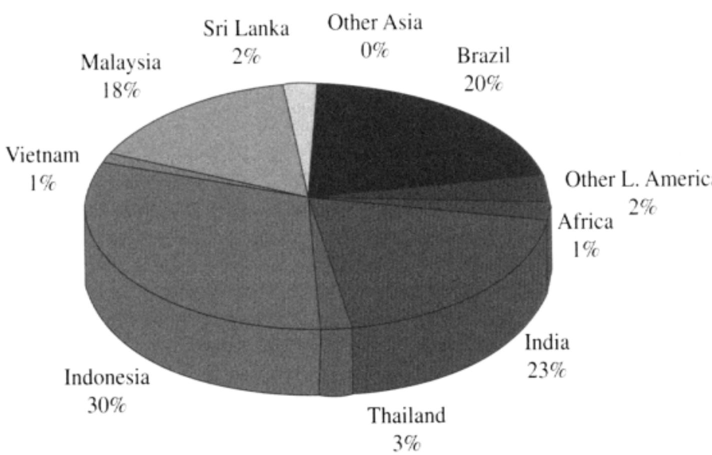

Figure 8.1.11 Exports 1980.

differentiation of pepper use in food industries, institutional catering and household consumption must be considered almost impossible at the moment as there are only rough estimates of shares available, but nothing on changes in these percentages. More important and useful would it be if the market for black and white pepper could be modelled separately. For this it is only needed that import statistics distinguish them.

As far as aggregation of consuming countries or regions is concerned, the European Union (of the 12) could be taken as one region or as several separate countries or regions; the first option was chosen, although there are marked differences in the development of demand over time, especially between Northern and Southern European countries. The same applies for the other European groupings: The countries united in the early 1990s in the European Free Trade Association (EFTA) and Eastern Europe in combination with the CIS. It may be argued that after the falling apart of the communist block in 1989 there is not much reason left to take the CIS and the Eastern European Countries together. However as trade channels have not changed much since and for reasons of consistency in the analysis, they will still be taken together. Only the reunion of the two Germanics has been incorporated. It should be stressed that pepper consumption will increase in Eastern Europe and the CIS only after political and economic reforms have been successful and income starts to rise. The Middle East, where growth in consumption is high, but imported quantities are still small in absolute terms was treated separately as was China, where, although statistical information is lacking, consumption as well as production is said to increase rapidly. Some other groupings are obvious such as the United States & Canada, Japan, Latin America (except Brazil), Australia & New Zealand and the rest of the world (divided in African and Asian countries).

To estimate data for consumption imports were used as the dependent variable and Gross Domestic Product as independent variable, mostly accompanied by population size. In mathematical terms:

$$mppcxx = f(ypcxx)$$

with $mppcxx$ = import of pepper per capita in region xx
$ypcxx$ = income per capita in region xx

Then follows the resulting estimated, "normal" level of import as a proxy for consumption:

$$cpxx = nxx * \hat{mppcxx}$$

with $cpxx$ = consumption of pepper in region xx
nxx = population in region xx

The effect of changes in income needs some explanation. In some countries a rise in income leads to more meat consumption as people can afford to buy more and as a result particularly household use of pepper increases. In very rich countries, such as the USA or the countries of the EU a rise in income leads to more outdoor fast and/or ready-made food consumption as well as to a greater variety in food choice, including exotic, spicy dishes. The increase in the use of pepper is concentrated in the institutional catering and food processing. A somewhat different story applies to Japan, where growth of GDP is related to openness of the country and this openness is correlated with changing patterns in food consumption and taste. Here household consumption of pepper and other uses are equally affected.

The estimation of data for changes in stocks was done by deducting consumption as estimated above from import.

$$\Delta zpxx = mpxx - cpxx$$

with $\Delta zpxx$ = changes in stock

To arrive at an equation explaining behaviour of stockholders was not an easy task. First of all, high prices lead to a decline in stocks. The second aspect is that stockholders are assumed to reduce their stocks if the carry-over from last year was large, implying that the level of lagged stocks should have a negative influence on current year's change in stocks. Further, a large level of export compared to consumption results in a positive change in stocks. Comments will be given when discussing the country results whenever necessary. Basically the model for region *xx* is

$$\Delta zpxx = f(\Delta rpsny, zpxx_{-1}, (xprw - cpw), \text{etc.})$$

with $\Delta rpsny$ = change in the real price of pepper

$zpxx_{-1}$ = level of stock lagged 1 year

$xprw - cpw$ = difference between export and consumption in the world

For forecasting consumption the equation used to derive consumption data is used as well. The equation representing the behaviour of stockholders is used to project changes in stocks. Projections of import then result from adding projected changes in stocks to projections of consumption:

$$mpxx = cpxx + \Delta z\hat{p}xx$$

Below estimation results are discussed by country or region. The models are presented in Appendix A. As an example only for the first region, North America, the graph is shown. For the others, mostly running along the same line, graphs are presented along with the projections (Figures 8.1.30–8.1.35).

North America (USA and Canada)

Explaining imports in terms of income is used to estimate data for consumption. Obviously, in view of the purpose of the equation, the regression estimation results are not very good in terms of R2. The income elasticity is 1.19 which is slightly above 1. Figure 8.1.12 shows consumption and imports of pepper in North America. Modelling stocks in North America runs along the standard lines with the starting stocks and the price level as explanatory variables, both with a negative relationship: if prices are low, traders will keep more stock, expecting prices to increase again some time in the near future, and if stocks are high, traders will tend to sell.

Japan

As already mentioned, demand in Japan depends on GDP in more than one way. A change to more outdoor and ready-made food, in particular Western food goes along

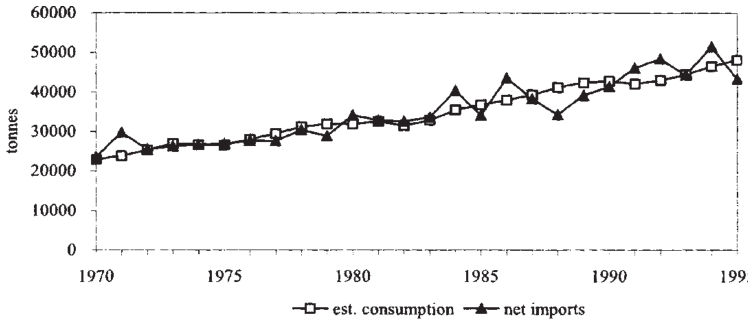

Figure 8.1.12 Net imports and estimated consumption of pepper in North America.

with a rising GDP. The income elasticity is 0.85, somewhat below North America. For Japan the change in stocks was best modelled similarly to the North America: depending on the level of the price as well as the level of the stock at the end of last year. Again the coefficients are found to be negative as it should be.

Australia and New Zealand

The analysis on consumption is straightforward as in the cases of the previously discussed countries. Again the per capita income elasticity is 0.90, slightly below 1. Regarding modelling stocks, no influence of the price could be found and the lagged stock level did not yield proper results as explanatory variable either. So, stock levels have now in principle been related to consumption, but a reduced form was taken, using income as explanatory variable.

European Union (EU)

To get estimates of consumption the starting point as usual was a regression of per capita imports on per capita income. The income elasticity is very high 1.38. This will be largely due to a shift in the eating pattern in Europe: more prepared food, more fast food. There appears to be an inconsistency in the data base, presumably resulting from a change in the statistical system. Western Europe, as most regions, is price conscious, as far as stock formation is concerned. Also, the level of stocks at the end of the previous year has a reasonably significant influence.

Rest of Western Europe, EFTA

From 1988 onwards Switzerland presents import data on pure pepper, whereas until then these figures also included pimento and capsicum. The figure for 1988 was exceptionally low: presumably some data problems. The final income elasticity is

0.83, somewhat less than 1. Stock formation could be explained reasonably well from changes in the price.

Eastern Europe and CIS

For Eastern Europe and the CIS estimating the relationship between income and food consumption gave a very low income elasticity, 0.53. Of course, and on top of this, the economic problems have had a devastating effect on imports since 1990, necessitating the use of dummies for 1992 and 1993. For results see also Figure 8.1.13. Stock formation could reasonably well be explained from changes in prices.

Latin America

Import of pepper per capita did not show any significant increase and no equation could be found explaining imports per capita. For that reason imports rather than imports per capita were taken as dependent variable and were explained from income. The periods 1976–1980 and 1985–1988 gave significantly lower figures than the rest of the sample period. Explaining stock formation from lagged stocks and prices was reasonably successful.

Asia and Pacific, excl. China, Producing Countries, Singapore, Australia and New Zealand

This region excludes China, the other producing countries, Singapore, Australia and New Zealand, because those are treated elsewhere. The import/consumption equation could best be estimated without transforming the variables to logarithms. Apparently there have been shifts in the data, which have been accommodated in the analysis. Regarding modelling stocks, some influence of the level of the price and of lagged stocks could be found.

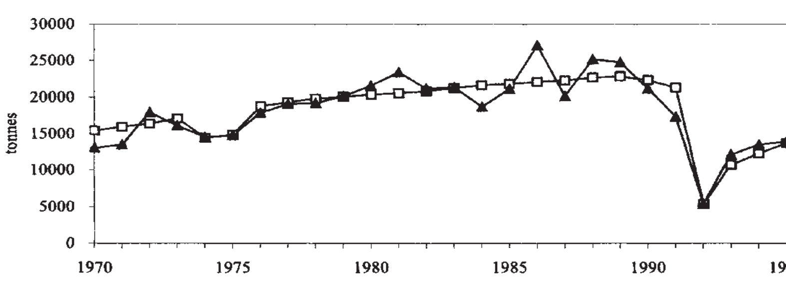

Figure 8.1.13 Estimated consumption and imports of pepper in Eastern Europe and CIS.

China

China was a small importer with rather high levels in the latter part of the 1970s. Imports have now dwindled.

Middle East and North Africa

The import figures for this region are somewhat irregular as can be seen from Figure 8.1.34. No transformation to import and income per capita was made, because of the quality of the estimation results of imports per capita. Looking at the data for this region the years 1980–1983 and the years 1991–1992 were out of line. Stock formation was influenced by price changes.

Rest of Africa

Import of pepper per capita did not show any significant increase as was the case in Latin America. Therefore imports rather than imports per capita were taken as dependent variable and were explained from income. The period since 1990 gave significantly higher figures than the rest of the sample period. Stock formation could again be explained from price changes.

The International Distribution of Pepper Consumption

As for exports but not as dramatically there is a change in the 1970s (Figures 8.1.14 and 8.1.15); here basically only an increase in the share of the Middle East and North Africa where apparently the oil situation has led to more consumption of pepper. The picture for 1990 is quite similar to the one for 1980. If one draws the picture for the situation as of 1992 (Figure 8.1.16), the dwindling share of the CIS and Eastern Europe makes the graphs look different.

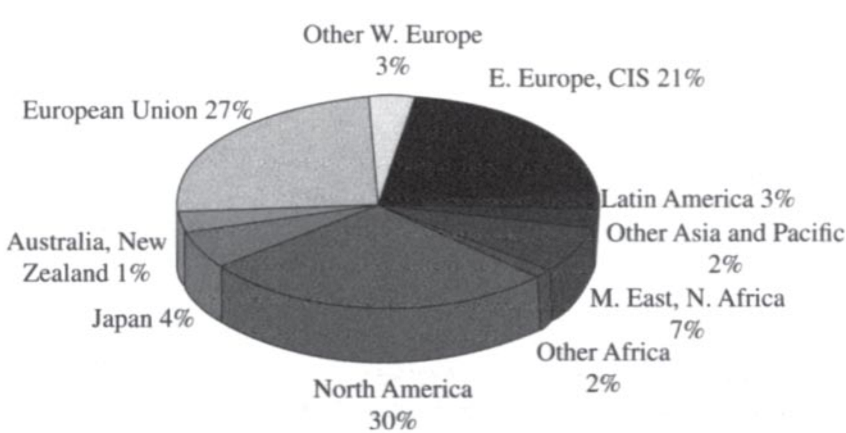

Figure 8.1.14 Consumption 1970.

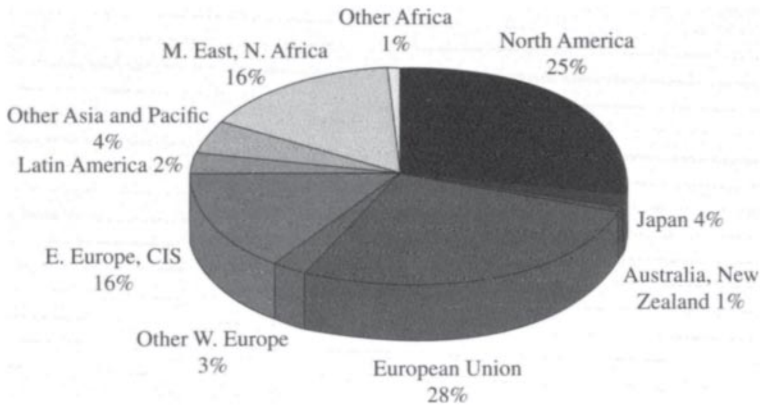

Figure 8.1.15 Consumption 1980.

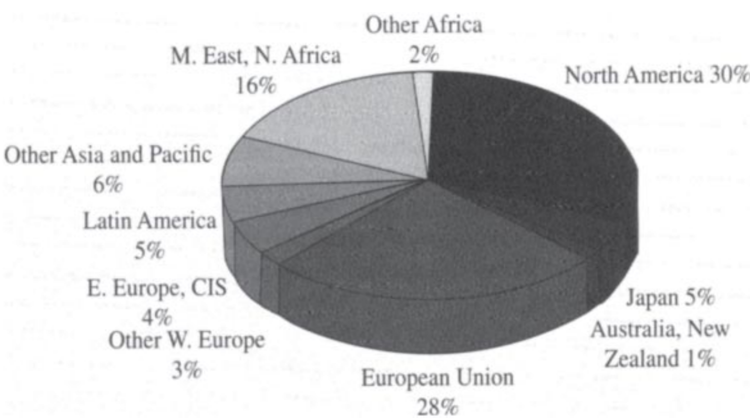

Figure 8.1.16 Consumption 1992.

ANALYSIS OF THE PEPPER ECONOMY—THE WORLD MARKET AND PRICES

Introduction

The focus of this section is on the determination of local prices and world market prices as they result from the required balance between demand and supply. First some remarks are made about the position of Singapore especially in relation to data. Then a review is given on the relationships between local prices in domestic currencies and world market prices. Finally the chosen world market price is discussed and the development in and explanation of such a price is elaborated upon.

Singapore

More needs to be said about the special position of Singapore as an entrepot for pepper and its consequences. The import and export statistics were adjusted as they revealed that exports exceeded imports by an average 10,000 tons a year. There is still an important though decreasing role of Singapore for Malaysia. Therefore gross exports from Malaysia was used as independent variable. The estimation indicates that 69 per cent of Malaysian pepper exports is shipped via Singapore. This could be slightly over-estimated especially for the future, as it is the concrete policy of the Pepper Marketing Board to encourage direct trade. The function of Singapore as an entrepot is accounted for by the variable total exports of producing countries minus estimated world consumption, which is merely an estimate of the change of stocks outside producing countries. Singapore is expected to import part of these stocks and keep the major part of it as carry over stocks. This is reflected by the negative sign in the export equation. Some part of pepper imports are of course consumed, but no statistics of pepper consumption in Singapore are available. If it is assumed that the change in stocks outside the producing countries has an expected value of zero, i.e. positive and negative changes balance, then consumption would be approximately 1 per cent of imports. Finally, the significance of the price indicates that presumably pepper traders are more interested in trade if prices are high, which does not seem unrealistic as margins will probably be correlated with the height of the price. The above has resulted in the model presented in Appendix A.

Local Prices

About the determination of local prices one can be relatively brief. To model the differences in f.o.b. prices and prices in final markets correctly one would have to look at costs of freight and insurance. The precision of an exercise like that would however be in sharp contrast with the crudeness of the rest of the model and add little to the accuracy of price projections and simulation results. In the modelling exercise it was decided to take a constant relationship between the price in New York and the price in a producing country converted into US$ (Figures 8.1.17 and 8.1.18). For reasons of comparison only black pepper prices were used. For the producing countries this resulted in the regression equations presented in Appendix A.

Along with these some definitions of other prices are given, that are straightforward and take account of inflation and depreciation effects. These prices are used as explanatory variables in area and supply equations in the producing countries.

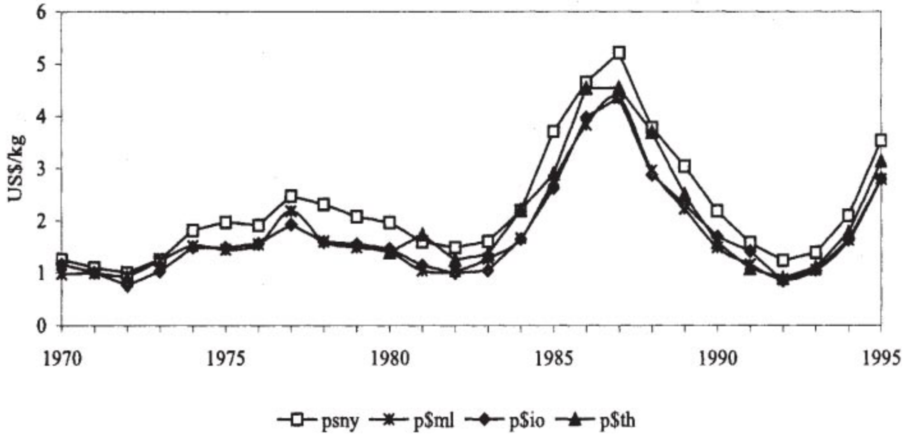

Figure 8.1.17 Pepper prices, f.o.b. N.Y., Malaysia, Indonesia, Thailand.

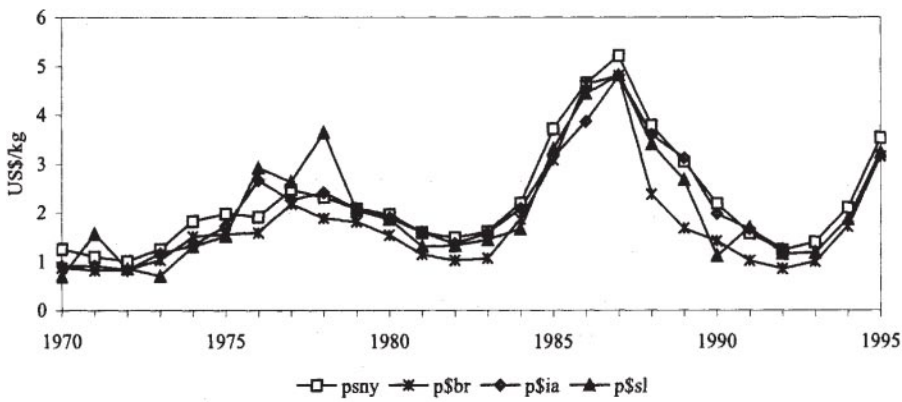

Figure 8.1.18 Pepper prices, f.o.b. N.Y., Brazil, India, Sri Lanka.

Equilibrium on the Market

The model assumes that prices are determined as resulting from equilibrium between demand and supply. So the model is solved by deriving a level of the price that clears the market. The clearing price is the real price of pepper in New York. The model is therefore closed with the following *identities:*

$$mpw = xpw$$

where

mpw = total world net imports
xpw = total world net exports

PROJECTIONS OF THE PEPPER ECONOMY-PRICES, SUPPLY AND DEMAND

It is the purpose of this section to draw a picture of the future of the pepper economy using the model that was presented earlier startirtg with developments in prices, followed by projections of supply and afterwards by projections of demand.

The Outlook for Pepper Prices to the Year 2020

Before embarking on the presentation of figures for likely future developments, it needs to be stressed again, that the results in this section in some cases would benefit from a more solid database. In interaction with country experts and using additional data, improvements are expected to be possible. One of the aspects not yet sufficiently captured is e.g. the size of the Indian supply responses to price fluctuations. For all countries the investment side is not yet represented adequately for long-term analyses. Stock formation at various levels needs further work as well. In this way a list of necessary activities can be formulated, depending of the concrete policy question at hand: an investment policy question requires elaboration in a different direction than a question about the feasibility of a buffer stock. Nevertheless, the projected figures are likely to have been accurate predictions or at least accurate indicators of moments and directions of changes.

Three earlier sets of projections were derived. The first one in late 1990 and presented in a paper called *Modelling the pepper market* to the International Workshop on “Cooperation among the IPC member countries in the development and use of a computer simulation model for forecasting supply, demand and prices of pepper”, Jakarta, 12–21 March 1991. At that time the projections indicated a slight recovery in prices in 1991, compared to 1990. Unfortunately, the recession took longer than expected, especially because of the situation in Eastern Europe and the CIS. In a paper *The pepper economy—present and future*—for the International Workshop on the Progress and Development in the Control of Pepper Diseases in the Producing Countries, Lampung, Indonesia, 3–5 December 1991, the projections were based on the same model but including all available new information and data. The model indeed projects lower prices in 1991 but higher prices especially in 1993. This has materialized. All this refers to real prices, obtained as nominal prices deflated by a price index. The third set of projections continues from the previous one and was done especially for the purpose of assessing supply management policies; the reader is referred to Bade, Smit and Haryanto, 1994.

It is now possible to make projections of the pepper economy incorporating to the extent possible the 1995 information into the model described above. No sound information on 1996 is available. The figures for 1996 therefore are model estimates and not data. When using a model for the purpose of making projections it is necessary to make assumptions regarding variables which are not explained by the model. This is especially the case for two categories of variables:

a. developments in population and income (GDP) per country or region, and
b. developments in exports by those countries which are not covered in detail by the current model, notably Vietnam, China and other Asia and Madagascar and other Africa.

The following assumptions have been made. Regarding population the database of the ESI on population projections has been used; this database is slightly adjusted from projections by the United Nations and the World Bank. For projections of GDP a model is available at the ESI. This model as well as the projections for population and GDP are summarized in Appendix B. This model results in cyclical developments continuing to dominate the world economy with troughs repeating roughly every 10 years, the next one around the year 2001. The average world GDP growth rate will be around 2.5 per cent.

Projections for pepper exports from Vietnam, China and other Asia and Madagascar and other Africa could not as yet be derived nicely from the data since these countries have only recently become more outward looking. Vietnam and China are assumed to increase exports. This completes the major assumptions apart from some standard projections about exchange rates and deflation.

Here only price projections are given. The following two sub-sections concentrate on supply and demand respectively. Figure 8.1.19 shows these projections of prices. It can be concluded that the model projects price cycles of around 7 years to continue in future, showing that the 10-year cycles in income have very little impact. Further there will not be an increase in average real prices. Obviously, with inflation of about 4 per cent per year, nominal prices do increase on average.

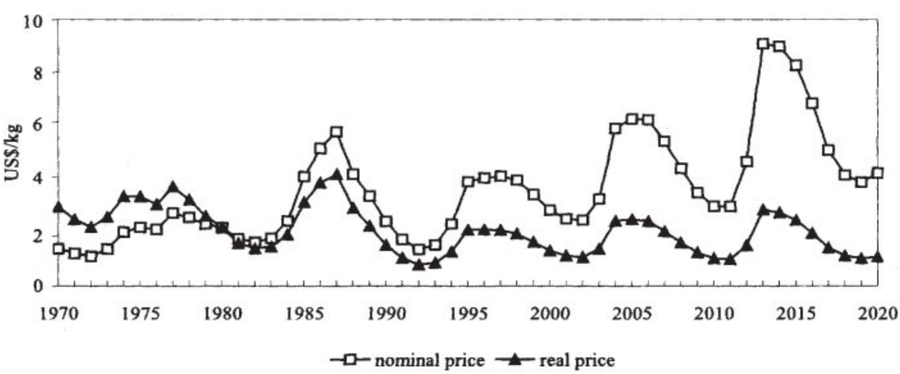

Figure 8.1.19 Price simulation spot price Lampung black in New York.

The Outlook for Pepper Supply to the Year 2020

Projections for the six major producing countries for which a model was developed for area, production and exports results are shown in Figures 8.1.20 to 8.1.25. Brazil, Malaysia and Thailand are expected to decline because of the increase in labour costs. For the three countries or regions Vietnam, China and other Asia and Madagascar and other Africa, for which simple equations were postulated, the projections are shown in Figures 8.1.26 to 8.1.28. Brazil shows a modest decline on

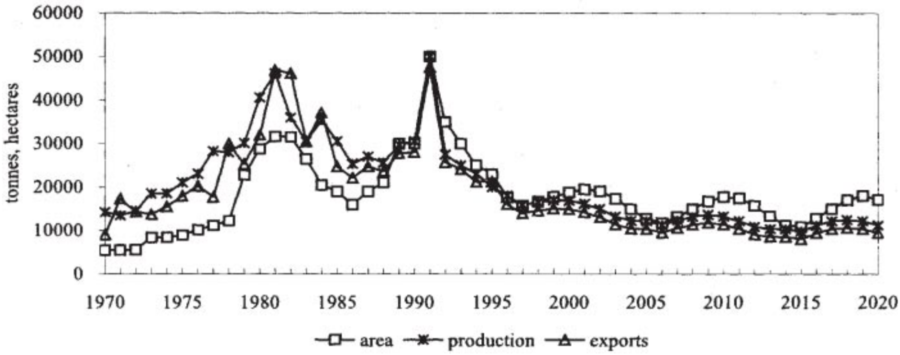

Figure 8.1.20 Brazil.

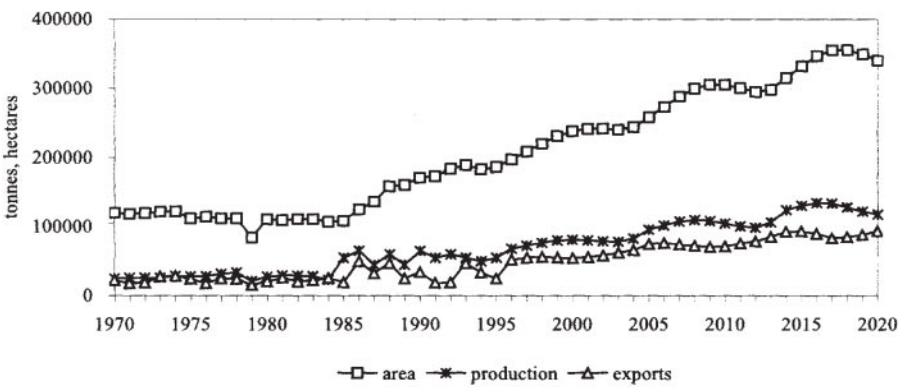

Figure 8.1.21 India.

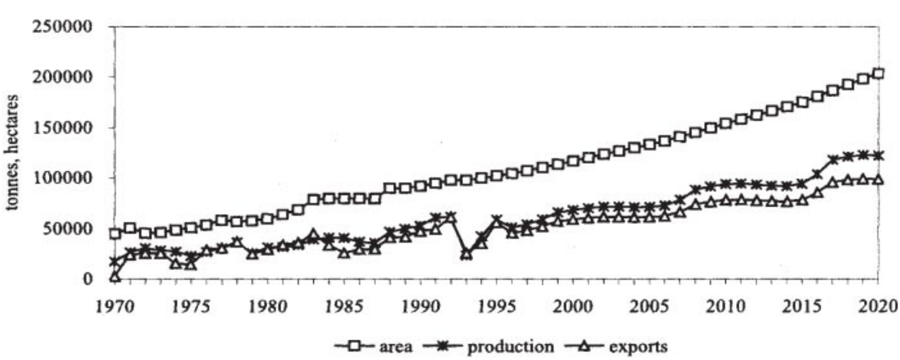

Figure 8.1.22 Indonesia.

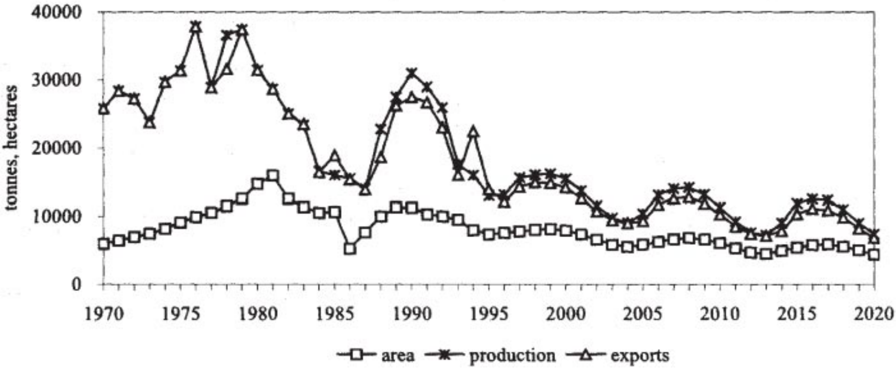

Figure 8.1.23 Malaysia.

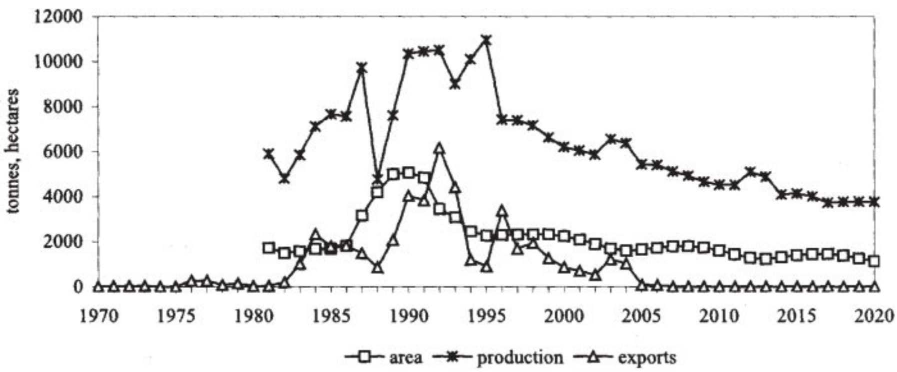

Figure 8.1.24 Thailand.

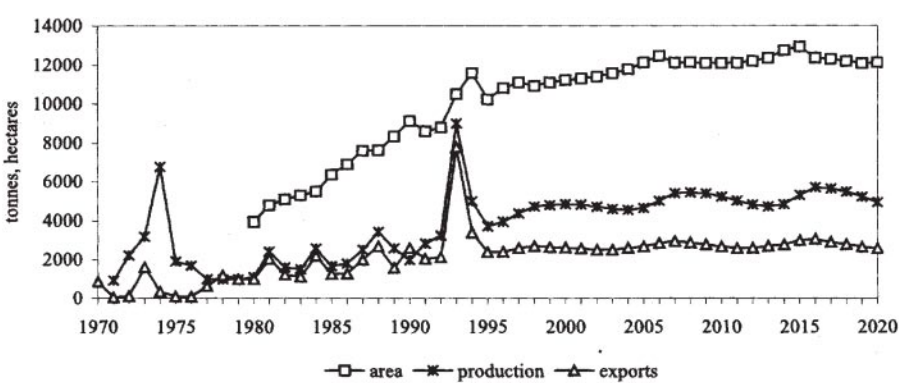

Figure 8.1.25 Sri Lanka.

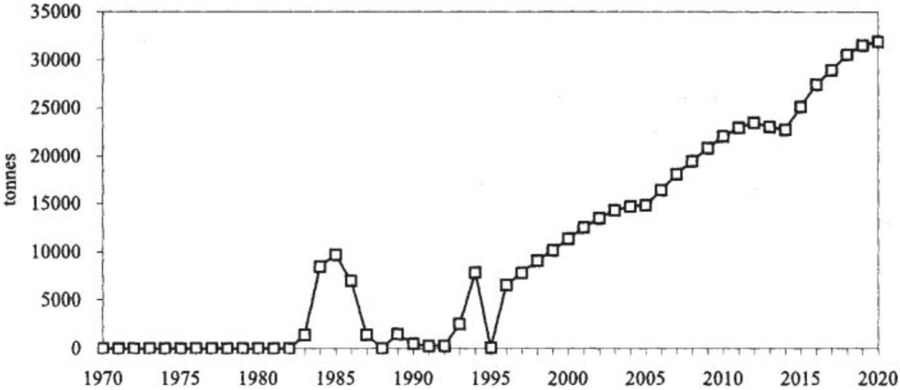

Figure 8.1.26 China and other Asia.

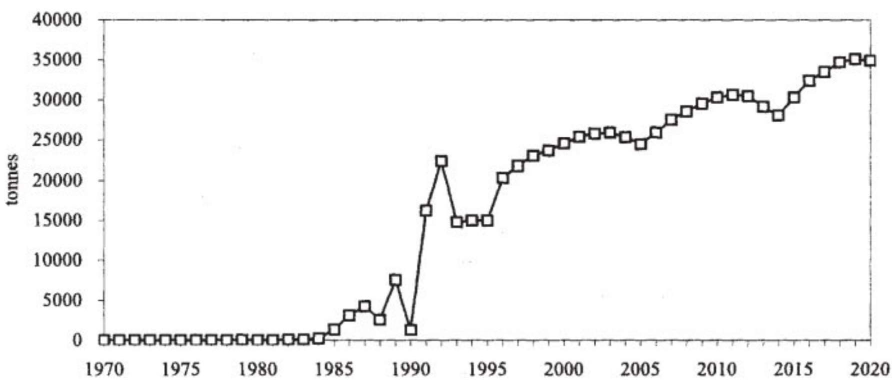

Figure 8.1.27 Vietnam.

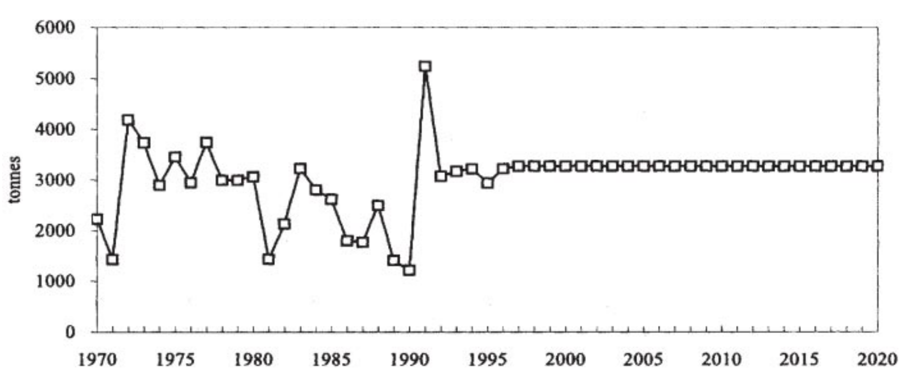

Figure 8.1.28 Madagascar and other Africa.

average, while India and Indonesia show a strong growth. The same conclusion as for Brazil can be drawn for Malaysia and Thailand: these countries become too rich to grow agricultural labour intensive crops. Sri Lanka is expected to level off, largely because of limited area.

Exports from Vietnam and China and other Asia are expected to grow rapidly, reaching an aggregate of over 60,000 tonnes. These countries have to fill the gap left behind by the relatively rich countries Brazil, Malaysia end Thailand and not filled by the the traditional major producers India and Indonesia. Exports from Madagascar and other Africa are expected to be steady. This leads to the conclusion that almost all pepper will come from Asia (Figure 8.1.29).

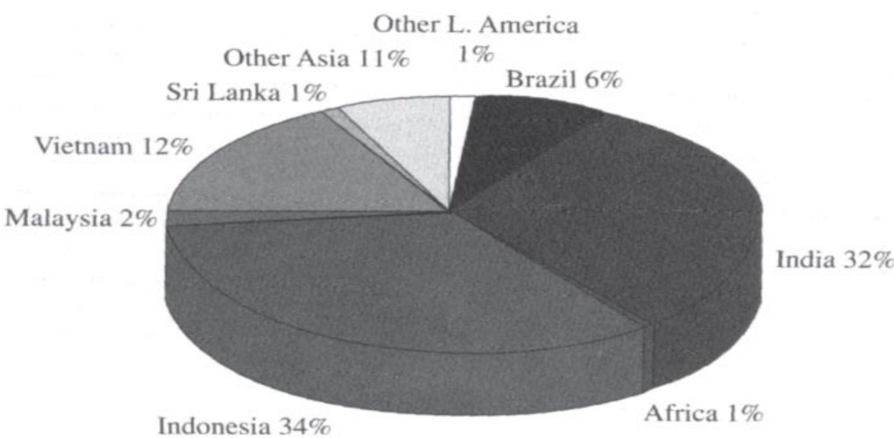

Figure 8.1.29 Exports 2020.

The Outlook for Pepper Demand to the Year 2020

On the consumption side as an example, results for only five regions are depicted: North America, Japan and the European Union show a steady growth (Figures 8.1.30 to 8.1.32). Important are developments in Eastern Europe (Figure 8.1.33) and upcoming other Asia and the Pacific, which will be a major consumer in a few decades. Figure 8.1.34 shows the result for a major consuming area, the Middle East and North Africa. This leads to modest changes in the international distribution of consumption (Figure 8.1.35).

Projections of the Pepper Economy—Summary and Conclusions

In the previous section price projections are shown and developments by country are described, both for supply and demand. There appears to be enough pepper for exports to satisfy consumption in non-producing countries: the two graphs follow each other closely as can be seen in Figure 8.1.36.

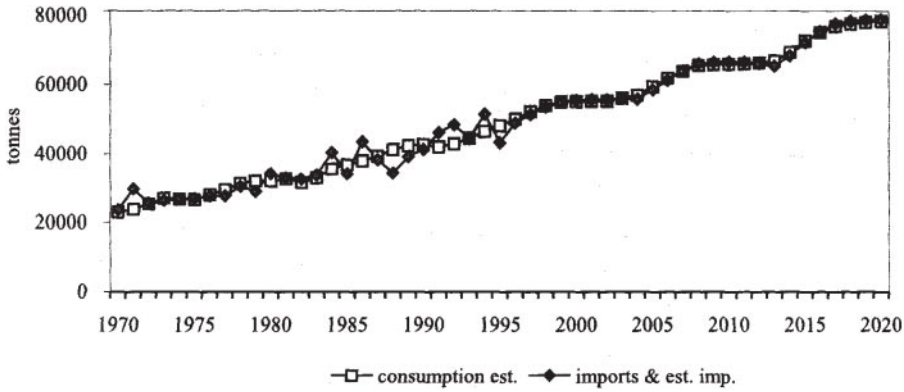

Figure 8.1.30 North America.

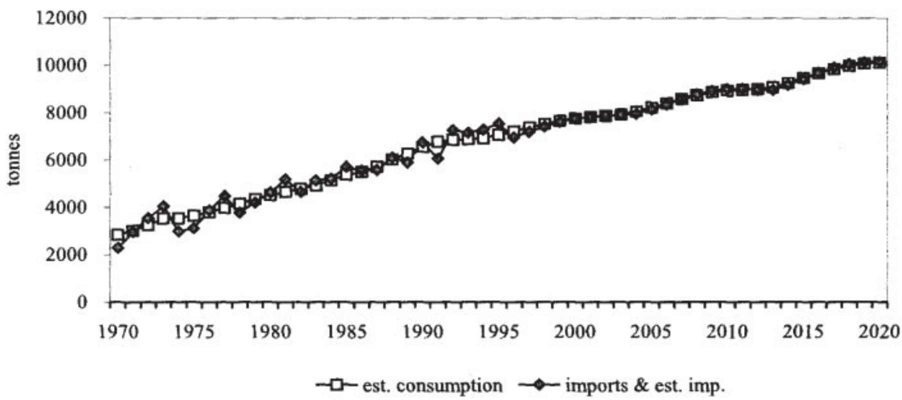

Figure 8.1.31 Japan.

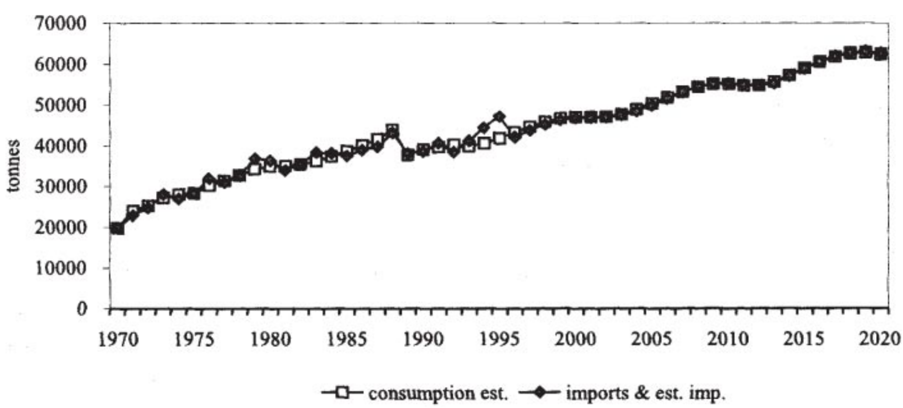

Figure 8.1.32 European Union (12).

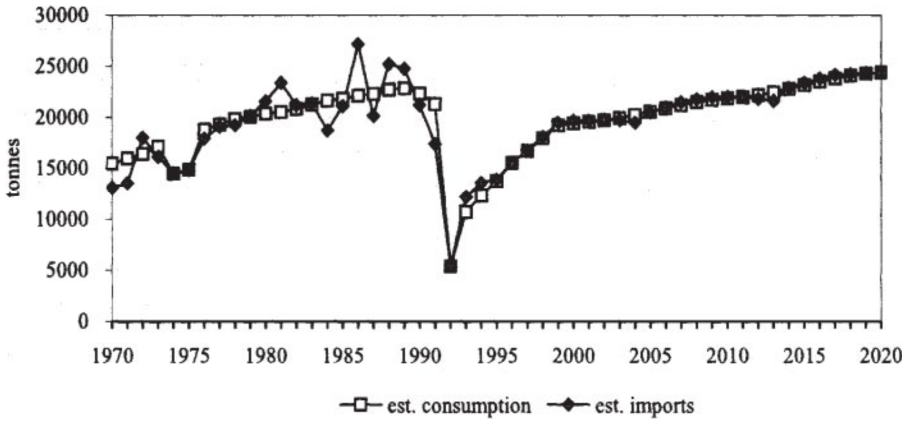

Figure 8.1.33 Eastern Europe and CIS.

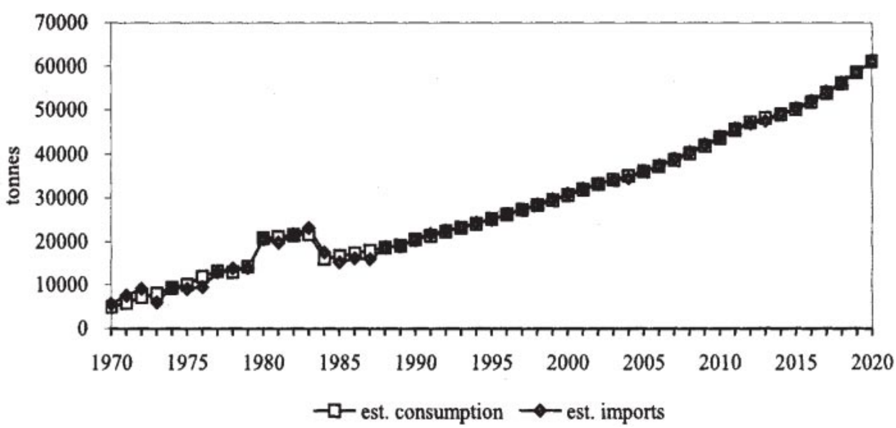

Figure 8.1.34 Middle East and North Africa.

On the supply side the following three groups can be distinguished:

a. the traditional producers which have become high-cost producers: Brazil, Malaysia and Thailand
b. the other major traditional producers which continue to be major producers: India, Indonesia and Sri Lanka
c. the other producers including the emerging producers.

At this stage it looks as if the increase in consumption and the decline of the three major high-cost producers is largely accommodated by the three other traditional major producers India, Indonesia and Sri Lanka (see Figure 8.1.37). The emerging

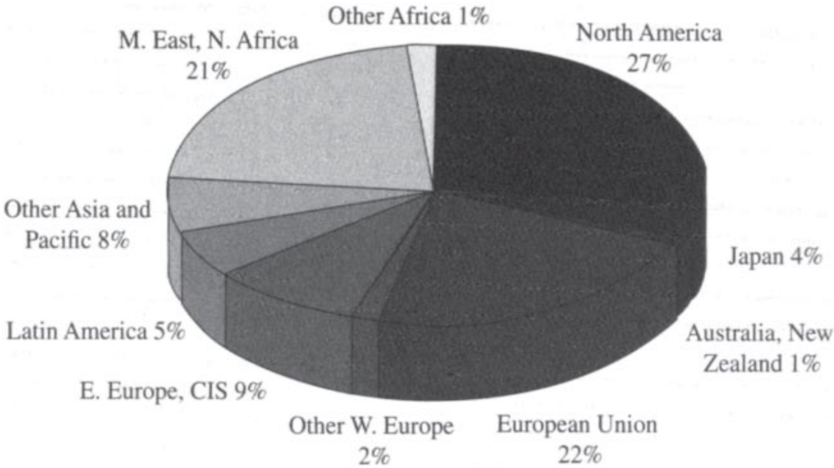

Figure 8.1.35 Projected pattern of consumption for the year 2020.

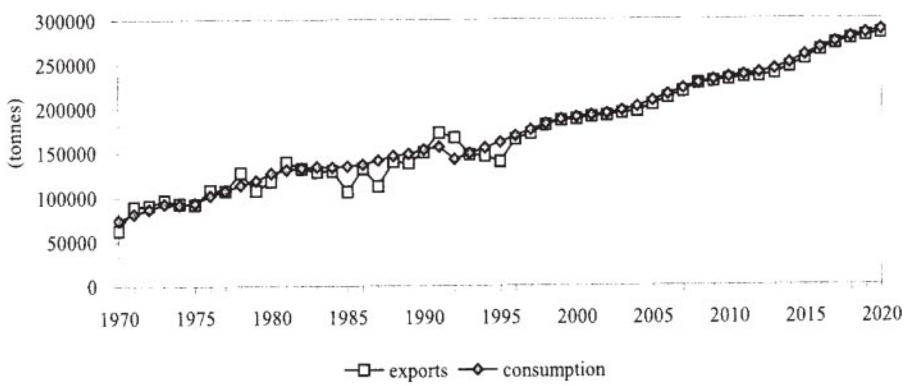

Figure 8.1.36 The projected exports and consumption of pepper up to 2020.

producers in Asia and to some extent in Central America also increase in exports but at moderate levels. However, there is definitely scope for expansion at the expense of the traditional producers.

APPENDIX A. THE STRUCTURAL PEPPER MODEL IN MATHEMATICAL NOTATION

All quantities of pepper are in tons unless stated otherwise. The explanation of the abbreviated variables can be found at the end of Appendix A. An *"l"* before a variable

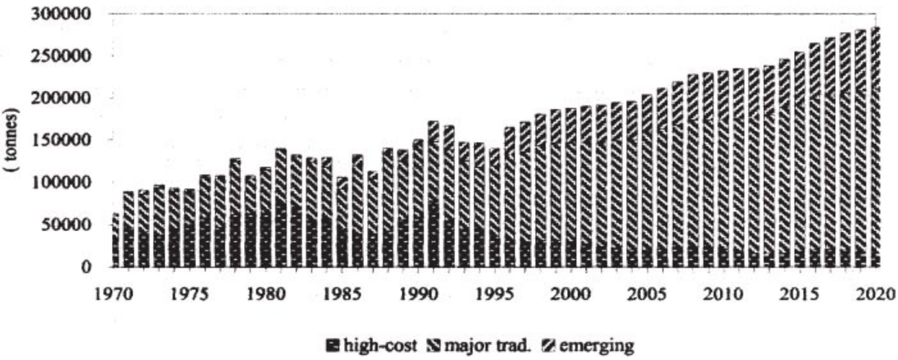

Figure 8.1.37 Changing pattern of exports of major groups of pepper producers in coming decades.

name means that its natural logarithm was taken, while an additional *"d"* in front means a first difference.

SUPPLY SIDE

Brazil

$$dlapbr = -0.16 + 0.30\ lpcbr_{-3} + 0.53\ d79 + 0.52\ d91 \quad (A.1)$$

$$lqpbr - lapbr = 1.20 + 0.27\ lpcbr_{-1} - 0.40\ lt + 0.44\ d84 \quad (A.2)$$

$$xpbr = -1565.77 + 0.98\ qpbr - 8250.7\ d77 + 12538.8\ d82 \quad (A.3)$$

India

$$dlapia = -0.22 + 0.09\ lpcia_{-1} - 0.29\ d79 + 0.28\ d80 - 0.05\ d7081 \quad (A.4)$$

$$lqpia - lapia = -2.17 + 0.17\ lpcia_{-1} + 0.18\ lt - 0.25\ d84 + 0.51\ d8586 \quad (A.5)$$

$$lxpia - lqpia = \min\ [-0.26 + 0.63\ l(rpsny/rpsny_{-1}) - 1.10\ d85\# -0.66\ d9192, 0.8] \quad (A.6)$$

Indonesia

$$dlapio = -0.02 + 0.01\ lpcio_{-3} + 0.11\ d83 + 0.09\ d88 \quad (A.7)$$

$$lqpio - lapio = -1.86 + 0.15\ lpcio_{-4} + 0.06\ lt + 0.21\ d78 - 0.14\ d79 \quad (A.8)$$

$$lxpio = 1.18 + 0.88\ lqpio - 0.53\ d74 - 0.44\ d75 - 0.36\ d85 \quad (A.9)$$

Malaysia

$$dlapml = -0.24 + 0.22\ lpcml_{-1} - 0.21\ d82 - 0.85\ d86 \quad (A.10)$$

$$lqpml - lapml = 0.28 + 0.28\ lpcml_{-2} + 0.43\ d86 + 0.34\ d91 + 0.38\ d92 \quad (A.11)$$

$$lxpml = -0.79 + 0.94\ lqpml + 0.13\ lqpml_{-1} + 0.15\ ln(pcml/pcml_{-1})\# + 0.16\ d85 \quad (A.12)$$

Thailand

$$dlapth = -0.54 + 0.16\ lpcth_{-1} + 0.35\ d87 - 0.26\ d92 \quad \text{(A.13)}$$

$$lqpth - lapth = 1.17 + 0.66 \ln(pcth/pcth_{-1}) - 0.87\ d88 - 0.47\ d89 \quad \text{(A.14)}$$

$$qpth - xpth = 6832.66 - 0.28\ (qpth_{-1} - xpth_{-1}) + 3028.34\ d87 \quad \text{(A.15)}$$

Sri Lanka

$$lapsl = 6.13 + 0.98\ lt70 + 0.06 \ln(pcsl_{-1}/pcsl_{-2}) - 0.09\ d84 + 0.09\ d90 \quad \text{(A.16)}$$

$$lqpsl - lapsl = -1.78 + 0.18\ lpcsl_{-3} \quad \text{(A.17)}$$

$$lxpsl = 2.15 + 0.65\ lqpsl + 0.29 \ln(qpsl/lqpsl_{-1}) + 0.07\ lpcsl + 0.67\ d90 \quad \text{(A.18)}$$

Madagascar

$$xpmd = 4970.98 - 1002.68\ lt - 1126.65\ d81 \quad \text{(A.19)}$$

Vietnam

$$lxpvm = \ln(22000) - 0.11\ lrpsny - 0.05\ lrpsny_{-1} - 0.06\ lrpsny_{-2} \quad \text{(A.20)}$$

China (Hainan)

$$lxpch = \ln(6000) - 0.11\ lrpsny - 0.05\ lrpsny_{-1} - 0.06\ lrpsny_{-2} \quad \text{(A.21)}$$

Mexico

$$xpmx = 1500 + 500\ pmx_{-1} \quad \text{(A.22)}$$

Singapore

$$mpsp = 4268.46 + 0.70\ xpml + 2553.40\ rpsny + 0.18\ (xprw - cpw) \quad \text{(A.23)}$$

$$xpsp = 0.99\ mpsp - 0.15\ (xprw - cpw) \quad \text{(A.24)}$$

$$\Delta zpsp = m\hat{p}ap - x\hat{p}sp \quad \text{(A.25)}$$

Prices

Brazil

$$\begin{aligned} p\$br &= -0.40 + 1.01\ psny - 1.04\ d88 - 0.99\ d89 \\ pcbr &= p\$br/pius * 100 \end{aligned} \quad \text{(A.26)}$$

India

$$\begin{aligned} p\$ia &= 0.26 + (0.55 + 0.10\ lt70)\ psny + 0.97\ d76 \\ pcia &= (p\$ia * eria)/piia * 100 \end{aligned} \quad \text{(A.27)}$$

Indonesia

$$p\$io = -0.092 + 0.82\, psny$$
$$pcio = (p\$io * erio)/piio * 100 \quad \text{(A.28)}$$

Malaysia

$$p\$ml = -0.072 + 0.81\, psny$$
$$pcml = (p\$ml * erml)/piml * 100 \quad \text{(A.29)}$$

Thailand

$$p\$th = -0.21 + 0.95\, psny \quad \text{(A.30)}$$

Sri Lanka

$$p\$sl = -0.15 + 0.96\, psny + 1.24\, d76 + 1.57\, d78 - 0.82\, d90 \quad \text{(A.31)}$$

Demand side

North America (USA and Canada)

data:

$$lmppcna = 2.37 + 1.19\, lypcna \quad \text{(A.100)}$$
$$cpna = nna * mpp\hat{c}na \quad \text{(A.101)}$$
$$\Delta zpna = mpna - cpna \quad \text{(A.102)}$$

model:

$$lcppcna = 2.37 + 1.19\, lypcna \quad \text{(A.103)}$$
$$\Delta zpna = 3819.48 - 0.27\, zpna_{-1} - 1189.09\, rpsny + 7827.57\, d86 \quad \text{(A.104)}$$
$$mpna = cpna + \Delta z\hat{p}na \quad \text{(A.105)}$$

Japan

data:

$$lmppcjp = 2.21 + 0.85\, lypcjp \quad \text{(A.110)}$$
$$cpjp = njp * mpp\hat{c}jp \quad \text{(A.111)}$$
$$\Delta zpjp = mpjp - cpjp \quad \text{(A.112)}$$

model:

$$lcppcjp = 2.21 + 0.85\, lypcjp \quad \text{(A.113)}$$
$$\Delta zpjp = 528.82 - 96.02\, rpsny - 0.30\, zpjp_{-1} - 796.22\, d91 \quad \text{(A.114)}$$
$$mpjp = cpjp + \Delta z\hat{p}jp \quad \text{(A.115)}$$

Australia and New Zealand

data:

$$lmppcaz = 2.73 + 0.90\ lypcaz \qquad (A.120)$$

$$cpaz = naz * mpp\hat{c}az \qquad (A.121)$$

$$\Delta zpaz = mpaz - cpaz \qquad (A.122)$$

model:

$$lcppcaz = 2.73 + 0.90\ lypcaz \qquad (A.123)$$

$$zpaz = 22.50 + 1.46\ yaz + 252.81\ d90 \qquad (A.124)$$

$$mpaz = cpaz + \Delta z\hat{p}az \qquad (A.125)$$

European Union (EU)

data:

$$lmppceu = 2.27 + 1.38\ lypceu - 0.14\ d70 - 0.20\ d8995 \qquad (A.130)$$

$$cpeu = neu * mp\hat{p}ceu \qquad (A.131)$$

$$\Delta zpceu = mpceu - cpceu \qquad (A.132)$$

model:

$$lcppceu = 2.27 + 1.38\ lypceu - 0.14\ d70 - 0.20\ d8995 \qquad (A.133)$$

$$\Delta zpeu = 1333.77 - 0.15\ zpeu_{-1} - 607.65\ rpsdr + 2420.37\ d79\# + 2034.66\ d83 - 2465.31\ d92 \qquad (A.134)$$

$$mpeu = cpeu + \Delta z\hat{p}eu \qquad (A.135)$$

Rest of Western Europe, EFTA

data:

$$lmppcre = 2.90 + 0.83\ lypcre - 0.22\ d88 + 0.09\ d7687 \qquad (A.140)$$

$$cpre = nre * mpp\hat{c}re \qquad (A.141)$$

$$\Delta zpre = mpre - cpre \qquad (A.142)$$

model:

$$lcppcre = 2.90 + 0.83\ lypcre - 0.22\ d88 + 0.10\ d7687 \qquad (A.143)$$

$$\Delta zpre = 3.79 - 181.61\ \Delta rpsdr - 221.05\ d78 - 178.15\ d88\# - 193.83\ d89 + 106.38\ \mathrm{d8283} \qquad (A.144)$$

$$mpre = cpre + \Delta z\hat{p}re \qquad (A.145)$$

Eastern Europe and USSR

data:

$$lmpee = 6.30 + 0.53\ lyee - 1.31\ d92 - 0.56\ d93 - 0.20\ d7475 \quad \text{(A.150)}$$

$$cpee = nee * mpp\hat{c}ee \quad \text{(A.151)}$$

$$\Delta zpee = mpee - cpee \quad \text{(A.152)}$$

model:

$$lcpee = 6.30 + 0.53\ lyee - 1.31\ d92 - 0.56\ d93 - 0.20\ d7475 \quad \text{(A.153)}$$

$$\Delta zpee = -121.22 - 1347.94\ \Delta rpsdr + 5372.17\ d86 - 4267.12\ d91 \quad \text{(A.154)}$$

$$mpee = cpee + \Delta z\hat{p}ee \quad \text{(A.155)}$$

Latin America

data:

$$mpla = -489.95 + 16.61\ yla + 2871.02\ d91 - 2778.31\ d8588\# - 1641.10\ d7680 \quad \text{(A.160)}$$

$$cpla = m\hat{p}la \quad \text{(A.161)}$$

$$\Delta zpla = mp\hat{l}a - cpla \quad \text{(A.162)}$$

model:

$$cpla = -489.95 + 16.61\ yla + 2871.02\ d91 - 2778.31\ d8590\# - 1641.10\ d7680 \quad \text{(A.163)}$$

$$\Delta zpla = 878.71 - 0.50\ zpla_{-1} - 203.27\ rpsdr + 1804.75\ d81\# + 1085.90\ d7079 \quad \text{(A.164)}$$

$$mprla = cprla + \Delta z\hat{p}rla \quad \text{(A.165)}$$

Asia and Pacific, excl. China, Producing Countries, Singapore, Australia and New Zealand

data:

$$mppcap = 2.15 + 30.40\ ypcap - 3.71\ d82 - 5.12\ d70776 - 4.10\ d8688 \quad \text{(A.170)}$$

$$cpap = nap * mpp\hat{c}ap \quad \text{(A.171)}$$

$$\Delta zpap = mpap - cpap \quad \text{(A.172)}$$

model:

$$mppcap = 2.15 + 30.40\ ypcap - 3.71\ d82 - 5.12\ d70776 - 4.10\ d8688 \quad \text{(A.173)}$$

$$\Delta zpap = 641.14 - 185.70\ rpsdr - 0.16\ zpap_{-1} - 1168.37\ d84\# + 1234.93\ d85 - 1343.99\ d93 \quad \text{(A.174)}$$

$$mpap = cpap + \Delta z\hat{p}ap \quad \text{(A.175)}$$

Middle East and North Africa

data:

$$mpmn = -5755.42 + 65.41\, ymn + 6184.87\, d8083 + 6248.02\, d9192 \quad \text{(A.190)}$$

$$cpmn = nmn * mpp\hat{c}mn \quad \text{(A.191)}$$

$$\Delta zpmn = mpmn - cpmn \quad \text{(A.192)}$$

model:

$$cpmn = -5755.42 + 65.41\, ymn + 6184.87\, d8083 + 6248.02\, d9192 \quad \text{(A.193)}$$

$$\Delta zpmn = (-349.58 + 350) - 1105.90\, \Delta rpsdr + 2639.40\, d90\# - 2173.58\, d76 - 2077.40\, d8384 \quad \text{(A.194)}$$

$$mpmn = cpmn + \Delta z\hat{p}mn \quad \text{(A.195)}$$

Rest of Africa

data:

$$mprf = 558.23 + 5.35\, yrf + 1164.78\, d9092 - 368.69\, d7477 \quad \text{(A.200)}$$

$$cprf = mp\hat{r}f \quad \text{(A.201)}$$

$$\Delta zprf = mprf - cprf \quad \text{(A.202)}$$

model:

$$cprf = 558.23 + 5.35\, yrf + 1164.78\, d9092 - 368.69\, d7477 \quad \text{(A.203)}$$

$$\Delta zprf = (-91.70 + 100) - 105.63\, \Delta rpsdr + 179.68\, d7582\# + 559.41\, d84 + 446.78\, d92 - 387.71\, d90 \quad \text{(A.204)}$$

$$mprf = cprf + \Delta z\hat{p}rf \quad \text{(A.205)}$$

Identities

$$cpw = cpeu + cpna + cpjp + cpmn + cpee + cpap + cpaz + cpre\# + cpla + cprf \quad \text{(A.81)}$$

$$mpw = mpeu + mpan + mpjp + mpmn + mpee + mpap + mpaz + mpre\# + mpla + mprf \quad \text{(A.82)}$$

$$xprw = xpbr + xpia + xpio + xpml + xpmd + xpsl + xpth + xpvm\# + xpch \quad \text{(A.83)}$$

$$xpw = xprw + \Delta zpsp \quad \text{(A.84)}$$

$$mpw = xpw \quad \text{(A.85)}$$

$$rpsny = \text{clearing price} \quad \text{(A.91)}$$

Explanation of variable abreviations:

*ap*** = total area under pepper in hectares**

*cp*** = consumption of pepper by**
dxx = dummy variable, having the value one in the year 19xx and zero in other years
dxxyy = dummy variable, having the value one for the years between 19xx and 19yy and zero otherwise
*er*** = exchange rate of**
*mp** = net imports of pepper by**
mpw = total world net imports
*n*** = population size of**
*pc*** = f.o.b. price of black pepper in** in constant (1980=100) local prices
*p$*** = f.o.b. price of black pepper in** in current US$
*pi*** = consumer price index of**
psny = yearly average New York spot price of Lampong black pepper in $ct/kg.
*qp*** = total production of pepper**
rpratio = $rpsny/rpsny_{-1}$
rpsdr = yearly average spot price of black Lampung in New York in constant 1980 special drawing rights per kg.
rpsny = yearly average spot price of black Lampung in New York in constant 1980 US dollar cents per kg.
t70 = linear trend starting in 1970: $t=t_{-1}+1$, in this case used to estimate technical progress or shift in cultivation
t75 = linear trend starting in 1975: $t=t_{-1}+1$
t80 = linear trend starting in 1980: $t=t_{-1}+1$
*xp*** = total exports of pepper from**
xprw = total net exports of pepper producing countries
xpw = world net exports=*xprw+?zpsp*
*y*** = Gross Domestic Product of**
*zp*** = stocks in**
*?zp*** = estimated change of carry-over stocks in**

Explanation of country abbreviations:

***ap* = **Asia and the Pacific excl. China, prod, countries, Australia and New Zealand
***az* = ** Australia and New Zealand
***br* = ** Brazil
***ch* = ** the People's Rep. of China
***eu* = ** the European Union (12)
***ee* = ** Eastern Europe and the USSR
***ia* = ** India
***io* = ** Indonesia
***jp* = ** Japan
***la* = ** Latin America (Brazil excl.)
***md* = ** Madagascar

**ml	=	** Malaysia
**mn	=	** the Middle East and North Africa
**mx	=	** Mexico
**na	=	** North America
**re	=	** the EFTA-countries
**rf	=	** the rest of Africa
**sl	=	** Sri Lanka
**sp	=	** Singapore and Hong Kong
**th	=	** Thailand
**us	=	** the US
**w	=	** world

APPENDIX B. PROJECTIONS OF THE WORLD ECONOMY

In this Appendix projections will be provided for world economic growth as well as for growth per country or region. Also projections of growth in population by country or region will be given.

World Economic Growth—A Simple Analysis and Projections

It would obviously have been wonderful to have a fully fledged model per country for the purpose of making projections of economic growth. This is not possible within the context of this study. Besides, to our knowledge there are no reliable and generally accessible long-term forecasts available for GDP per country or region from other sources. Finally, having a model running permits the design of scenarios. For the purpose of obtaining projections of economic growth per country, a very simple set of equations has therefore been set up. They can be considered as reduced form equations of a full economic model. The most important coefficients of the equations for individual countries are provided in detail in Burger and Smit (1997). First we concentrate on world economic growth, leaving economic growth per country or region to be discussed afterwards.

The basic approach is to explain current growth in GDP from past figures. The model used here is first briefly described. The following system of variable names is used:

ggdp	=	GDP growth rate for the world total;
Dumxx	=	Dummy variable; equal to 1 in year xx and 0 otherwise;
Dumxxyy	=	Dummy variable; equal to 1 from year xx up to year yy and 0 otherwise.

The following equation for the world total has been estimated:

The regression results for the world are in the scheme below. The dependent variable is ggdp, the growth rate in world GDP. The sample range is 1971–1992.

$$ggdp_t = \alpha_1 + \alpha_2 {*}\mathrm{Dum74} + \alpha_3 {*}\mathrm{Dum91} + \alpha_4 {*}\mathrm{Dum7492} + \alpha_4 {*}\mathrm{ggdp}_{t-1} +$$

$$\alpha_5 {*} ggdp_{t-2} + \alpha_6 {*} ggdp_{t-8} + \alpha_7 {*} ggdp_{t-9} + \alpha_8 {*} ggdp_{t-10}$$

Variable	*Coeff.*	*Std. error*	*T. statisti*		
ggdp (−1)	0.51	0.219	2.34	Sum of squared residuals	2.808
ggdp (−2)	−0.54	0.228	−2.36		
ggdp (−9)	0.48	0.118	2.55	log likelihood	−7.839
ggdp (−10)	0.19	0.166	1.11	R-squared	0.839
ggdp (−11)	0.33	0.135	2.45	F-statistic	0.520

As can be seen there are two groups of lagged effects: recent, 1 or 2 years back, and long-term effects with lags running from 8 to 10 years. This very simple model gives the projections for world GDP growth rates as in Figure 8.1.38. According to this analysis world economic growth rates will hover around 3 per cent.

Economic Growth by Country or Region—Historical Developments and Projections

Below the modelling and projection results are presented for the 65 countries or regions into which the world has been divided. There are estimated models for 53 countries or regions. In these models country growth rates in GDP have been explained from world growth rates as well as from lagged country growth rates. Details of the estimates are presented in Burger and Smit (1997). In view of the most irregular developments during the past few years, e.g. in Eastern Europe and the CIS, no models could be estimated for those (groups of) countries. This concerns 12 (groups of) countries for which the coefficients for future economic growth have been fixed in a simple and intuitive way. For some regions future growth rates have been adjusted downwards for the more distant future by adjusting the constant term. This refers to regions, especially in East and South-East Asia, which enjoy very high growth rates now. Such high growth rates cannot be kept up for decades, as has been clearly shown by other countries with high growth rates in the past.

Growth rate data and projections for a selection of countries are presented graphically in Figures 8.1.39 to 8.1.43. A summary for all countries is presented in Table 8.1.1. These simple analyses show that the USA in the long term is running at just under 2 per cent growth. Japan will recover but does not appear to reach the growth levels of the USA, after the period of high growth up to 1990. In Western Europe growth rates will vary around 1 to 3 per cent. The countries of Eastern Europe, the CIS and the former Yugoslavia are expected to come back, but on average at rather moderate levels of economic growth.

Growth rates in Latin America will be somewhat higher than in Europe. In South Asia, India is maintaining a steady growth of around 5 per cent, with Pakistan somewhat higher and the other countries slightly lower. In South-East Asia, the outlook for the Philippines is still rather moderate while the other countries will show high, but somewhat declining, rates. The same applies to China, while Vietnam will reach around 4 per cent growth. Africa is showing very moderate growth rates with the possible exception of Nigeria.

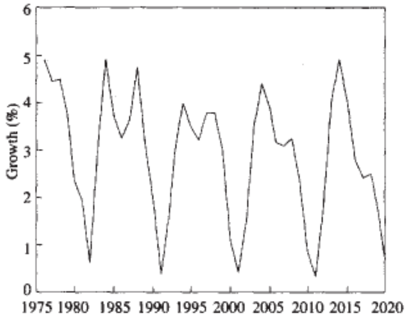

Figure 1.39 GDP growth rate, USA.

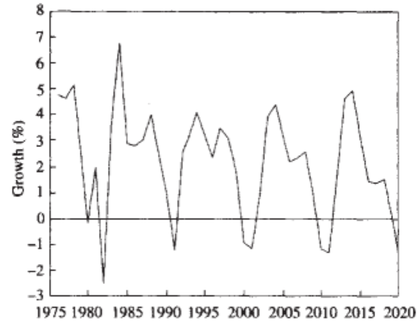

Figure 1.38 World GDP growth rate.

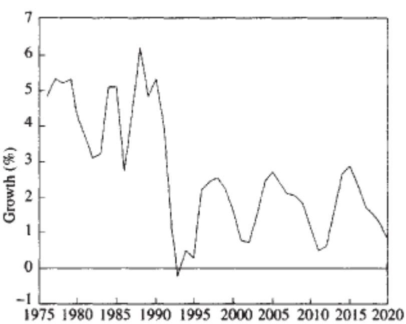

Figure 1.40 GDP growth rate, Japan.

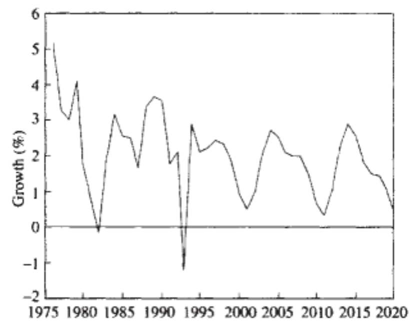

Figure 1.41 GDP growth rate, Germany.

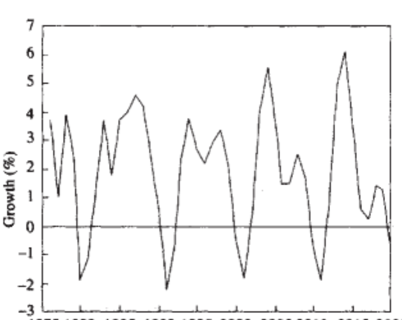

Figure 1.42 GDP growth rate, United Kingdom.

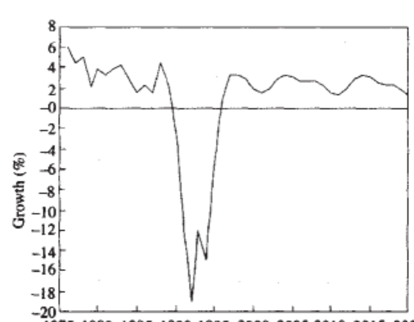

Figure 1.43 GDP growth rate, CIS.

Table 8.1.1 Growth rates in GDP in constant prices, compound annual growth rates over 5 or 10 year periods.

	Period						
	80/75	*85/80*	*90/85*	*95/90*	*00/95*	*10/00*	*20/10*
United States	3.3	2.5	2.6	2.3	2.0	1.8	1.6
Canada	3.7	2.8	3.0	1.7	2.0	1.7	1.5
Japan	5.0	4.0	4.7	1.2	2.2	1.8	1.6
Australia	2.9	3.1	3.1	2.5	2.3	1.9	1.7
New Zealand	0.1	3.0	0.5	1.9	1.2	1.2	1.1
Germany	3.4	1.6	2.9	1.5	2.0	1.7	1.5
France	3.3	1.5	3.2	1.2	1.8	1.6	1.5
United Kingdom	1.8	1.9	3.1	1.2	2.0	1.8	1.6
The Netherlands	2.6	1.0	2.7	1.9	1.8	1.4	1.2
Belgium and Luxembourg	3.1	0.7	3.3	1.3	2.1	1.6	1.3
Denmark	2.5	2.6	1.6	2.3	1.8	1.7	1.5
Iceland	4.1	1.4	3.0	1.0	2.4	1.3	1.1
Sweden	1.3	1.8	2.2	–0.1	1.4	0.6	0.4
Switzerland	1.8	1.4	2.8	0.2	1.7	1.2	0.9
Ireland	4.6	2.6	4.6	4.2	4.2	3.6	3.3
Norway	4.8	3.9	1.6	3.5	3.0	2.8	2.5
Finland	3.0	3.0	3.4	–0.6	1.6	1.3	1.1
Austria	3.4	1.2	3.0	1.9	2.7	2.2	2.0
Italy	4.8	1.6	3.0	1.2	2.3	1.6	1.3
Spain	2.0	1.4	4.5	1.5	2.4	1.8	1.5
Portugal	5.4	0.9	4.7	1.2	3.4	3.1	2.8
Greece	4.4	1.3	1.8	1.2	1.7	1.4	1.2
Turkey	2.6	4.6	6.0	2.7	4.3	3.9	3.6
Former Yugoslavia	5.6	0.7	–1.4	–12.1	2.6	2.5	2.3
Other Western Europe	11.5	1.7	6.5	2.8	2.6	1.6	1.3
Poland	1.2	–0.8	–0.2	0.2	2.7	2.5	2.3
Czech and Slovak Republics	3.7	1.8	1.1	–2.4	1.9	1.6	1.4
Hungary	3.7	1.5	–0.1	–1.3	2.6	2.5	2.3
Romania	7.2	3.0	–2.7	–1.9	3.2	2.9	2.7
Other Eastern Europe	6.2	4.8	2.3	–2.4	2.1	2.0	1.9
CIS	4.3	3.2	1.5	–10.9	2.5	2.5	2.3
Brazil	6.7	1.0	1.9	3.2	3.2	2.1	1.9
Argentina	2.2	–2.1	–0.2	5.3	2.1	2.6	2.4
Mexico	6.7	1.6	1.2	3.8	4.5	3.8	3.4
Chile	7.5	–0.4	6.1	5.5	5.5	4.9	4.5
Venezuela	3.3	–1.1	2.8	3.0	3.9	3.5	3.2
Other Latin America	7.5	–1.8	2.1	3.8	4.1	3.3	2.8
India	3.5	5.6	5.9	3.5	5.0	4.8	4.4
Sri Lanka	5.5	5.2	3.4	5.8	3.7	2.9	2.5
Bangladesh	5.1	3.8	4.0	4.4	3.9	3.7	3.5
Pakistan	6.0	6.6	6.0	4.9	5.1	5.0	4.8
Other South Asia	3.5	3.6	2.7	4.3	2.3	1.9	1.7
Philippines	6.2	–1.3	4.5	2.5	2.1	1.6	1.2
Thailand	7.9	5.6	9.9	8.0	8.1	5.6	4.8

Table 8.1.1 continued

	Period						
	80/75	*85/80*	*90/85*	*95/90*	*00/95*	*10/00*	*20/10*
Singapore	8.6	6.2	8.0	8.6	7.3	5.5	4.6
Hong Kong	11.9	6.3	6.9	5.5	5.6	4.0	3.7
Korea	7.7	8.4	9.3	5.5	3.9	4.3	4.1
Taiwan	9.4	6.2	8.2	7.1	6.3	5.6	5.2
China	6.0	10.0	7.5	10.3	5.5	4.5	4.2
Vietnam	1.7	1.0	1.7	5.5	4.4	3.9	3.6
Other East Asia	0.2	0.5	1.5	2.0	2.6	2.5	2.3
Other S-E Asia and Oceania	7.7	7.5	5.4	5.0	3.1	2.9	2.7
Iran	–4.7	7.9	–0.4	4.4	4.5	5.5	5.2
Saudi Arabia	9.3	–1.3	4.5	2.7	2.9	2.1	1.8
Iraq	7.8	–4.9	–1.8	–3.2	2.2	1.9	1.7
Israel	3.5	2.8	3.8	5.4	5.5	4.9	4.5
Algeria	10.1	2.5	0.9	0.5	2.6	2.0	1.7
Other Oil Producing Countries	9.5	–1.6	3.3	4.3	2.5	2.1	1.9
Egypt	8.4	7.6	4.9	1.4	1.8	2.4	2.0
Other Middle East and North Africa	5.5	3.4	4.0	4.7	4.4	2.3	1.6
Nigeria	3.7	–2.1	5.6	3.6	4.8	3.3	2.9
South Africa	3.5	1.1	1.7	1.1	1.7	1.4	1.2
Other Africa	3.0	2.4	2.9	2.0	2.4	2.1	1.9
World	4.0	2.8	3.3	2.2	3.0	2.6	2.5

World Population Growth—Historical Developments and Projections

The scenario for population projections follows projections by the United Nations. The results for selected years are presented in Table 8.1.2.

Table 8.1.2 Population by country or region (millions).

	1960	*1980*	*1990*	*2000*	*2020*
United States	180.7	227.8	249.9	275.1	320.6
Canada	17.9	24.6	27.8	31.0	36.9
Japan	94.1	116.8	123.5	126.5	124.0
Australia	10.3	14.6	16.9	19.2	23.6
New Zealand	2.4	3.1	3.4	3.8	4.3
Germany	72.7	78.3	79.4	81.7	77.9
France	45.7	53.9	56.7	59.0	60.9
United Kingdom	52.4	56.3	57.4	59.0	60.9
The Netherlands	11.5	14.1	15.0	15.9	16.3
Belgium and Luxembourg	9.5	10.2	10.3	10.7	10.8
Denmark	4.6	5.1	5.1	5.2	5.1

Table 8.1.2 continued

	1960	*1980*	*1990*	*2000*	*2020*
Iceland	0.2	0.2	0.3	0.3	0.3
Sweden	7.5	8.3	8.6	9.0	9.6
Switzerland	5.4	6.3	6.8	7.5	7.8
Ireland	2.8	3.4	3.5	3.6	3.9
Norway	3.6	4.1	4.2	4.4	4.7
Finland	4.4	4.8	5.0	5.2	5.4
Austria	7.0	7.5	7.7	8.1	8.3
Italy	50.2	56.4	57.0	57.3	53.6
Spain	30.5	37.5	39.3	39.8	38.3
Portugal	8.8	9.8	9.9	9.8	9.7
Greece	8.3	9.6	10.2	10.6	10.1
Turkey	27.5	44.4	56.1	67.7	86.5
Former Yugoslavia	18.4	22.3	23.9	25.4	27.2
Hungary	10.0	10.7	10.4	9.9	9.5
Romania	18.4	22.2	23.2	22.6	22.0
Other Eastern Europe	9.5	11.5	12.4	13.1	14.3
CIS	215.2	265.5	288.0	305.5	332.8
Brazil	72.6	121.3	148.5	174.8	220.6
Argentina	20.6	28.1	32.5	36.6	44.4
Mexico	36.9	67.1	84.5	102.4	130.6
Chile	7.6	11.1	13.2	15.3	19.0
Venezuela	7.6	15.1	19.5	24.2	32.9
Other Latin America	70.2	114.8	142.2	176.0	276.5
India	442.3	688.9	850.6	1,022.0	1,327.1
Sri Lanka	9.9	14.8	17.2	19.5	24.0
Pakistan	50.0	85.3	121.9	161.8	261.9
Other South Asia	147.8	172.5	188.4	206.1	250.2
Indonesia	96.2	151.0	182.8	212.7	264.1
Malaysia	8.1	13.8	17.9	22.3	29.8
Philippines	27.6	48.3	60.8	74.6	99.3
Thailand	26.4	46.7	55.6	61.9	71.5
Singapore	1.6	2.4	2.7	3.0	3.3
Hong Kong	3.1	5.0	5.7	6.0	6.0
Korea	25.0	38.1	42.9	47.1	53.3
Taiwan	11.8	17.5	20.3	23.6	31.8
China	682.0	996.1	1,105.7	1,242.3	1,440.7
Other S-E Asia and Oceania	11.7	19.4	24.2	29.1	37.5
Iran	21.6	39.3	58.9	74.6	115.5
Israel	2.1	3.9	4.7	6.1	7.5
Other Oil Producing Countries	24.3	48.2	69.5	97.4	154.2
Egypt	27.8	43.7	56.3	69.1	92.0
Other Middle East	26.5	44.9	57.5	77.5	114.1
Nigeria	42.3	72.0	96.2	128.8	214.6
South Africa	17.4	29.2	37.1	46.2	66.4
Other Africa	195.6	332.7	447.1	600.9	1,085.3
World	3,089.5	4,452.0	5,230.4	6,104.1	7,917.5

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8.2. ECONOMY AND MARKETING OF BLACK PEPPER IN INDIA

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In 1951, 70 per cent of world's pepper cultivation was concentrated in India, and this has gone down to 46 per cent by 1991. Similarly India was contributing 66 per cent of the world's production in 1951, but by 1991 India's share was only 30 per cent. This was reflected in exports too. The share of India in the global pepper market has come down from 56 per cent to 23 per cent during the same period. At the same time, pepper production in other countries registered remarkable increase, but again the 1990's are witnessing alarming fall in production in many major producing countries.

INDIA AND FOREIGN TRADE

Pepper is mainly cultivated in India for the export market. Pepper exports from the country has shown a steady increase from 15,700 tons in (1950–51) to 31,870 tons in 1990–91. Nineties has witnessed a highly fluctuating trend in the export of the crop, mainly on account of the unsteady prices. In 1995–96, there was a deep fall in the quantity exported (0.238 lakh tons), though value (Rs.179.33 crores) was not affected much, primarily due to a high unit price (Rs.75.35 kg^{-1}). The unit price has doubled from Rs. 36.74 kg^{-1} in 1991–92 to Rs. 75.35 kg^{-1} within a span of four years and since then the price was on the rise, touching an all time high in 1997 (>Rs. 200 kg^{-1} approximately).

The International Pepper Community has estimated for 1997 a global production of 188,563 tons and an export of 118,200 tons. In these estimates, India tops the list of producing countries with 65,000 tons, followed by Indonesia (46,000 tons), Thailand (9773 tons) and Sri Lanka (4850 tons). Another 30,000 tons are expected from non IPC countries like Madagascar, China and Vietnam, and a total export contribution of 22,000 tons. The remaining 96,200 tons is to be met by the IPC member countries.

India exports spices to more than 120 countries in the world. Of these, export to 23 countries account for 82 per cent of foreign exchange earnings from spices trade. In the case of pepper, India is the major supplier to 83 countries, USA tops the list with an annual growth rate of five per cent in quantity and three per cent in value (1990–94). Of the total spices import of USA, nearly 15 per cent is pepper, nearly 50 per cent of which is supplied by India. USA is also the major importer of spice oils, mainly pepper oleoresin, and India is the major supplier contributing 86 per cent (1994). It is a matter of concern that India's share of pepper export to USA, the mega consumer, is showing a declining trend. The quantity imported by USA was 12,330 tons in 1992–93 (56 per cent of pepper exports from India), and it was only 7250 tons in 1995–96 (30 per cent of pepper exports). However, a point worth mentioning here is that the unit value realisation from exports to USA are comparatively lower than that from other countries (Rs. 70.73 kg^{-1} in 1995–96). It was maximum from Russia (Rs. 85.03 kg^{-1}) followed by Italy (Rs. 80.03 kg^{-1}), Poland (Rs. 80.41 kg^{-1}) and Canada (78.41 kg^{-1}).

The pattern of spice consumption in USA showed a visible shift to hot spices like pepper over the last two decades resulting in an increase by 75 per cent. The US trade association projects the spice consumption in USA to the level of 1000 million pounds by the turn of the century (Cheriankungu 1996a). Importance of quality maintenance assumes greatest priority in this regard. USFDA has detained 1164 consignments of Indian spices due to contamination with seeds of noxious weeds in 1995. The cases of detention of imported goods were 140 in 1991, and 757 in 1994 (Sivadasan 1996). The Spices Board in India in their effort to maintain quality at the producer level has initiated several R&D and extension programmes for improving and upgrading the quality of pepper.

USSR was the largest pepper importing country from India with an import of 19,400 tons in 1989–90, which has come down to 6,060 tons in 1994–95 following major political changes (Cheriankungu 1996a). Despite the economic instability and uncertainty, Russia still continues to be a major consumer. Russian imports of pepper from India amounts to 3240 tons worth Rs. 27.25 crores. Italy and Canada came next in the list of major importing countries of Indian pepper worth of Rs. 16.31 crores and Rs. 11.42 crores respectively (1994–95).

Pepper exports to countries like Hungary, North Korea, Maldives, Trinidad, Yemen, Arab Republic and Yugoslavia has considerably reduced whereas new consumers have entered the scene. They include Chile (13.47 tons valued at Rs. 8.75 lakhs), Kazhakistan (16 tons valued at 11.43 lakhs), Tajikistan (13 tons valued at Rs. 8.88 lakhs) and Venezuela (1 tonne valued at 1.42 lakhs).

Apart from these countries, potential market opportunities exist in some other countries. Japanese food habits are reported to be changing fast to western style, using spices. Japan's domestic spice production is very low and over 95 per cent of the consumption is met by imports. During 94–95 Japan imported 41911 million tons of spices, of which 17.78 per cent was pepper. Bulk of the spices is consumed by the industrial sector, followed by the household and service sectors. The annual rate of increase in spice import by Japan is estimated to be five per cent (Cheriankungu 1996b). Pepper constitute 20 per cent of total spice import in 1990, but reduced to 17.8 per cent later, though the absolute figures show an increase. Share of India in Japan's pepper imports is negligible (almost stagnant around 5.5 per cent) compared to that of Malaysia (68 per cent) and Indonesia (31 per cent). India should plan strategies to exploit this potential market.

Israel is a major exporter of processed food and hence can be considered as a potential buyer of spices. Israel had imported 69.02 metric tonne of pepper (94–95) valued Rs. 3,339 million (Anon. 1996). Singapore imports spices for re-export. Imports of pepper by countries of EEC stagnates around 4,200 tons for the past five years. However, in value terms the export has shown an increasing pattern (Anon. 1996).

India should try to widen her markets as well as identify potential centres. Nevertheless efforts should also be concentrated to sustain and improve the trade relations with existing markets. USA, Russia, UK, Japan and Canada are reported to be countries with a lower level of instability in pepper imports (Jeromi and Ramanathan 1994). Concentrating on these centres ensures a steady market for the produce.

According to rough estimates by International Trade Centre, Geneva, the world trade in spices during last five years was on an average 450,000 metric tons valued $1500 million. Pepper is the major spice in international trade accounting for 30 to 35 per cent in quantity and 20 to 25 per cent in value (Peter 1996b).

India, being a country with much expertise and many comparative advantages in pepper production, should aim at reaping the fruits of a prospective world market.

PEPPER PRODUCTION IN INDIA

Pepper was cultivated in 80,000 ha. in 1950–51 with 98 per cent of the area in Kerala. The area under the crop has been steadily increasing (with occasional changes) to reach 195,050 ha. in 1994–95. An analysis of the growth trends in the area, production and productivity of the crop separately for the country/state was done (Log Y=a+bt) and the results are presented in Table 8.2.1.

The growth rate in area and production of pepper has been exhibiting a diminishing trend since 1950's till 1970's. Though seventies witnessed an uptrend in productivity levels, this was not enough to offset the effect of fall in area and production. Kerala was experiencing a declining trend in production in that period and because Kerala accounts for nearly 98 per cent of area, the production, trends in this state has a direct bearing on that of the country.

Table 8.2.1 Growth rates of area, production and productivity of black pepper in india and kerala. (log y=a+bt) (per cent per annum).*

Particulars		*1950's*	*1960's*	*1970's*	*1980's*	*1990's*	*Overall*
Area	India	0.87	1.12	1.05	1.81	1.11	0.68
	Kerala	0.94	0.19	–0.19	1.85	1.00	0.70
Production	India	1.36	–0.50	0.34	2.43	–0.32	0.63
	Kerala	0.40	–0.88	–0.40	2.26	0.70	0.68
Productivity	India	0.44	–1.40	1.27	0.63	–1.40	–0.05
	Kerala	0.46	–1.07	–0.22	0.41	–0.01	–0.02

* Source: Economic Review, Govt. of Kerala.

However, eighties showed an improvement in all these parameters-area, production and productivity of pepper in the State, and this was reflected in the national scene too. It is a matter of serious concern that these trends are not maintained thereafter. Though more area seems to be brought under cultivation, the productivity levels are showing a diminishing trend at an annual rate of 1.40 per cent. Pepper crop in Kerala is facing serious disease problems which results in stagnation of productivity despite various crop promotion programmes. The scope of area expansion has limitations due to obvious reasons, so the attention should be focused on high yielding, disease resistant varieties and management practices to boost productivity. Official estimates have shown that growth in area is largely concentrated in Kerala (more than doubled from 75,000 ha. in 1950's to 188,000 ha. in 1995–96) and the state still accounts for a lion's share of total area/production in India. Area under crop stagnates around 2900 ha (from 83–95) in Karnataka and shows a gradual increase from 670 ha (1983) to 2980 ha (1995) in Tamil Nadu. The production levels also remain around 740 tons in Karnataka and shows a fluctuating trend from 110 tons to 600 tons in Tamil Nadu during the period. When the productivity levels of Karnataka are very close to Kerala, it shows a highly unpredictable pattern in Tamil Nadu. However, observations in the field and personal discussions with the officials in the Spices Board give a different picture. It is reported that Coorg, Chikmaglore and Hassan Districts of Karnataka (where coffee production is concentrated) have large areas of pepper grown as an intercrop in coffee plantations. They are trailed on silver oak trees, that grow to a height of 20+ meters and the pepper yields are as high as 10–15 kg (dry) per vine. The South Canara, North Canara and Shimoga districts also grow pepper in combination with arecanut. The Gudallur region, Palani Hills, Anamalais, Yercaud and Kanyakumari areas of Tamil Nadu also have started growing pepper either as pure plantation or in combination with coffee and tea. Some unofficial estimates conclude that the share of Kerala in total pepper area might have reduced to 60 per cent instead of the official estimate of 98 per cent due to large scale change over to rubber in the plains. This change is the result of damage due to the foot rot disease. Ramadasan (1992) has also expressed concern over the official statistics on pepper. The area estimation under the varying production systems, like homestead farming and intercropping in coffee/tea plantations poses serious difficulties. Pepper is largely grown along with tall growing main crop or live standards. Moreover large scale planting of pepper takes place in encroached forest areas. A correct assessment of the coverage of the crop might not have taken place, resulting in incomplete statistics and it is generally felt that the actual area under pepper is much less. (See P.S. at the end of the chapter).

Pepper in Kerala

The over all rate of growth in pepper area and production in Kerala State is slightly higher than the national average, estimated at 0.70 per annum for area and 0.68 per cent for production. The productivity levels remain stagnant for all these years since 1950's with a positive growth rate only during fifties and eighties (Table 8.2.1).

Pepper cultivation in Kerala State is largely concentrated in certain districts. The inter district pattern of pepper production is analysed by estimating the per centage contribution in area and production of the crop at a five year interval period (Table 8.2.2). Kannur, Kozhikode, Kollam and Thiruvananthapuram districts (in that order) together contributed to more than 80 per cent of the total pepper area and 75 per cent of the production in the State in 1960–61. Later on, the share of these districts declined to 33 per cent and 29 per cent respectively in 1993–1994. Idukki, Wyanad and Kannur districts emerged as major pepper growing areas with a total share of 60 per cent of area and 67 per cent of production.

Idukki district leads the position with 21.13 per cent of area and 26.61 per cent of production (1993–94). The district was formed reorganising the districts of Ernakulam and Kottayam during 1972. But the increase in pepper acreage in these districts nullified the loss due to reorganisation of geographical boundaries. Area under the crop increased from 16,689 ha in 1972–73 to 16,943 ha. in 1973–74 in Kottayam and from 7,940 ha to 9,778 ha in Ernakulam. Since its formation, Idukki district registered a steady increase, both in area and production to top the position. At the same time relative share of Ernakulam and Kottayam districts, steadily declined to half, both in area and production (from 6 per cent and 12 per cent of area to 3.27 per cent and 4.76 per cent respectively and 4 per cent and 16 per cent of production to 2.41 per cent and 3.34 per cent).

Wyanad district, the second leading producer of the crop was formed in 1980 reorganising the districts of Kozhikode and Kannur. During the last decade it has emerged as a very potential pepper growing area contributing nearly 25 per cent of total production in the State. The proportionate share of pepper area has doubled from 10.06 per cent in 1985–86 to 20.04 per cent in 1993–94. Unfortunately the productivity seems to fluctuate highly from 533 kg/ha in 1985–86, 286 kg/ha in 1990–91 and 333 kg/ha in 1993–94.

Kannur district was the leading producer of pepper in the state with 43 per cent of the area and 30 per cent of production in 1960–61. The trend continued till 1980–81. Even though the relative share in area had declined to nearly half (24.59 per cent), it continued to maintain a share of 27 per cent of production through improved productivity level. With the formation of Wynad district, Kannur district was relegated to the status of the second major cultivator and producer of pepper in the State, though the share was drastically reduced to 14 per cent and 16 per cent respectively. Since then the area as well as production shows a steady increase but with falling productivity levels (Table 8.2.3). In recent years there is large scale replacement of pepper with rubber and cashew in Kannur District, prompted mainly by disease problems and fluctuating prize levels.

The fluctuating productivity in the major production centres warrants a closer look. This falling productivity levels may be recognised as a major problem of pepper economy in India. India will be able to meet the world demand only if the productivity levels are improved. Production constraints in each of these areas may be identified separately to chalk out appropriate remedial measures. Moreover, in the erstwhile pepper growing districts like Thiruvananthapuram, Kottayam, Kozhikode and Ernakulam, efforts should be made to identify the socio-economic factors which led to the decline in pepper cultivation. Rapid urbanisation and the resultant changes in socio-economic situation put the farmers in a situation of labour shortage and increased cost of cultivation.

Table 8.2.2 District-wise distribution of area and production of pepper in Kerala (%).

Year		*TVM*	*QLN*	*ALPY*	*PTA*	*KTM*	*IDKI*	*EKM*	*TCR*	*PGT*	*MLPM*	*KZD*	*WYD*	*CNR*	*KSD*	
1960–61	A	8.69	5.25	1.63	–	14.20	–	7.03	0.69	3.43	–	6.10	–	42.98	–	100
	P	14.79	9.87	1.65	–	0.11	–	9.51	1.01	2.01	–	11.24	–	29.81	–	100
1965–66	A	8.45	4.78	1.28	–	14.49	–	6.83	0.74	3.49	–	16.03	–	43.91	–	100
	P	14.06	9.25	1.14	–	0.23	–	9.34	1.49	2.05	–	11.02	–	31.42	–	100
1970–71	A	8.71	4.92	1.28	–	14.34	–	6.75	0.63	2.96	–	16.51	–	43.90	–	100
	P	15.09	10.07	1.89	–	20.33	–	8.79	2.35	2.07	–	10.56	–	28.85	–	100
1975–76	A	5.40	8.08	4.83	–	11.95	9.40*	6.00	1.42	0.79	5.53*	6.36	–	30.24	–	100
	P	5.08	12.10	3.00	–	15.50	8.45	4.44	1.00	0.03	4.83	19.14	–	26.43	–	100
1980–81	A	4.96	9.10	4.48	–	11.83	11.35	6.16	3.70	1.42	3.73	8.68	–	24.59	–	100
	P	7.11	12.07	3.53	–	6.23	6.49	4.43	2.42	0.60	3.89	26.40	–	26.83	–	100
1985–86	A	4.17	6.49	3.00	3.85*	9.60	17.62	5.19	3.08	1.43	3.37	10.54	10.06*	13.97	7.63*	100
	P	4.73	8.99	1.96	4.60	3.24	14.60	3.27	1.71	1.47	4.23	8.77	19.69	15.81	6.93	100
1990–91	A	2.46	4.81	1.37	3.21	6.48	20.63	4.14	3.36	1.63	4.51	9.09	15.74	18.53	4.04	100
	P	2.35	6.22	0.59	3.39	4.28	30.12	2.73	2.29	0.74	3.02	7.25	16.19	16.86	3.97	100
1993–94	A	2.52	4.88	0.94	2.42	4.76	21.13	3.27	2.80	2.03	5.38	7.47	20.04	18.72	3.64	100
	P	2.33	5.61	0.47	3.01	3.43	26.53	2.41	1.60	1.00	3.48	6.76	4.66	16.36	2.35	100

* The District was formed during these period. A—Area and P—Production.
TVM—Thiruvananthapuram, QLN—Kollam, ALPY—Alappuzha, PTA—Pathanamthitta, KTM—Kottayam, IDKI—Idukki, EKM—Ernakulam, TCR—Thrissur, PGT—Palakkad, MLPM—Malappuram, KZD—Kozhikode, WYD—Wayanad, CNR—Kannur, KSD—Kasarkode.

Table 8.2.3 Productivity of pepper in the districts of Kerala over the years.

Year	*TVM*	*QLN*	*ALPY*	*PTA*	*KTM*	*IDKI*	*EKM*	*TCR*	*PGT*	*MLPM*	*KZD*	*WYD*	*CNR*	*KSD*
1960–61	370	421	270	–	301	–	289	401	142	–	145	–	152	–
1965–66	375	421	278	–	311	–	297	438	140	–	149	–	147	–
1970–71	369	436	314	–	302	–	277	791	149	–	136	–	140	–
1975–76	213	340	141	–	304	216	168	161	172	181	235	–	206	–
1980–81	378	350	208	–	139	151	190	172	111	275	373	–	288	–
1985–86	309	378	178	326	92	236	172	151	279	342	227	533	308	247
1990–91	265	359	118	293	183	405	183	189	125	186	221	286	253	274
1993–94	249	311	114	337	195	340	199	155	131	175	245	333	236	174

TVM—Thiruvananthapuram, QLN—Kollam, ALPY—Alappuzha, PTA—Pathanamthitta, KTM—Kottayam, IDKI—Idukki, EKM—Ernakulam, TCR—Thrissur, PGT—Palakkad, MLPM—Malappuram, KZD—Kozhikode, WYD—Wayanad, CNR—Kannur, KSD—Kasarkode.

Kerala is the most suitable area for pepper production. In the light of above findings it can be concluded that the twin targets of area extension and productivity improvement should be the thrust areas. Production planning and management programmes in the State may be centered around the following three production systems:

Pepper as pure plantations

Monocrop area under pepper is confined to the districts of Idukki and Wynad and constitute only three per cent of total area (George *et al.* 1989). Efforts to ensure scientific management of the crop in these systems may be taken up. Produce management in this system should be aimed at meeting the export markets, so that the produce can be processed and handled to suit international standards with very little effort and many comparative advantages.

Pepper as an intercrop in coffee and tea plantations

Our own experiences at Wynad and lessons from neighbouring States proves that pepper offers good potential as an intercrop in coffee, cardamom and tea plantations. The high range districts of Kerala, where these plantations are concentrated, can be identified as potential zones. Silver oak, which is used as shade tree in these plantations proved to be good support for pepper. Package of practices should be developed for this kind of pepper production to determine the optimum levels of management at complementary levels of resource sharing, before entering the zones of competition. In fact, India can achieve a quantum jump in production by scientifically managing the coffee, tea and cardamom plantations in Idukki, Wynad, Coorg, Chickmagalur and Hassan areas.

Pepper in home gardens

Pepper has been a component in most of the traditional home gardens of Kerala. Mostly trailed on the trees like coconut, arecanut, mango, jack, tamarind, etc. and managed with low levels of inputs. Transformation of home gardens due to various socio-economic reasons largely reduced this practice. Coupled with this the foot rot disease also swept away a considerable number of pepper plants in homesteads. Management practices with low input levels to suit the home garden system may be developed for the crop. Further, programmes to reintroduce pepper in home gardens, both in urban and rural areas may be thought of. Bush pepper can be an ideal crop in urban home gardens. Pepper production in the home gardens should be managed to meet the full domestic demand. It is reported that domestic consumption of pepper in India is around 30 per cent of our production. This is substantially high in comparison to other major producers like Indonesia (15 per cent), Brazil (17 per cent) and Malaysia (3 per cent).

Economics of pepper cultivation in Kerala

Realistic estimation of the cost structure of the crop was attempted by Vinod (1984) in Idduki and Santhosh (1985) in Kannur. Year wise estimation of important items of expenditure was done upto prebearing age of seven years and thereafter upto 40 years when the costs and yield stabilise. The details are presented in the Tables 8.2.4 and 8.2.5.

Pepper proved to be a highly labour intensive crop accounting for more than 50 per cent of total cost. The present situation of scarcity of agricultural labour and high wage rates might also have influenced the gradual decline in pepper cultivation. Though Idukki district is leading in cultivation, the profitability of the crop is higher in Kannur district. The Benefit-Cost ratio was estimated as 1.09 in Idukki and 1.16 in Kannur (Vinod 1984, Santhosh 1985).

The pay back period of pepper cultivation was estimated as 10 years in Idukki and 11 years in Kannur. The corresponding Net Present Worths were Rs. 4181 and Rs. 6656 at 10 per cent discount rate. The Internal Rate of Return in Idukki was 13.48 per cent while in Kannur it was 17.22 per cent.

Marketing

As in the case of most of the agricultural commodities the rural pepper market in Kerala is ruled by the village traders. However, bulk of the small farmers are prepared to sell to the village traders, in spite of the fact that on any given day the wholesaler offered higher prices. This was mainly because of the transportation difficulties. The village traders will be collecting produce from the farmers field or in the nearby village markets.

Vinod (1984) identified village merchants, upcountry wholesalers, commission agents, brokers, exporters and internal wholesalers as important market intermediaries. The marginal farmers generally effect village sales in the nature of a preharvest contract. The upcountry wholesalers transport the produce to Cochin when the sale will be initiated by commission agents. These commission agents negotiate with exporters/ internal wholesalers/brokers. The brokers act on behalf of the internal wholesalers/ exporters and negotiate with the commission agents. At the exporters' premises the lot is processed and graded. Before the lot is officially cleared for export, it is subjected to check sampling and all the tests for grading. The consignment thus cleared for export is typically handed over on paper to the clearing or forwarding agency. All the other functions are done by the agency.

Four major marketing channels were identified in Idukki district while there was five in Kannur. The share of producer on the Free on Board price of pepper was estimated to be 86.06 per cent. Compared to this the producer enjoyed a higher share of internal consumer price (88.80 per cent), when the produce moved through the channel for domestic consumption.

Futures market

Future trading was initiated over a hundred years ago in India as an insurance against the price risk of commodities handled by the traders. Indian Pepper and Spice Trade Association (IPSTA) took the lead role in establishing the forward trading in pepper in the country, in 1957, in Kochi (Sethuram 1995). This effected the risk transfer and price

Table 8.2.4 Cost of cultivation of pepper, inputwise analysis (1983) (Rs/ha) (Idukki District) (in rupees).*

Sl. no	*Item*	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*
1.	Hired labour	1637.00 (27.52)	951.42 (24.03)	721 (17.38)	945.55 (20.63)	1130.54 (23.07)	1392.79 (25.73)	1422.55 (25.84)
2.	Family labour	1652.83 (27.77)	1276.98 (32.26)	1252.43 (30.18)	1284.09 (28.01)	1384.25 (28.24)	1500.28 (27.72)	1548.90 (28.13)
3.	Vines and standards	898.08 (15.09)	53.98 (1.36)	–	–	–	–	–
4.	Tying material	–	66.32 (1.68)	81.17 (1.96)	67.37 (1.47)	68.88 (1.41)	71.61 (1.32)	71.56 (1.30)
5.	Plant protection material	0.67 (0.01)	6.73 (8.25)	42.19 (1.02)	53.35 (1.16)	55.85 (1.14)	57.35 (1.06)	58.72 (1.07)
6.	Soil additives	406.05 (6.82)	326.73 (8.25)	717.73 (17.29)	849.58 (18.53)	857.22 (17.49)	924.52 (17.08)	933.46 (16.95)
7.	Interest on working capital	257.37 (4.32)	161.78 (4.09)	184.25 (4.44)	228.50 (4.98)	248.62 (5.07)	299.67 (5.53)	304.77 (5.54)
8.	Total operating cost	4853.00 (81.53)	2843.94 (71.84)	2999.11 (72.26)	3428.44 (74.79)	3745.36 (76.41)	4246.22 (78.46)	4339.76 (78.81)
9.	Depreciation	76.12 (1.28)	86.39 (2.18)	113.20 (2.73)	116.06 (2.53)	116.66 (2.38)	12.90 (2.27)	122.89 (2.23)
10.	Land revenue	4.94 (0.08)	4.94 (0.12)	4.94 (0.12)	4.94 (0.11)	4.94 (0.10)	4.94 (0.09)	4.94 (0.09)
11.	Rental value of land	988.00 (16.60)	988.00 (24.96)	988.00 (23.80)	988.00 (21.55)	988.00 (20.16)	988.00 (18.25)	988.00 (17.94)
12.	Interest on fixed capita	30.48 (0.51)	35.37 (0.89)	45.30 (1.09)	46.43 (1.01)	46.49 (0.95)	50.30 (0.93)	50.24 (0.91)
	Total fixed cost	1099.54 (100)	1114.70 (28.16)	1151.44 (27.74)	1155.43 (25.21)	1156.09 (23.59)	1166.17 (21.54)	1166.27 (21.19)
	Total cost	5952.54 (100)	3958.64 (100)	4150.55 (100)	4583.87 (100)	4901.45 (100)	5412.39 (100)	5506.03 (100)

Figures in parentheses indicate percentages of the yearly total cost.
* Source: Vinod 1984.

Table 8.2.5 Cost of cultivation of pepper-input wise analysis based on ABC cost concepts (Rs./ha) (Kannur District).

Sl. no	*Item*	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Aggregate total*
1.	Hired human labour	1708.58 (30.48)	563.02 (22.75)	998.66 (28.68)	1027.91 (29.25)	1454.91 (36.44)	2099.91 (44.54)	2962.91 (52.15)	10815.90 (36.71)
2.	Plant protection chemicals	–	–	28.83 (0.83)	38.45 (1.09)	38.45 (0.96)	38.45 (0.82)	38.45 (0.68)	182.63 (0.61)
3.	Ropes	42.31 (0.75)	44.10 (1.78)	48.01 (1.38)	–	–	–	–	134.42 (0.46)
4.	Vines	220.08 (3.93)	23.01 (0.93)	–	–	–	–	– (0.82)	243.09
5.	Manures	119.60 (2.13)	239.20 (9.66)	358.80 (10.31)	358.80 (10.21)	358.80 (8.99)	358.80 (7.61)	358.80 (6.32)	2152.80 (7.31)
6.	Fertilizers	–	–	113.61 (3.26)	151.93 (4.32)	151.93 (3.81)	151.93 (3.22)	151.93 (2.67)	721.33 (2.45)
7.	Depreciation	81.87 (1.46)	84.71 (3.42)	93.03 (2.67)	93.03 (2.65)	93.03 (2.33)	93.03 (1.97)	93.03 (2.67)	631.73 (2.14)
8.	Land tax	5.00 (0.09)	5.00 (0.20)	5.00 (0.14)	5.00 (0.14)	5.00 (0.13)	5.00 (0.11)	5.00 (1.64)	35.00 (0.12)
9.	Cost of standards	770.00 (13.74)	78.01 (3.15)	–	–	–	–	– (2.88)	848.01
10.	Interest on working capital	343.26 (6.12)	113.69 (4.59)	185.75 (5.33)	189.25 (5.38)	240.49 (6.02)	317.89 (6.74)	421.45 (7.42)	1811.78 (6.15)
	Total Cost A	3290.70 (58.71)	1150.74 (46.49)	1831.69 (52.61)	1864.37 (53.05)	2342.61 (58.67)	3065.01 (65.00)	4031.57 (70.96)	17576.69 (59.65)
11.	Rental value of land	1000.00 (17.84)	1000.00 (40.40)	1000.00 (28.72)	1000.00 (28.45)	1000.00 (25.05)	1000.00 (21.21)	1000.00 (17.60)	7000.00 (23.76)
12.	Interest on fixed capital	34.00 (0.61)	37.16 (1.50)	38.41 (1.10)	38.41 (1.09)	38.41 (0.96)	38.41 (0.81)	38.41 (0.68)	263.21 (0.89)
	Total Cost B	4324.70 (77.16)	2187.90 (88.40)	2870.10 (82.43)	2902.78 (82.59)	3381.02 (84.68)	4103.42 (87.03)	5069.98 (89.23)	24839.90 (84.30)
13.	Value of family labour	1280.30 (22.84)	287.16 (11.60)	611.70 (17.57)	611.70 (17.57)	611.70 (15.32)	611.70 (10.77)	611.70 (10.77)	4625.96 (15.70)
	Total cost C	5605.00 (19.02)	2475.06 (8.40)	3481.80 (11.82)	3514.48 (11.93)	3992.72 (13.55)	4715.12 (16.00)	5681.68 (19.28)	29465.86 (100)

Figures in paranthesis represents the percentage to the total, Source: Santhosh 1995.

recovery in the trade successfully. The risk is transferred from the hedgers to the speculators and the latter also provided liquidity to the market. Future markets are standardised as to trading specifications and terms of delivery. International prices in pepper shows a trend which is unfavourable to most of the producing countries. This can be greatly attributed to fluctuations in supply rather than production. International Pepper Community in an effort to ensure a better price management system, conducted a study (by UNCTAD) on the viability of pepper futures contract. Based on this a working group consisting of representatives from IPC member countries was set up to examine the requirements of a global pepper futures contract. Consequently Indian Pepper and Spice Trade Association, Cochin has initiated action for the setting up of an International Pepper Exchange in Cochin. It is expected to trigger pepper trading both in domestic and international market and also ensure better prices and extend hedging facility to exporters of all the member countries. Further, it is proposed to link Cochin pepper exchange with the Kuala Lumpur Commodity Exchange in due course, when a second trading floor would be started. The globalisation of the economy in general and increasing volatility of pepper prices, necessitated the establishment of a global pepper market, for trading the pepper futures contracts. This also facilitates a free trade regime in pepper, as it can be freely moved between the countries without tariff barriers and quota restrictions.

Indian pepper prices in the international market is comparatively higher than that of its competitors. The relatively low yield and the resultant high unit cost of production as well as better prices in domestic market leads to higher international price. The improved stock holding capacity of the farmers also determine price. The low market arrivals are also due to farm gate procurement by corporates. Speculation also plays a role in pushing up price. Futures trade envisages a constant supply and steady price for the product. However, there are strong criticism against the exchange from some corners. The scope of extending the advantages of the exchange to the real producers are largely questioned. Pepper production is mainly scattered in the small holdings. The market awareness of farmers with regard to price situation is very poor. About 72 per cent of farmers are neither aware of the changes nor bothered to obtain the information and the percentage of such farmers is more in small farmer's groups (George *et al.* 1989). These small individual farmers do not have either the quantity nor the expertise to enter the exchange market. It is seen that the active participants of futures trading in Cochin have been representatives of exporters. Pepper marketing is overpowered by the village traders and preharvest contractors. The history of futures trading in pepper shows the absence of producers, even the large ones in its operations. The Primary Agricultural Credit Societies (PACS) has also not attempted it. The State marketing Federation and State Trading Corporation had unpleasant experiences in futures trading in pepper. They incurred heavy losses in the business. The possibilities of creating an artificial market situation which is detrimental to the interests of producers, by the strong members in the exchange floor cannot be ruled out completely. Ensuring fair trading practices assumes prime importance in this context.

However, the IPSTA is optimistic in narrowing the disparity between the farm gate and market prices, and removing the numerous middlemen involved in transactions to ensure a more remunerative price to farmers. The liquidity of traders are expected to be increased as banks are willing to advance 80–90 per cent of the value of the produce when it is hedged against adverse price fluctuations through the instrument of future contract. Reckless speculations will be avoided by imposing limit on open position, daily price band fluctuations bound both up and down and collection of special margin deposits to curb speculative activity through financial restraints.

Crop Promotion Programmes

The crop development programmes suggested for pepper should have an integrated approach, involving pre and post harvest management aspects.

Productivity improvement

Productivity of Indian pepper is reported to be very low (320 kg/ha) compared to Malaysia (2000 kg ha^{-1}), Brazil (1571 kg ha^{-1}) and Indonesia (800–2000 kg ha^{-1}). But the estimation procedure of productivity are to be critically viewed before making hasty conclusions. The yield per bearing vine estimates are to be made under different management systems for a realistic assessment of the productivity. George *et al.* (1989) have estimated the yield per vine as 880 gms per stand, small holders realising better yields. There are situations where the average yield per vine in the home gardens ranges from 2–5 kg dry pepper $year^{-1}$. In India there are varieties which can yield more than 3000 kg ha^{-1} and some progressive farmers have already realised this yield. The realised yield in research stations are to the extent of over 4000 kg ha^{-1}. There are information that in many plantations in the Kodagu (Coorg) District of Karnataka an yield level of more than 10 kg dry per stand has already achieved on a regular basis. Of course they are large plants trailed on silver oak trees. Unfortunately reliable data is not available on production and productivity; but productivity may not be as low as reported, considering the present problems of available statistics. The productivity levels under the high density planting and scientific management can never be compared on an equal footing with the systems exist in India. However, programmes to boost productivity levels are to be developed considering the peculiar socio economic situation of each production system.

Nearly, 50 per cent of area under the crop is reported to be unproductive and senile (Ramadasan 1992). Massive extension programmes should be planned to undertake replanting of these areas with latest high yielding, good quality vines, under scientific management practices.

Area expansion

Eventhough the scope of bringing more area under the crop is less in Kerala, efforts to popularise pepper planting as an intercrop in plantations and as a component in rural and urban home gardens hold considerable potential. Taking advantage of the prevailing attractive farmgate prices for pepper, replanting/gap rilling programmes using high yielding varieties in the traditional pepper growing districts of Thiruvananthapuram, Ernakulam and Kozhikode can be implemented successfully.

An organised programme for crop development in the neighbouring states as well as identifying potential areas of crop introduction can also be thought of. The North East region of India comprising the states of Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland and Tripura are reported to grow pepper in early medieval period. At present 1896 ha. of land in upper Assam and 608 ha. in Meghalaya is under pepper cultivation. During 8th plan period Rs. 236.47 lakh has been earmarked for pepper development in North Eastern region (Peter 1996a).

Value addition

Product diversification is yet another important area to be cared. Value addition and market promotion activities are to be triggered to exploit untapped markets as well as existing ones. Pepper is traded in international market in the form of various products such as green pepper in brine, black pepper, dehydrated green pepper, freeze dried pepper, sterilised pepper, white pepper, cocktail pepper, pepper oil, pepper oleoresin, etc. and offers more opportunities in the wake of a widening agro-processing sector. Farm level value addition should be popularised to derive maximum benefits for the producers as well, especially in home gardens. As the pepper marketing system in the State is comparatively efficient (George *et al.* 1989), the price advantage can be fully realised by the producers.

The Ministry of Agriculture has sanctioned a scheme for the development of spices during 8th five year plan with an outlay of Rs.125 crores. An overall growth rate of eight per cent per annum is envisaged during 8th plan as against four per cent in 7th plan. Accordingly the spices production target of 29.35 lakh tons has been fixed for 1996–97 and 37.40 lakh tons for 2000 AD. The corresponding figure for pepper is 85,000 tons and 107,000 tons respectively.

Market information system

The farmers should be educated as to the importance of acquiring market news and marketing process in pepper. In order to avoid distress sale, the holding capacity of farmers should be improved through credit support if necessary. The farmers should be able to reap the full advantages of a favourable market through better marketing management. Co-operative marketing system as a remedy to most of the problems in marketing can be tried in pepper. In the case of rubber, the Marketing Societies are reported to be advantageous to small farmers in realising a better share of consumer price. The possibilities of emulating such institutions in pepper marketing should be thought of.

Research and development support

Presently, most of the technologies are developed for the monocropped situations. Research efforts are to be concentrated in evolving ideal management practices under various situations like monocropping, intercropping, mixed cropping and home gardens.

CONCLUSIONS

There has been a widening supply-demand gap in world pepper market since 1995 which is estimated to the tune of 35,000 tons in 1997. Most of the producing countries have already exhausted their stocks and the demand is to be fully met by the current year's production. Indian pepper harvests begin by January-February which is the earliest among major producing countries and it is known for its unique organoleptic properties. All major consuming nations have entered the Indian pepper market and pepper prices have reached the record level. Indian pepper production are to be tuned, to enjoy the full advantages of this market situation through planned release of the product. Price mechanism plays the lead role in ensuring a better productivity in most of the crops.

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P.S.

The Statistics on area and production in India is shrouded in confusion, especially the matter of relative contribution of the three states, Kerala, Karnataka and Tamil Nadu. The latest published figures put the total area as 198030 ha (1995–96) and 179590 (96–97) and production at 61580 and 55370 tonnes respectively during the same period.

The state-wise area & production is as follows (area in ’000 ha, Production ’000 tons) (Anon. 1998)

	1995–96		1996–97	
States	*Area*	*Production*	*Area*	*Production*
Karnataka	3.55	0.88	3.53	0.87
Kerala	190.84	59.94	172.6	53.77
Tamil Nadu	3.21	0.67	3.02	0.64
Pondicherry	0.01	0.01	0.01	0.0
Andamans	0.42	0.08	0.43	0.08
Total	198.03	61.58	179.59	55.37
Trade estimates		60.00		60.00

However, unofficial estimates by plantation sector put the pepper production in Karnataka to be around 22,000 tons during 98–99, and the contribution of Karnataka is put at approximately 25% of the national production. But authentic published information is lacking.

The export of pepper was 39615 t. in 1996, 36081 t. in 1997, 33679 t. in 1998 amd 40,000 t. in 1999 (25,500 during Jan.–June and an estaimated 14500 during July-December). In comparison the exports from other countries during 1998 were in (mt): Indonesia—40,511, Malaysia—17883, Brazil—17025, Srilanka—5493, Thailand 502, China—2000, Vietnam—22000, Madagascar—339 (Anon. 1999).

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8.3. ECONOMY AND MARKETING OF BLACK PEPPER: THE MALAYSIAN SCENARIO

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In Malaysia, pepper has been cultivated for more than a century. About 98 per cent of the crop is grown in the state of Sarawak while the remaining two per cent of production comes from Sabah and Johor. In 1995 total exports of black and white pepper from Malaysia amounted to 14,040 tons, a decline of 37 per cent from the previous year. In 1979, exports of pepper from Malaysia peaked at 37,430 tons. While annual export figures have been erratic and are not totally representative of industry performance, a declining trend can be seen in terms of acreage and estimates of production. Acreage has come down by 14 per cent, from 11,512 ha in 1990, to 9867 ha in 1995 and production from an estimated 31,000 tons in 1990 to 13,000 tons in 1995, a decline of 58 per cent.

While production and export trends have been linked to price movements in the past, with each period of high prices followed by increased production, and low prices by declines in production and exports, the recovery from declines as a result of the low prices of 1992 appears to be slow in forthcoming. Taking into consideration the rapid development in Sarawak (where more than 95 per cent of Malaysian pepper is grown), the increasing cost of labour and competition from other agricultural and non-agricultural activities, it appears that the Malaysian pepper industry is at a crossroads. Will the decline continue? Will there be a recovery in production and exports commensurate with the increased prices prevailing in 1995 and 1996? Some of the underlying issues that affect the marketing and production of pepper in Malaysia need to be considered before these questions can be addressed.

THE DEVELOPMENT OF THE PEPPER INDUSTRY IN MALAYSIA

Early History

Pepper has been cultivated in Sarawak from as far back as 1856, though commercial production only began about 20 years later. In 1884 a duty was first levied on pepper exports from Sarawak. There were some efforts made to encourage Chinese migrants to take up pepper production by making land available but it was only in 1928, that acreage increased significantly, as a result of a surge in prices. During the Japanese Occupation, poor prices and disease marked a decline in pepper cultivation, though the industry recovered quickly. A research laboratory was set up in 1956 to look into the root disease which had caused extensive damage to holdings during the early fifties, providing the beginnings of the research facilities that are in existence today.

The export levy, which had lapsed during the war, was reinstated in 1960, as a means of stabilising returns by providing assistance to farmers during times of low prices and also to discourage excessive new plantings when prices were high. In 1972, the Department of Agriculture implemented the Pepper Subsidy Scheme, to help farmers establish new pepper gardens. Also in 1972, the International Pepper Community was formed, with Malaysia, India and Indonesia as founding members, though the Secretariat of the Community was only established in 1976, in Jakarta, Indonesia.

Supply: Area, Production and Exports

The area under pepper cultivation saw significant increase during the seventies, from an estimated 6360 ha in 1970 to 12,870 ha in 1980. Since then, total planted area has fluctuated between 9000 to 12,000 ha. Production figures have been much more volatile, ranging from 37,000 tons in 1979 to an estimated 13,000 tons in 1995. Export quantities have been more stable, reflecting a tendency to hold stocks at times of lower prices to be released when prices recover. Thus exports only amounted to 22,000 tons in 1992 though production was estimated at 26,000 tons, while in 1994, as prices picked up, exports rose to 22,480 tons with only 16,074 tons of pepper produced, as seen below from Table 8.3.1.

Generally, production has been influenced by various factors; in the short term, rainfall, disease, application of production inputs are significant but the underlying

Table 8.3.1 Area, production and exports of pepper from Malaysia

Year	*Area (1) (Hectares)*	*Production (Tonnes)*	*Export (2) (Tonnes)*
1970	6,861	31,600	26,208
1975	12,038	31,400	31,309
1980	13,849	31,570	31,460
1985	9,327	15,186	18,891
1990	11,512	31,191	27,970
1991	11,262	29,069	25,547
1992	10,197	26,515	22,046
1993	9,107	18,003	16,031
1994	8,686	16,370	22,480
1995	9,867	13,268	14,100
1996	9,865(e)	12,276	18,765*

(e)—Estimate.
*—Sarawak exports only.
Source: (1) Department of Agriculture, Sarawak, Sabah and Johor.
(2) Department of Statistics, Sarawak, Sabah and Malaysia.

factor contributing to long term production trends appears to be the price of pepper. Immediate responses to higher prices can be seen as farmers increase fertilizer application and take better care of farms. However, given the three years needed for pepper vines to come into production, periods of high price are generally followed by higher production while prolonged low price periods lead to lower production. For example, it is accepted that the high production of 1990 and 1991 (31,200 tons and 29,100 tons respectively) is a response to the high prices of 1986 and 1987. The relatively low production in 1995 (13,300 tons) and 1996 (12,300 tons) appears to be a consequence of the low prices of 1991 and 1992.

Government Intervention

During the early 1970's, the government of Malaysia, recognising the problems inherent in the pepper industry such as the poor quality, the difficulties farmers faced in marketing, the lack of adequate facilities for efficient processing and cleaning and the overwhelming dependence on Singapore as an export market, set up the Pepper Marketing Board. The functions of the Board were to "…regulate, manage, control and improve the marketing of pepper, to promote markets for pepper…." The Board implemented the Pepper Marketing Scheme, licensing buyers at all levels of the marketing chain and requiring licenced buyers to follow simple procedures such as issuing receipts for all purchases, using certified weighing scales, displaying prices at their premises and paying cash for all purchases. The implementation of these requirements was complemented by extension efforts to teach farmers the importance of good post-harvest practices, to ensure that pepper of good quality was marketed. A grading scheme was introduced and facilities for cleaning pepper before export was set up at the main ports in Sarawak and Johore.

Market promotion efforts were undertaken to widen markets for Malaysian pepper. These efforts bore fruit with the increased acceptance of "Sarawak Pepper" in world markets. The direction of pepper exports changed, as more consuming countries became aware of the availability of quality pepper from origin, specifically Sarawak, rather than from Singapore. In 1980, only 23.8 per cent of Malaysian exports (7550 tons) were direct to consuming countries, with just over 10 per cent being exported to Japan. By 1990, almost 62 per cent of Malaysian pepper exports (17,609 tons) was being sent direct to consuming countries, including 14 per cent to Japan and 20 per cent to the United States. In 1995, more than 65 per cent of Malaysian pepper was exported direct to 29 countries, mainly to Japan, Korea, Taiwan, Germany, and Spain, but also to destinations as diverse as Sweden, Saudi Arabia, Greece and Finland.

The Board's entry into pepper trading was also instrumental in encouraging direct trade in pepper with consumers. A reliable supply of quality certified pepper from a government agency was an asset in encouraging "new" buyers. At the same time, farmers benefitted as the Board's trading operations were targeted at purchasing from farmers at competitive prices. Since the Pepper Marketing Board's advent into trading in pepper in 1982, it has emerged as a major exporter of Sarawak pepper and a price leader at farm level.

Statutory Grading of Pepper

Since the seventies, the most significant development that has taken place in the pepper industry in Malaysia, specifically Sarawak, has been the improvement in quality of exports brought about by the introduction of statutory grading and the provision of processing (cleaning) facilities at the main export points. The effective implementation of statutory grading in 1975 (the Interim Grading Scheme) enabled Malaysian pepper exporters to sell directly to traders and importers on the basis of specific grades. The licensing of exporters and standardisation of documentation and export procedures greatly enhanced the reliability of shipments from Sarawak, while the promotional activities undertaken to familiarise traders and users in foreign markets with statutory grading and grade specifications helped widen the market for Sarawak Pepper.

In 1972, before the implementation of statutory grading, direct exports of pepper to 15 consuming countries amounted to only 4174 tons or 16.2 per cent of total exports, with the rest being exported through traders in Singapore. By 1980 this had increased to 23.1 per cent and 58.5 per cent of all exports were of graded pepper. In 1990, 58 per cent of Sarawak pepper was exported directly to 28 consuming countries, and all exports were of graded pepper and by 1995, 60 per cent of Sarawak pepper was exported directly to consuming countries, with 8 per cent being sent to Peninsular Malaysia for domestic consumption.

Of the 14748 tons of black and white pepper graded in Sarawak in 1995, more than 92 per cent was at least of Fair Average Quality (FAQ) or better while 6190 tons or 42 per cent achieved Sarawak Special Grade. This is a significant improvement in overall quality of exports, compared to 1980, when only 380 tons of Special Grade Pepper were exported and the proportion of pepper exports meeting at least FAQ requirements was only 28 per cent, with less than 3 per cent exported as Sarawak Special. The Processing Centres set up at the main ports of Sarawak (Kuching, Sarikei and Sibu) by the Pepper Marketing Board as well as by the larger exporters contributed substantially towards upgrading the quality of pepper produced and ensuring that exports complied with grade specifications.

THE CURRENT SCENARIO

Production

It is estimated that some 45,000 farm families are involved in pepper production in Sarawak at present (1996), with about 9800 ha planted. There are about 100 ha of pepper in Sabah, and about 75 ha in Peninsular Malaysia, mainly in the state of Johore. Most of the production in Johore is sold as green pepper for canning, while Sabah exported about 20 tons of pepper in 1995. Generally, pepper is a smallholder crop with most farms less than 0.4 ha in size, growing about 400 vines or less per holding.

Pepper is grown as a monocrop, using hardwood poles as supports, and the planting is relatively intensive. Establishment costs are high, with fertilisers, pesticides and hardwood (belian) poles adding significantly to costs. The use of family labour is prevalent, except during harvesting when hired labour may be used. Up to 70 per cent of the total production is processed into black pepper. White pepper production, by soaking in streams and ponds before washing of the skin of the berries and sun drying the pepper, is dependent on the premium paid over the price of pepper as well as the availability of a good water source.

Marketing

Farmers have the option to sell their pepper to village collectors/dealers, to their Area Farmers' Associations or to the Pepper Marketing Board (PMB). More than 70 per cent of all pepper is sold to the private sector but the presence of the Marketing Board as a buyer ensures that a competitive price prevails. Recently, some Area Farmers Associations have become more active in purchasing pepper from producers, for sale to PMB or other exporters. From village collectors, pepper is sold to dealers or exporters. Cleaning is undertaken by exporters before the pepper is packed into new gunny bags and graded for export.

More than 90 per cent of pepper from Sarawak is exported. Domestic (Malaysian) utilisation of pepper is estimated at about 1000 tons. Most exports are in the form of whole berries, with exports of black pepper being significantly more than white. In 1995, 10,491 tons of black pepper were exported from Sarawak amounting to 69 per cent of total pepper exports, while 4712 tons (31%) of white were exported (including exports to Peninsular Malaysia, 550 tons of white and 664 tons of black). A small amount of ground pepper, 518 tons, were also exported, less than 4 per cent of the total. The main markets are the Far East, (Singapore, Japan, Korea, Taiwan and Hong Kong), Western Europe, and the Middle East. Exports to the United States vary from year to year, depending primarily on the availability of quality pepper from other origins.

Domestic utilisation of pepper is relatively low. Per capita consumption is estimated at less than 50 gms per annum, primarily as ground pepper for household use and in spice or curry mixes. Industrial utilisation, by the food processing and canning industry holds some prospects but present levels of use are not significant. The development of the fast-food industry and increasing demand for ready-to-eat foods provide some indication of increasing domestic demand.

Intervention

During the seventies and the eighties, the thrust of intervention by the government was to regulate the industry to ensure fair returns to producers, introduced a grading scheme to provide assurance of quality of exports, provided subsidies to farmers and undertook market promotion activities. Today the emphasis has shifted to efforts to make the industry more competitive vis-a-vis other producing countries. Extension efforts by the Department of Agriculture are focused on encouraging farmers to adopt lower-cost production methods, such as the use of live supports, ground cover to reduce weeding and nutrient requirements and improved planting materials more resistant to disease and pests. While production subsidies are being phased out, farmers in selected areas are being provided with some inputs to encourage acceptance of specific programs.

Improved quality at farm-level has also become an area of focus for extension, with farmers being encouraged to clean and prepare pepper for export before sale. Some simple blowers and sieves are being provided to farmers for this purpose. Premiums are paid for export quality pepper as incentives for farmers to upgrade their product; this has the advantage of increasing value, reducing the quantity of pepper to be transported from the farms and decreasing the amount of waste that has to be disposed of at the ports.

The Pepper Marketing Board buys pepper from farmers in competition with local buyers and exports pepper to users, to ensure that farmers receive prices commensurate with the prevailing market and to develop new markets. In its efforts to stabilise returns to growers, the Board has recently introduced a scheme to allow farmers to store their pepper at the PMB godowns. Storage certificates are issued, which may be transferred, traded or used as collateral by the owners of the stored pepper. Farmers who hold stocks of pepper are assisted in finding markets through a system of offering pepper ready for shipment to exporters.

The Board also undertakes licensing activities, marketing extension to farmers and intermediaries, market promotion and development of new pepper-based products. Under the licensing scheme, all intermediaries who trade in pepper are required to obtain a licence issued by the Board and to comply with specific conditions. These include the use of purchase invoices to evidence all purchases, use of certified weighing scales, display of prices at the premises of the licensee, and immediate payments for all purchases. Storage areas are inspected from time to time and exporters are required to maintain minimum levels of cleanliness.

Marketing extension for farmers and intermediaries is primarily aimed at improving quality of exports, through talks, workshops, demonstrations, distribution of extension material and advisory visits, while market promotion activities are geared towards providing a wide range of buyers for Sarawak pepper. Market promotion is targeted at both the local and the export markets; efforts to promote the consumption of pepper locally are directed at manufacturers, food processors and institutional buyers as well as household consumers. Overseas promotion is aimed primarily at end-users, to identify the demand for high quality pepper products and meet their specific requirements.

Problems and Issues

The production and marketing of pepper in Sarawak faces some specific problems. Much of the pepper is cultivated in relatively less accessible areas and transport costs to the main ports are high. Areas closer to towns are being most affected by the higher cost of hired labour and availability of alternative employment opportunities for farmers. As such, these are the areas where the price declines of the early nineties and continuing price instability have had the most effect. At the same time, farmers in the interior are faced with higher input costs and difficulties in obtaining fertilisers, planting materials and pesticides. While there is some new planting taking place as a result of the improved prices currently prevailing, there is not much evidence of replacement of old vines. A general lack of conviction as to the sustainability of present price levels has not encouraged replanting, while farmers are reluctant to forego the returns from present price levels.

Competition from other crops (oil palm and rubber) is not serious in most areas in the interior, as pepper has an advantage in that the output is less bulky and more easily stored and transported. Farmers closer to towns and settlement schemes, however are venturing into oil palm and other crops that do not require as much labour as pepper and have more stable prices.

Acceptance of new production technology (live supports, ground cover, lower height of vines, etc.) is slow and yet to be demonstrated effectively. Extension activities that seek to introduce new technology that can improve yields, lower costs and make production less labour intensive are being undertaken but the areas in the interior are relatively less accessible and many of the older farmers are less responsive to the "new" ideas.

In terms of marketing, while there is demand for improved products that take into account specific requirements of buyers (such as low levels of bacteria, uniformity of colour and size for white pepper, free of chemical contaminants, etc.) the prices paid for these products are less than commensurate with the costs of producing these higher quality products.

The volatility of pepper prices, in the short term from month to month or even from week to week and in the long term, the cyclical pattern of world market prices resulting from fluctuations in supply, have curtailed investment in production and new technology. Farmers are reluctant to undertake new plantings even though higher yielding vines are available, not knowing if prices in the future will be giving a good return on their investment. In the short term, many farmers often need to sell their pepper immediately after harvest, to meet expenses, at times when prices may not be favourable. The absence of any widespread mechanisms to allow producers and traders to maximise their returns vis-a-vis their selling price makes price fluctuations a serious consideration in the development of the pepper industry in Sarawak.

THE ECONOMICS OF PRODUCTION

Cost of Production

As is to be expected, the cost of production has increased over the years. Improvements in yields through better planting materials, farm maintenance and cultural practices have been more than offset by increasing costs of inputs and labour.

The cost of hardwood supports, a major costly item in planting pepper, has gone up from RM 4.00 in 1980 to RM 6.00 per piece in 1995, an increase of 50 per cent; for a one hectare farm this would mean an increase from RM 7904 to RM 11,856. Farm labour costs have also increased significantly, from an average of RM 5.00 per workday for lighter work such as harvesting and weeding and RM 8.00 per workday for heavier work such as land clearing, preparation, and planting in 1980, to RM 9.50 and RM 11.50 respectively in 1995.

On average, cost of farm inputs have increased by the equivalent of 48 sen per kg of black pepper, between 1980 and 1995; farm wages have increased by 49 sen per kg and the cost of production of a kilogram of pepper has increased from RM 1.43 in 1980 to RM 2.40 in 1995, an increase of 68 per cent (4.5% per annum). For white pepper production, costs have increased from RM 1.73 per kg to RM 2.88, or 66 per cent during the same period. Some low-cost technologies are now available to producers, but these have not been adopted widely enough to have significant impact on production costs generally.

At the same time, while there has been some narrowing of the gap between farm and export prices since 1992, this has not been significant, as seen below. Absolute margins between farm and export prices have tended to vary with the price level, though in percentage terms, there has been a general reduction in margins at farm level.

THE MARKETING OF PEPPER

On-farm Processing

Most processing of Sarawak pepper at farm level is relatively simple. For black pepper, berries are harvested when mature green, despiked and dried in the sun. For white pepper, berries that are beginning to ripen are put into bags and soaked in ponds or streams to soften; the pericarp is then washed off and the seeds are dried in the sun. The quality of water used for soaking the berries is important, as pepper soaked in muddy or dirty water may be discoloured or have foreign odours. For both black and white pepper, the quality of the product sold by farmers is much dependent on the weather, as almost all the pepper is sun dried.

The higher prices for white pepper prevailing currently (relative to the price of black pepper) as well as the premiums being paid for high quality have resulted in increase in production of good quality white pepper. Efforts to provide soaking tanks and use of clean water sources are beginning to show results, with some pepper of commendable quality being produced. Price premiums commensurate with the additional labour and other inputs are essential if these efforts are to continue.

Efforts to improve quality have also focussed on cleaning of dried pepper at farm level prior to sale. Simple sieves and blowers have been made available to villages, to enable farmers to remove stalks, dust and foreign matter and to reduce the content of light berries in their pepper. This process adds value to the pepper by improving quality, reduces the volume of material that has to be transported to the ports (by as much as 10%) and reduces the cleaning operations that need to be undertaken at the export point. As long as farmers perceive that they receive value for their efforts, they are more than willing to undertake the additional work required.

Improvements in processing of black pepper need to focus on the drying process. In an area where there is rainfall almost all the year round and ambient humidity is quite high, the quality of black pepper produced is very much dependent on drying. While there have been some efforts to introduce mechanical dryers at farm level, they have met with limited success. The cost of drying using fossil fuels is relatively high (compared to sun-drying) and other forms of drying such as solar-driers or solid fuel driers have not been found to be as effective.

Increased Marketing Options

The participation of the Pepper Marketing Board in purchasing pepper increased competition at farm level. During the 1990's, various Area Farmers' Organisations have also become active in trading pepper. This has heightened competition and provided an incentive for some level of investment in primary processing and storage facilities. Farmers now have the option of selling their black and white pepper to a village dealer, the Pepper Marketing Board or to the local Farmers' Association. Prices offered by all these buyers are generally competitive and reflect the prevailing market situation. Local dealers are able to compete by anticipating market trends and taking positions as indicated by their principal buyers, while the Board and the Farmers' Association play a more conservative role and base their purchases on current export prices. Tables 8.3.2 and 8.3.3 give farm and export prices of black pepper and white pepper respectively for the last many years. Such information and prevailing market trends help the PMBM to fix up procurement prices, that will be generally beneficial for the producers

Since 1995, a scheme has been implemented that gives farmers the option to store their pepper at designated stores in exchange for storage certificates. Such pepper can then be sold at a later date when prices are considered favourable. The storage certificates can be used as collateral, to give farmers access to cash when they need it, without losing ownership of their pepper, often at times immediately after the harvest

Table 8.3.2 Difference between farm price and fob price for black pepper (in Malaysian Ringgit per 100 Kg).

Year	*Average farm price*	*Average FOB price*	*Difference*	*Percentage*
1975	251	310	50	20
1980	261	308	47	18
1985	598	713	116	19
1990	336	402	65	19
1991	247	319	73	30
1992	186	222	36	19
1993	236	286	50	21
1994	380	426	45	12
1995	507	587	80	16
1996	456	526	70	15

Table 8.3.3 Difference between farm price and export price for white pepper (in Malaysian Ringgit per 100 kg).

Year	*Average farm price*	*Average FOB price*	*Difference*	*Percentage*
1975	337	398	61	18
1980	385	445	60	16
1985	749	905	156	21
1990	422	481	59	14
1991	327	396	70	21
1992	291	334	44	15
1993	471	496	25	5
1994	673	729	56	8
1995	809	894	85	11
1996	780	858	78	9

when prices tend to be depressed. In addition to helping, farmers have better control of their selling decisions, the stock is held in clean, relatively safe and insured warehouses and thus contributes to overall improvement in quality and reliability of supplies.

Almost all trading in pepper in Sarawak is done for delivery or export within a very short time frame. Most deliveries are specified within a month with some contracts for three months. Without a mechanism to provide for longer term price discovery or to provide for contract performance internally, exporters are reluctant to sell on longer term contracts. With a view to correct these shortcomings, a physical delivery futures market is being planned to encourage market players and farmers to make commitments for longer periods.

THE FUTURE OF THE PEPPER INDUSTRY IN MALAYSIA

Production

While production of pepper has declined significantly over the last three years and the recovery from the effects of low prices experienced in 1991–92 is not as quick as in previous cycles, it would be premature to write-off the pepper industry in Malaysia (and Sarawak in particular). Pepper remains an important cash crop in the less accessible areas of the state. Other crops are not as durable as pepper, in that well-dried pepper can be stored and easily transported to nearby towns for sale. Fresh produce cannot be marketed as easily and crop like oil palm requires processing facilities nearby. Pepper farmers in the interior tend to look on their pepper as a store of value and transport what is needed to the nearest town when they need money. Though this is changing as the rural economy becomes more monetarised, it is unlikely that farmers will abandon a traditional crop, without a viable substitute.

Recent years have seen a change in the areas where pepper is grown. Pepper farms near the main towns have given way to market gardens, fruit orchards and industrial estates. Farming communities in areas close to large oil palm estates with palm oil mills have taken to cultivation of oil palm. The overall area under pepper however, has not declined significantly; fall in production are more attributable to less inputs, poorer maintenance, disease, and older vines. It is not too optimistic to note that improved prices have encouraged some new plantings and rehabilitation of old farms, albeit at a slower rate than before. While the area planted with pepper is not expected to increase significantly beyond 10,000 ha, there is every likelihood that production will improve if prices remain stable or do not fall below 1994 levels.

Processing and Marketing

The emphasis on value added products at farm level is primarily aimed at stabilising returns to farmers. With the prospect of increased returns from improved quality and more diversified products, there is every likelihood that farmers will increase the level of processing at farm level and become more involved in processing off-farm. The Area Farmers' Organisations are expected to play a part in this involvement, but individual farmers are also becoming interested in selling their pepper to levels higher up the marketing chain than the village level collector. In addition to improved quality of product sold by farmers, the pepper storage scheme and the physical forward contract is likely to encourage farmers to become more independent and venture further when selling their pepper. This is very much facilitated by the improved transport and communications systems that have been put in place in Sarawak in the last decade. Farmers have access to daily prices through the press and radio and are able to compare prices ex-farm with prices for graded pepper at export points.

CONCLUSIONS

Pepper in Malaysia is a small holder crop predominantly grown in the state of Sarawak in East Malaysia. This commodity is considered as a vital cash crop among rural farmers. The pepper industry is an export oriented industry and as can be noted from statistics of world pepper exports from 1989–1992 (both inclusive), black pepper dominates with an average share of 78 per cent of total exports. The share of white pepper in 1993 decreased, averaging its share at about 22.5 per cent of total pepper exports. Thus black pepper supply conditions have a very important role in the world pepper market. The discussion of the above issues leads us to the following conclusions.

Like other primary commodities, pepper exports are exposed to price risks. This may be due to unstable prices in the international market where they are faced with daily short term price fluctuations and sometimes confusing and conflicting market information. It may be noted that price fluctuation is caused by many factors but there are only two major factors. The first one is caused by unclear or conflicting conclusions about the world pepper supply conditions and the second one is attributed to misleading statements by speculators so that the response of the market participants will favour the speculators.

The world supply of black pepper is normally dominated by five producing countries namely, India, Indonesia, Vietnam, Brazil and Malaysia, whose aggregate production represents 90 per cent of the whole world supply. It may be noted that there will be no supply pressure from other black pepper producing countries especially from Brazil and Indonesia.

Pepper like other spices and other agricultural commodities passes through a series of value-added activities starting from farmer and the final stage with the consumer. Each of these activities, derives revenue and profit by adding value to the product.

Ng and Kanbur (1993) worked on a modelling of the Malaysian pepper industry using three major components of supply, demand and price. Although Ng's model was a simple model with nine equations, it did manage to capture the main aspects of the pepper industry. These aspects were:

1. the relative instability of the supply of pepper
2. the relative stability of the demand for pepper
3. the frequent fluctuations of pepper price.

It may be noted that the volatility in pepper supply is attributed mainly to the high susceptibility of the pepper vines to disease and pests. These and other natural factors play an important role in determining yield of pepper. Apart from being volatile, the supply of pepper according to Ng and Kanbur's study is price inelastic in the short run. Price inelasticity is however a common feature of most primary commodities due to long gestation period. On the supply side research in exploring ways and means to control diseases and pests must be intensified and encouraged so that a more stable supply base is achieved. Existing support policies must constantly be reviewed and improved upon so that maximum benefits can be derived from these policies.

A possible way to stabilise the price of pepper at a derived level is to maintain an international buffer stock. A model based on the stock adjustment principles could estimate the actual quantity of buffer stock required to stabilise the price at a given level.

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9.1. PHARMACOLOGY, TOXICOLOGY AND CLINICAL APPLICATIONS OF BLACK PEPPER

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PHARMACOLOGY

Many spices used in food seasoning have broad spectrum of antimicrobial activity. Their antioxidant activity against lipid peroxidation enhances the keeping quality of food. Apart from the use as a popular spice and flavouring substance, black pepper as drug in the Indian and Chinese systems of medicine is well documented (Nadkarni 1976, Kurup *et al.* 1979, Atal *et al.* 1975). In the *Ayurvedic* descriptions, pepper is described as *katu* (pungent), *tikta* (bitter), *usbnaveerya* (potency, leading to storing up of energy, easy digestion, diaphoresis, thirst and fatigue), to subdue *vatta* (all the biological phenomena controlled by CNS and autonomic nervous system) and *kapha* (implies the function of heat regulation, and also formation of various preservative fluids like mucus, synovia etc. The main functions of *kapha* is to provide co-ordination of the body system and regularization of all biological activities). Pepper is described as a drug which increases digestive power, improves appetite, cures cold, cough, dyspnoea, diseases of the throat, intermittent fever, colic, dysentery, worms and piles; also useful in tooth ache, pain in liver and muscle, inflammation, leucoderma and epileptic fits (Ayier and Kolammal 1966, Kirtikar and Basu 1975). Black pepper is called *maricha* or *marica* in Sanskrit, indicating its property to dispel poison. In Chinese medicine, it is used externally for snake and scorpion bite. These descriptions explain the diverse actions of pepper, which is being used in the Indian system of medicine either as such or as an ingredient in many formulations. But in the allopathic system, pepper or its active constituents did not find any therapeutic or clinical use. The above mentioned activities may be attributed to piperine and other phenolic amides and essential oil constituents (see chap. III). But in *Ayurveda,* the active principle-based specific activities of substances are not taken into consideration. Hence the pharmacological and toxicological aspects of pepper and its constituent secondary metabolites were not studied. Many of the clinical uses mentioned above were time tested and have been in use for generations. But to establish a scientific basis for many activities for which it has been used, pepper and its active constituents should be studied pharmacologically with well defined experimental protocols as used in modern drug development. Several studies were reported during the last ten or fifteen years, many of the results were encouraging and supported some of the clinical uses in the traditional Indian systems. Analgesic, antipyretic, antinflammatory, antimicrobial, and antineoplastic activities were reported both under *in vitro* and *in vivo* studies in experimental systems. Very promising results could be obtained in insecticidal and insect repellent activities. There seems to be scope for developing pepper based insecticides and insect repellents which are nontoxic to human beings.

Piperine is the major alkaloidal constituent of pepper. Systematic pharmacological studies on piperine have revealed its analgesic (alleviate pain), antipyretic (reduces fever), antinflammatory (reduces painful swelling caused by tissue injury) and central nervous system depressant activities. The essential oil constituents are mainly responsible for the antimicrobial actions.

Analgesic and Antipyretic Actions

The use of pepper and pepper containing preparations for the treatment of intermittent fever, neuritis, cold, pains and diseases of throat are practised in the *Ayurvedic, Yunani, Siddha* and folklore medicines in India. In the Chinese system, pepper and chenghan (*Dichora febrifuga* L, its active constituents, febrifugin and isofebrifugin, show anti-malarial property 50 times stronger than quinine) are used for the treatment of malaria (Das *et al.* 1992). Pepper is also used as an antiperiodic in malarial fever (Nadkarni 1976). The curative effects claimed in the above cases can be attributed to the analgesic and antipyretic actions of the active constituents of black pepper. Lee *et al.* (1984) have studied the analgesic and antipyretic actions of piperine on rabbit and mice and found strong antipyretic effect on typhoid vaccinated rabbits at a dose of 30 mg/kg body weight when administered orally. Acetaminophen was used as the reference substance. The antipyretic effect of piperine was found to be stronger than reference compound. For the determination of analgesic activity, acetaminophen and aminopyrine were used as reference compounds. Piperine gave a strong activity with an ED_{50} of 3.7 mg/kg on writhing method and 104.7 mg/kg on tailclip method.

Antinflammatory Activity

The antinflammatory potential was studied by several groups. Lee *et al.* (1984) reported that piperine showed a significant inhibition of increase in oedema volume in a carragenin induced test at an oral dose of 50 mg/kg body weight. Another group studied the effect on different acute and chronic experimental models (Mujumdar *et al.* 1990a). They evaluated the mechanism of antinflammatory activity by biochemical studies and concluded that piperine acted significantly on early acute changes in inflammatory process. The antinflammatory potential was supported by Kapoor *et al.* (1993).

Central Nervous System Depressant Activity

In the Ayurvedic medicine, pepper is used for the treatment of epileptic fits and to bring about sleep (Kritikar and Basu 1975). In the pharmacological evaluations, the

CNS depressant effect of pepper and piperine was established. It exhibited protection against pentetrazole seizure and showed weak protection against maximal electroshock seizure (Won *et al.* 1979). The LD_{50} value for piperine was 287.1 mg/kg i.p. and 1638.8 mg/kg orally. In another study Shin *et al.* (1980) showed that piperine at one-tenth of its LD_{50} value showed strong potentiating effect on hexobarbital induced hypnosis in mice. Decreased passivity, ptotic symptoms and decrease in body temperature were also observed. Protection against electroshock seizure and muscle relaxant effect were observed at relatively low dosage range with an ED_{50} of 15.1 mg/kg intraperitonial was reported (Lee *et al.* 1984). This was almost equipotent to the reference compound phenytoin. Petrol extract of pepper leaves was found to potentiate phenobarbitone-induced hypnosis in mice (Sridharan *et al.* 1978). Majumdar *et al.* (1990b) also reported that high dosage of piperine potentiates the phenobarbitone sleeping time by inhibiting the liver microsomal enzymes. It also acted partially through stimulation of pituitary adrenal axis. From the above studies it may be inferred that piperine may be effective in the treatment of petit mal.

A compound of great interest is antiepilepsirine (AE) isolated from white pepper. AE is 1-(3-benzodioxol-5yl)-1-oxo-2-propenyl)- piperidide. This is perhaps the only compound derived from pepper, clinically used, in the treatment of epilepsy. This is used as an alternative to dilantin therapy in Chinese hospitals (Ebenhoech and Spadaro 1992). Reports on human clinical studies show that 83.3 per cent cases respond favourably leading to 50–90 per cent reduction of seizures. According to Zhou (1981) AE was most effective against grand mal seizures. No toxic effect was noticed, even in pregnant women (Ebenhoech and Spadaro 1992). Liu *et al.* (1984) suggests that AE may release 5-hydroxy tryptamine (5-HT) from nerve endings. Studies on rats showed that AE increases concentration of 5-HT in the brain and there by intensifies anticonvulsive activity. AE also raises tryptophan level in the brain, causing elevation of serontin and monoamine levels, a suggestive cause to seizure control

Action on Liver Enzymes

Neither pepper nor piperine produces any hepatic toxicity. In fact, it exerts liver protective action as evidenced by the studies of several workers. By enzyme modulation, piperine functions as a chemopreventive substance. Dalvi and Dalvi (1991) studied the hepatotoxic effect of piperine on rats by estimating the hepatic mixed function oxidases and serum enzymes as specific markers of hepatotoxicity. An intragastric dose of 100 mg/kg body weight caused an increase in hepatic microsomal enzymes, 24 hours after treatment (cytochrome p-450, cytochrome-b5, NADPH-cytochrome C reductase, benzphetamine N-demethylase, aminopyrine N-demethylase and aniline hydroxylase were estimated). On the other hand, an intraperitonial dose of 10 mg/kg did not produce any effect on the activities of the drug metabolizing enzymes. However, at higher doses of 800 mg/kg (intragastric) and 100 mg/kg (intraperitonial), significant decrease in the levels of the enzymes was noted. But these treatments did not affect those serum enzymes which are specific markers of liver toxic conditions. Piperine exerts significant protection against chemically induced hepatotoxicity. Kaul and Kapil (1993), reports that this plant principle reduces *in vitro* and *in vivo* lipid peroxidation and prevents depletion of GSH and total thiols. Lipid peroxidation causes free radical production, which in turn produces tissue damage. GSH conjugates xenobiotics which are excreted out by subsequent glucuronidation. In this study, the hepato protective action was compared with a reference compound, silymarin, a known hepato protective drug, and found that piperine has slightly lower activity. A dose dependent increase in the levels of the hepatic biotransformation enzymes, (glutathione-s-transferase, cytochrome p-450, cytochrome b-5, acid soluble sulfhydril-SH), was obtained in a feeding experiment study using Swiss albino mice fed with a diet containing 1 per cent, 2 per cent and 5 per cent black pepper (w/w) for 10 and 20 days (Singh and Rao 1993). A lowered level of glucuronidation due to the inhibition of the enzyme UDP-glucose dehydrogenase was observed by Reen *et al.* (1993) in an *in vitro* study. While studying the hypoglycaemic action of several plants, Tripathi *et al.* (1979) reported that pepper fruits are devoid of any significant hypoglycaemic action in rabbits. The aqueous extract of pepper leaves in a dose of 10–20 mg/kg led to a moderate increase in the blood pressure of dogs (Sridharan *et al.* 1978). Piperine as well as AE (antiepilepsirine) are reported to have detoxifying qualities, that may increase the bioavailability of other drugs, hence altering the pharmokinetic parameter of the epileptic (Bano *et al.* 1969).

Mutagenic and Carcinogenic Effects

Investigations into the mutagenic and carcinogenic activities of pepper gave encouraging results on its beneficial effects. It was found to be nonmutagenic by Ames test. Pepper prevents chemical carcinogenesis by stimulating the xenobiotic biotransformation enzymes. The antioxidant properties of piperine and associated unsaturated amides play a preventive role in carcinogenesis. Dietary intake of natural antioxidants could be an important aspect of the body's defense mechanism against the degradative changes caused by mutagens. In addition to that, the essential oil constituents inhibits DNA adduct formation by xenobiotics. This observation shows the anticarcinogenic potential of pepper. However, studies with pepper extracts showed an increased incidence of tumour in mice and, an elevated level of DNA damage caused by piperine in cell culture investigations. Hexane, water and alcohol extracts of pepper were tested for mutagenicity on *Salmonella typhimurium* strains TA 98 and TA 100 by Ames assay and the results indicated the nonmutagenic effects of the extracts.

This study also gave evidence that the water extract exerts an antimutagenic action on carcinogen induced mutagenesis (Higashimoto *et al.* 1993). Pepper as well as its constituents increases the activity of biotransformation enzymes in the liver in a dose dependent manner, thereby playing a chemoprotective role (Singh and Rao 1993). The phenolic amides elicits a very significant antioxidant activity (Nakatani *et al.* 1986). It is well known that antioxidants exert a preventive mode of action in carcinogenesis. Hashim *et al.* (1994) studied the modulating effects of the essential oil of pepper and found that this also has an inhibitory activity. The volatile oil and its constituents suppress the formation of DNA adducts with aflatoxin B1. This action was modulated through the microsomal enzymes. When mice was fed with powdered pepper in diet (1.66% w/w of food) no impact on carcinogenesis was noticed, whereas feeding and painting of mice with solvent extract of pepper, 2 mg for 3 days per week for 3 months, resulted in an increase in the incidence of tumour bearing mice (Shwaireb *et al.* 1990). The pepper terpenoid d-limonene was found to reduce the carcinogenic activity of methycholanthrene, a potent carcinogenic compound (Wuba *et al.* 1992). Two minor constituents of pepper, safrole and tannic acid, are attributed with minor carcinogenic activity. In a tissue culture study using V-79 lung fibroblast cell lines, Chu *et al.* (1994) reported that piperine treated cell lines showed increased DNA damage compared to untreated ones. Piperine treatment lowered the activities of the enzymes glutathione-s-transferase and uridine diphosphate glucuronyl transferase indicating the cytotoxic potential. The *in vivo* formation of n-nitroso compounds from naturally occurring amines and amides contribute to the carcinogenic potential of certain foods and food additives. Piperine and other phenolic amides present in pepper are also known for their conversion to n-nitroso compounds in acidic conditions and hence treated as carcinogenic (Lin 1986). But it can be inferred that the presence of conjugated unsaturated system in the phenolic amide prevents the oxidation of the amide nitrogen to n-nitroso compounds to a large extent. Moreover, the essential oil constituents of pepper also contribute to its anticarcinogenic potential preventing DNA damage. Investigations reveal both carcinogenic and anticarcinogenic nature. However, black pepper as such exhibited antimutagenic and anticarcinogenic effects. This is the form in which it is usually used as spice and also in various medicinal formulations of the Indian System.

Antioxidant Activity

Antioxidants scavenge free radicals and control lipid peroxidation in mammalian system. Lipid peroxidation is a chain reaction, providing continuous supply of free radicals that initiate further peroxidation. This is responsible not only for the deterioration of food but also for damage of tissue *in vivo* where it may cause inflammatory diseases, ageing, atherosclerosis, cancer etc. Investigations revealed that pepper and the phenolic amides present in it, possess good antioxidant property. Tocopherol and vitamin-C are two important natural antioxidants. Chiapault *et al.* (1955) studied the antioxidant effectiveness of spices in a two phase aqueous fat system. Pepper has an antioxidant index of 6.1, compared to 103.0 for clove and 29.6 for turmeric. Saito and Asari (1976), in a study on different spices, reported that pepper exhibit antioxidant activity and they attributed it to the tocopherol content of pepper. But in an earlier work on the effect of the pepper oleoresin on fish oil, Revankar and Sen (1974) stated that the antioxidant property is due to the polyphenolic content. The autoxidation of unsaturated fatty acids and proteins was delayed by addition of pepper, and significant protection against oxidative degradation was obtained as evidenced by the studies of Abdel-Fattah and El-Zeany

(1979). From an investigation on the family *Piperaceae,* Nakatani *et al.* (1986) established that all the five phenolic amides present in *P. nigrum* possess very good antioxidant property, which is superior to that of the synthetic antioxidants like butylated hydroxy toluene and butylated hydroxy anisole.

Antimicrobial Activity

It should be noted that many of the spices possess antiseptic, antibacterial and antifungal effects. These properties are mainly due to the presence of volatile oil principles present in them. Volatile oils are mixtures of several constituents and it is logical to attribute the activity to more than one terpenoid constituents of the oil. The high value placed upon pepper as an important spice is due to its bactericidal and bacteriostatic activity. The addition of pepper to foods and processed foods increases their keeping quality and prevents their spoilage. The antimicrobial properties of pepper is due to its volatile oil as evidenced by several studies. Even the leaf extract possess activity, which was established even 40 years back (Subramanyan *et al.* 1957). The extract of pepper was not inhibitory to *E. coli., Aerobacter aerugenosa, Lactobacillus casei, Staphylococcus faecalis, S. aureus* and *S. sonnei* (Subrahmanyan *et al.* 1957). The essential oil obtained from pepper was found to be active against penicillin-G resistant strain of *Staphylococcus aureus*. Jain and Kar (1971) reported the inhibitory action of pepper oil on *Vibrio cholerae, Staphylococcus albus, Clostridium diphthereae, Shigella dysenteriae, Streptomyces faecalis, S. pyogenes, Bacillus pumilis, B. subtlis, Micrococcus* sp., *Pseudomonas pyogenes, P. solanacearum* and *Salmonella typhimurium*. The antibacterial action was determined by the agar well diffusion technique using cephazolin as standard (Perez and Anesini 1994). Pepper oil stopped the mycelial growth and aflatoxin synthesis by *Aspergillus parasiticus* at a concentration of 0.2 per cent to 1 per cent (Tantaoui and Beroud 1994). The leaf oil exhibits antifungal activity against *Candida albicans* (Jain and Jain 1972) and *Aspergillus flavus* (Rao and Nigam 1976). Salzer *et al.* (1997) studied the antibacterial effects of pepper extract, essential oil and isolated piperine *in vitro* against sausage micro flora (*Lactobacillus plantrum, Micrococcus specialis* and *Streptococcus faecalis*) and found that only isolated piperine had growth inhibiting effect at normal doses. Pepper powder and extract were active only at high concentrations. An alcoholic extract was found active against the deadly food borne bacterium, *Clostridium botulinum* (Huhtanen 1980). Another potential activity was revealed by a study carried out using tincture of pepper by Houghten *et al.* (1994). They have studied nine strains of *Mycobacterium tuberculosis* and found significant antibacterial activity against all the nine strains.

Pepper increases the bioavailability of medicaments and uptake of proteins and amino acids from food. In a study using *Trikatu,* an ayurvedic preparation containing *Piper nigrum, P. longum* and *Z. officinale,* it was found that pepper containing preparations enhance the bioavailability of other medicaments (Johri and Zutshi 1992). Piperine at a dose of 25–100 micromolar quantity, enhanced the uptake of l-leucine, l-isoleucine and l-valine and increased lipid peroxidation in an *in vitro* study using rat intestinal epithelial cells (Johri *et al.* 1992). These results suggest that piperine may interact to increase the permeability of intestinal cells. Predeep and Geervani (1994) reported that the protein uptake from pulses was enhanced by the addition of spices (pepper and other common spices used in Indian cooking) at a level of about 1.5 per cent of the diet.

Investigations on Human Subjects

Only a very few studies using human subjects were reported. In high doses, the gastric mucosal injury caused by pepper is comparable to that of aspirin. This rinding was obtained in a double blind study of intragastric administration of pepper to human volunteers (Mayore *et al.* 1987). Healthy human volunteers were given meals containing 1.5 g of pepper; aspirin (655 mg) and distilled water were used as the positive and negative control. However, the long-term effects of daily pepper ingestion are not known.

Vezyuez Olivincia *et al.* (1992) studied the effect of intestinal peristalsis by measuring the orocaecal transit time, utilising a lactulose hydrogen breath test on healthy human subjects. They were given 1.5 g of pepper in gelatine capsule and the OCTT was measured on several days and found that orocecal transit time increased significantly after pepper administration. This finding has clinical importance in the management of various gastrointestinal tract disorders. Another significant study reveals the usefulness of pepper extract volatiles in smoking cessation treatment. The results of the study by Rose and Behm (1994) on human subjects revealed that, cigarette substitutes, delivering pepper volatile constituents, alleviated smoking withdrawal symptoms. The results of these two studies with human subjects are encouraging, which has the potential to be exploited for future therapeutic use.

TOXICOLOGY

There are no data available on the acute or chronic toxicologic aspects of pepper and/ or its constituents. Pepper constituents are not used therapeutically in the allopathic system. Pepper has been in use since very early times as a spice and food additive. No health hazard or untoward action may arise in the concentrations used. The total contents of piperine and associated phenolic amides are of the order of 7–9 per cent w/w and that of the volatile oil are 2–4 per cent. At this level the actual doses of the different constituents available from the quantity of pepper powder, oleoresin or extractive used, will be very little to elicit any toxic reactions. Moreover, the pungent taste of piperine and flavour of the volatile oil constituents will themselves serve as a limiting factor for the intake of high doses. No acceptable daily intake (ADI) has been prescribed by the Joint FAO/WHO Experts Committee on Food Additives for piperine and/or the volatile principles. The major untoward action of pepper is the gastric mucosal injury at a dose of 1.5 g/kg food. There are a few reports about the carcinogenic potential of piperine. It enhances the DNA adduct formation, and extract of pepper produces an increased incidence of cancer in mice. El Mofty *et al.*

(1991) reported the formation of hepatocellular carcinoma, lymphosarcoma and fibrosarcoma in Egyptian toad by force feeding them with an extract of black pepper. However, large number of studies prove the anticarcinogenic effects. Anyway, to establish the carcinogenicity or anticarcinogenicity unequivocally, piperine has to be subjected to further screening. The observation that it enhances the liver microsomal enzyme activity also has to be investigated further. This is to ascertain whether constant use of pepper can produce any nonspecific enzyme induction.

CLINICAL APPLICATIONS

Clinical applications are not reported for black pepper or any of its constituent in Allopathic Medicine. However, in the Indian systems, *Ayurveda, Sidha* and *Unani,* pepper has been used in many clinical applications. But in any of these applications, piperine or other phenolic amides or the volatile oil constituents as such are not being used. Black pepper in the dried form along with other medicinal plants are used for preparing the particular formulations. Some important preparations used in *Ayurveda* are *Dasamulakatutrayadi Kasayam,* a formulation used for the treatment of Asthma, *Astacurnam*—used for dyspepsia and flatulence and as stomachic and carminative effect, *Amirtaristam*—for fever as an antipyretic, and as an antiperiodic, *Muricadi Tailam*—for inflammations and rheumatic pain, *Dasamularasayanam*—for cough and bronchitis, *Gulgulutiktaka ghrtam*—analgesic and antiinflammatery effect (See also the chapter on end uses).

The varied type of pharmacological activities of black pepper and its constituents justifiy many of its therapeutic uses in Ayurveda, even though an active constituent-dependent action and therapeutic effect is not the basis in this system. For pepper and its constituents to be used in the allopathic system, there is a long road to travel. However, pepper provides natural compounds with analgesic, antipyretic and antinflammatory activities which are promising areas demanding further investigation. Similarly, the use in malarial fever also needs more study. The antioxidant and antimicrobial activities are beneficial properties and support the use of pepper as an important spice and food additive. Moreover, pepper has good dietary value also. Umapradeep *et al.* (1993) reported that it has a high dietary fibre content (15–53%), iron (54–62 mg/100 g), calcium (1.0–1.5%) and also appreciable amounts of essential amino acids. Pepper has long been used as a digestive aid and is good for gastrointestinal upsets and flatulence (excessive gas in the body). The carminative property of pepper have been known since ancient times. Excessive gas in the alimentary tract is characteristic of many health disorders. Flatulence can cause pain and discomfort in other parts of the body. Pepper increases salivary flow and the secretion of the enzyme amylase which helps in the proper digestion of starch.

INSECTICIDAL ACTIVITY

Plants have been used for pest control from time immemorial. Many of the plant derived insecticidal compounds have the added advantage that while being toxic to the pest they are nontoxic to humans. The extract, the volatile oil and the various phenolic amides present in pepper have shown to exhibit insecticidal and/or insect repellent and ovicidal activities to different insects and pests harmful to mankind. The major alkaloid piperine was more toxic than pyrethrine, a standard insecticide, to house flies (Harvill *et al.* 1943). In many of the cases the insecticidal/repellent activity was obtained at low concentrations. Hence, this aspect of the biological activity of pepper is a very promising area which could be exploited in the field of insect control. The volatile oil of pepper was found to cause mortality to *Lasioderma serricorne* (cigarette beetle) (Samuel *et al.* 1984). The effect of the alcoholic extract of pepper was investigated by several groups and found that this was effective against cotton ball weevil, rice weevil and *Drosophila* (Su 1977, Scot and Mikiben 1978, Barakat *et al* 1985). The LD_{50} for topical application of the crude and purified extracts, obtained from 24 h dosage mortality were 3.4 μg and 4.8 μg/insect for adult *Sitophilus oryzae* and 4.5 μg and 7.2 μg/insect for adult *Callosobrunchus maculatus.* Acetone and petroleum ether extracts were also investigated for insecticidal properties by Samuel *et al.* (1984), Su and Sondengum (1980) and Su (1984). At moderate to low doses both the extracts were lethal to the storage insects like rice weevil *(Sitophilus oryzae),* pulse beetle *(Callosobrunchus chinensis)* and repellent to flour beetle *(Tribolaum castaneum)*. This was also found to be ovicidal for *Tetranychus* and toxic to the eggs of rice armyworm *(Spodoptera)*. Topical application of acetone extract caused high mortality of rice weevil, red flour beetle, cowpea weevil, lesser grain borer *(Rhizoperpta dominica)* and ricemooth (Gunathilagaraj and Kumaraswami 1979). The oleoresin, piperine and other amides were found to inflict lethality to culex mosquito *(Culex pipiens)* and also to pulse weevil (Su 1977). Piperonal, piperine, piperoline, pellitorine, pepercide and dihydropipercide also were investigated by Miya Kado *et al.* (1979), Masakazu *et al.* (1980) and Desmukh *et al.* (1982) and found that all these pepper amides possess good insecticidal activity towards pulse beetle, rice weevil, and *Drosophila* (growth inhibition of larva). The larvicidal activity of the acetone extract of pepper on *Anopheles subpietus* larvae was shown by Desai *et al.* (1997). The larvae showed 100 per cent mortality within 24 hours at 80 ppm.

CONCLUSIONS

Pepper is an essential ingredient in the Indian system of medicine, but plays no role in the allopathic or modern medicine. Only in China a compound from pepper is widely used for treatment against epilepsy in hospitals. Pepper and pepper components to be useful in modern medicine, there is a long road to travel. Recently a U.S. firm has taken a patent for the use of piperine for enhancing the bioavailability of drugs. Compound formulations with piperine will be more readily absorbed and hence will be useful in oral drug formulations. Further pharmacological studies are needed to asses the biological effects of various pepper constituents.

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9.2. END USES OF BLACK PEPPER

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Black pepper is one of the few spices having multiple uses-in processed food industry, in kitchen, on the dining table as the only spice always supplied, in perfumery and allied industries, in traditional medicine and even in beauty care. Pepper is valued for its pungency and flavour, the former due mainly to the alkaloid piperine and the latter to the volatile oil present. The oil consists of a large number of compounds, so the flavour is the total effect of all of them. The food processing industry makes use of the various ingredients (piperine and oil) either alone or in combination. The oleoresin extracted through solvent extraction contains both pungency and flavour components and hence is used as such in processed food industry. Considerable advances have been achieved in the field of value addition of black pepper and diversification of processed pepper products. Such value added pepper products may be classified into three major groups: (i) Green pepper based products (ii) Black and white pepper based products (iii) Pepper by-products. Pruthi (1997) lists the following products.

A. Green Pepper Based Products

1. Canned green pepper in brine
2. Bottled green pepper in brine
3. Bulk packaged green pepper in brine
4. Cured green pepper (without any covering tissue)
5. Frozen green pepper
6. Freeze dried green pepper
7. Sun dried or dehydrated green pepper
8. Green pepper pickles in oil/vinegar/brine
9. Green pepper mixed pickle in oil/vinegar/brine
10. Green pepper flavoured products
11. Green pepper paste

B. Black and White Pepper Based Products

12. Black pepper powder
13. White pepper powder

14. White pepper whole
15. Pepper oleoresin
16. Pepper oil
17. Other pepper products
18. Bye-products from pepper waste
19. Other forms of utilization—medicinal, culinary, industrial

The Pepper Marketing Board of Malaysia (PMBM) has made some pioneering efforts towards product development based on pepper. Pepper do not figure much in Malaysian cuisine (infact in most oriental cuisine). The PMBM as well as the private industrial houses have come up with many innovative pepper products (Fig. 9.2.1a,b). In order to facilitate planning, product development of black pepper has been structured by PMBM as follows (Abdullah 1997).

Pepper products

Whole black pepper in retail packs for table use, ground pepper in retail packs and dispensers.

Pepper based products

Flavoured ground pepper such as lemon pepper, garlic pepper, sauces and marinades that have pepper as the main component, pepper paste.

Spice mixtures and blends

Curry powders and spice blends for specific cuisines (such as five-spice powder, soup blends, etc.)

Pepper flavoured products

Pepper mayonnaise, pepper tofu, pepper cookies, pepper keropok (Prawn or fish crackers).

Products using pepper extracts

Pepper candy, pepper perfume, etc.

Other uses (Auxilliary uses)

Paper from pepper stalk, use of pepper stalk for growing mushrooms, etc.

Common Black Pepper Products

Ground pepper

The most widely used form of pepper is the ground pepper or pepper powder, and this is the only form in which it is used on the dining table. Ground pepper is also the only

Figure 9.2.1a Pepper products from Malaysia.

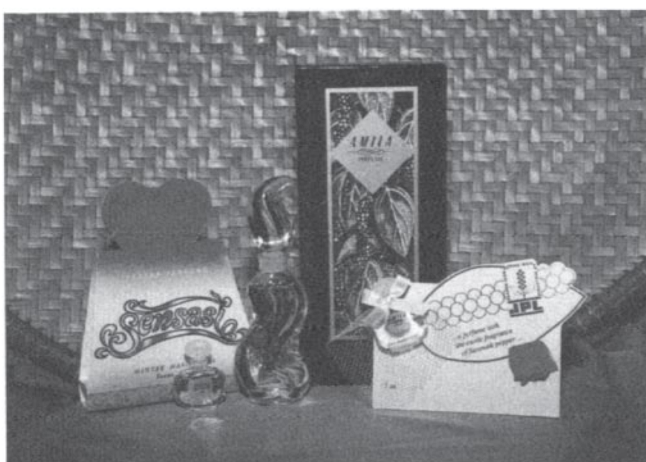

Figure 9.2.1b Perfumes Amila and Sensai with the exotic fragrance of Sarawak pepper.

spice served along with food in flights and fast food restaurants. It is used for seasoning food before, during or after cooking. Though ground pepper is the easiest product to manufacture and market, the following factors have to be taken into account:

* Microbiological cleanliness-freedom from bacteria and moulds should be ensured.
* Volatile oil content should not be affected significantly during the grinding process.
* Moisture level should be kept minimum—as high moisture will affect the storage life.

* Particle size should be optimum to ensure free flow for the duration of its shelf life and during the use period.
* Packaging has to be air tight and safe and retail packs must be of a suitable material that can prevent deterioration.

The product should be free from foreign matter, clean and packed in materials that can ensure safe shelf life.

Flavoured pepper

The Pepper Marketing Board of Malaysia (PMBM)has developed flavoured pepper powder such as lemon pepper and garlic pepper. Lemon pepper contains powder of lime or lemon, salt and pepper powder. This product can be used as table condiment or in kitchen to flavour salads, sandwiches, chicken, fish etc. Garlic pepper is a blend of pepper powder and dried dehydrated garlic powder.

Pepper sauce

PMBM has developed a pepper sauce that can be used as marinade for steaks, and other meat dishes and for stirfrying. This product uses black pepper, soybean extract, garlic and other ingredients to get a relatively mild dark sauce. Pepper is also an ingredient used extensively in a variety of related products such as the Worcestershire sauce, mayonnaise and various salad dressings in sauce, where pepper is used either in ground form or as oleoresin and oil for added flavour.

Spice mixtures and blends

Spice mixtures and blends are extensively used the world over for continental and various regional cuisines and pepper is an essential ingredient in such mixtures and blends. Spice mixes meant for a variety of dishes-such as for various meat, fish, vegetable preparations-are available in the modern supermarkets. Soup mixes have also been developed which contain pepper.

Pepper flavoured products

PMBM as well as private industrial houses have developed a variety of pepper flavoured products such as pepper flavoured mayonnaise, egg tofu, savoury pepper cookies, traditional biscuits with pepper flavour, pepper flavoured prawn and fish crackers (Keropak), etc. Infact many traditional dishes and snacks can be improved with enhanced flavour and taste by the addition of pepper. Pepper flavoured vinegar and pepper salt are also excellent products for kitchen use.

Pepper in manufactured foods

The food industry is the largest user of pepper. All meat and fish products invariably use pepper for seasoning to give both pungency and flavour. A wide assortment of ready made foods-soups, pickles and a variety of other products use pepper extracts or powder. In the oriental pickles whole green pepper is often an ingredient.

Pepper beverages

Pepper is used to flavour certain beverages and liquors such as pepper tea, coffee, pepper flavoured milk, pepper drinks such as Rasala, etc. Piperine and pepper oil are added to certain liquors such as some brands of brandy to impart a pungent taste and an exotic flavour.

Pepper perfumes

In perfumery the volatile oil from pepper can be used to impart a spicy, exclusive, oriental note. Some of the brands containing pepper oil are Revlon's "Charlie", Christian Dior's "Poison" and the perfumes developed in Malaysia—"Sensai" and "Amila" (Ng 1993).

Green Pepper Products

Immature or partly mature pepper fruits are used for the manufacture of various green pepper products such as green pepper in brine, oil/vinegar, desiccated green pepper, freeze dried green pepper, green pepper paste, etc. Most of the green pepper products are used by the catering sector to be served with meat dishes such as steaks and porks and by the food manufacturing industry in a variety of food products including certain types of cheeses.

Pickled green pepper and pepper spike

Tender spikes and fruits alone or in combination with tender cardamom pickled in vinegar and salt or sugar make delicious dishes.

Green pepper paste

Green pepper paste in polypack and in bottles is common now in supermarkets. This can be used in place of pepper powder and the green pepper paste gives a more refreshing taste and flavour to the fish and meat dishes, and is a welcome addition to the arsenal of the expert cheff.

Pepper Byproducts

In Malaysia, trials have been carried out successfully for the use of pepper stalks in the manufacture of handmade paper and board. It has been reported that good quality boards can be prepared from pepper stalk having unique texture and colour pattern, suitable for special uses such as invitation and greeting cards (Ng 1993). Pepper stalk is also shown to be a good substrate for the cultivation of oyster mushroom when grown in 1:1 mixture of pepper stalk and shredded paper (Siti Hajijah and Bong 1993).

In Malaysia the remains of the pepper processing industry-consisting mainly of the stalk and pericarp—are powdered and are being used as an organic manure (called pepper dust) either alone or in combination with other agricultural wastes, this is recommended for enriching the soil as mulch (Ng 1993).

PEPPER IN TRADITIONAL MEDICINE AND HEALTH CARE

Pepper is one of the most important and unavoidable drugs in *Ayurveda, Unani* and *Sidha,* the Indian systems of Medicine. It is used as single drug or in combination with long pepper *(Piper longum)* and dry ginger *(Zingiber officinale)* the combination is popularly known as *"Trikatu"*—the three acrids which cures the three disordered humours-*Vata, Pitta* and *Kapha* and helps to maintain normal health.

Maricham, the Sanskrit word for pepper literally means that which facilitates numbness of the tongue (*"Mriyate Jihwa Anena Iti Maricham"* i.e. the pungent property of the drug obstructs the sensory nerve endings of the taste buds). It also has the property of dispelling poison *("Mriyate Visham Anena")*. The various Sanskrit synonyms of the drug given in ayurvedic texts of India describe its characters and different uses. According to these classics, pepper is pungent and acrid, hot, rubefacient, carminative, dry corrosive, alternative, antihelminthic and germicidal. It promotes salivation, increases the digestive power, gives relish for the food and cures cough, dyspnoea, cardiac diseases, colic, worms, diabetes, piles, epilepsy and almost all diseases caused by the disorders of *vata* and *pitta*. Pepper is prescribed in cholera, flatulence, diarrhoea and various gastric ailments. It is employed as antiperiodic in obstinate fevers, particularly malarial fever, as an alternative in paraplegia and arthritic diseases, as an aromatic stimulant in cholera, weakness following fevers, vertigo, coma and as a stomachic in dyspepsia and flatulence. An infusion of pepper forms a useful stimulant gargle in relaxed sore throat, hoarseness, toothache and inflammation. Pepper is useful in diseases of the spleen, pain in the liver and muscles, leucoderma, lumbago and paralysis. In obstinate intermittent fever and flatulent dyspepsia, 7 gms of pepper is boiled in 1.5 kg of water until it is reduced to its quarter, allowed to cool during the night and taken in the morning. Externally it is valued for its rubefacient properties and as a local application for relaxed sorethroat, piles, alopacia and some skin diseases. Pepper is esteemed as a digestive tonic and is believed to be diuretic, emmenagogue and a good stimulant in cases of bites of venomous reptiles.

While explaining the properties and mode of preparations of different food articles to be used regularly to maintain normal health in the *Anna Swaroopa Vijnana,* Vagabhata advises to use pepper as a dietary adjuvant. It is used as an aromatic appetising agent in the preparation of vegetarian and non-vegetarian food. It helps proper digestion without upsetting stomach. *Ayurveda* prescribes pickles made of tender fruits of pepper with lime juice and salt.

There are many other popular therapeutic preparations using pepper. According to Charaka, powder of pepper mixed with honey and ghee kept on the tongue and dissolved slowly in the mouth relieves all kinds of cough. Water boiled with pepper powder is a remedy for chronic dysentery. According to Vagabhata, it is effective against night blindness; a paste made with black pepper and buttermilk is recommended for external application. Administering pepper powder with butter removes oedema in children. Undernourished children gain strength by taking this paste regularly.

A combination of pepper, milk and oil called *Marichadi tailam* applied externally is effective in curing rhinitis or coryza. An ayurvedic combination called *Sheetajwari Kashayam* with the same recipe is prescribed for internal use in different types of intermittent fevers. Pepper is a major ingredient in many other preparations like *Jeerakadi Kashayam, Vilangadi Kashayam, Nayanamrithavarthy* etc. which are administered in fevers, eye diseases etc. respectively. Externally it is applied to boils in the form of paste, relaxed sore-throat, piles, alopacia and other skin diseases. Rubbing the scalp with a mixture of pepper, onion and salt will make the hair grow again upon the bald patches caused by ringworm. Traditionally it is claimed to have excellent value in conditions simulating malaria and also considered to be a prophylactic for malaria. Five fruits of pepper along with ten *Tulsi* leaves chewed occasionally is advised for malaria. Indigenous practitioners use it in appendicitis, cholera and elephantiasis: 2–5 gm powder or 10–15 ml decoction along with 20 ml. honey is advised to be taken twice daily in such cases. Pepper powder mixed thoroughly with honey, ghee, sugar/ jaggery and lime juice is an effective treatment for intermittent fever. A decoction made by boiling pepper, *Tulsi* leaves *(Ocimum tenuiflorum)* and dry ginger is a very popular remedy for common cold, cough and influenza. A paste of pepper with milk is applied externally against itching and skin diseases. Fumes of pepper are made to be inhaled by epileptic patients during convulsions. Pepper powder mixed with fresh ghee and taken internally cures itching due to skin diseases on fingers, knees, hips etc.

White pepper is specially used in eye diseases. It is recommended as a tonic and used in toxic conditions more than the black variety. Pepper is also found useful in beauty and body care. It is a tightener and toner, helps curing acne and cares for hagged and sallow skins. It activates blood circulation and stimulate follicles (Bhandari 1989).

There are a number of home remedies in India known to grandmas using pepper, which are highly effective and rather inexpensive.

a) Milk boiled with pepper powder and sugar-candy and taken at night after dinner will facilitate better assimilation of food and thereby formation of *Rasadhatu,* the first body tissue directly formed from the essence of food.
b) For cataract, itching in the eyes etc., pepper ground in the juice of tamarind leaves is applied in the eyes.
c) For severe headaches, pepper paste prepared in water is applied on the fore-head. Application of the same paste on eyelids eliminates inflammation.
d) Black pepper powder with honey and saliva of horse applied on eyes is a good remedy for hypersomnia.

e) Powder five to seven black pepper and mix with half a teaspoon of butter and one teaspoon of honey. Place the paste in the mouth and chew it while swallowing saliva. This is repeated daily on empty stomach for a period of two to three months. This treatment will clean the circulatory system and also coronary blood vessels.
f) After frying well three or four leaves of pepper plant in gingelly oil, kept it over the vertex in luke warm condition. After an hour the leaves are removed and oil is wiped off with dry cloth. By this application, congested cold and neuralgic pains are completely removed and nose is cleared enabling normal breathing.
g) Powder of black pepper boiled with gingelly oil and applied to the head before bath prevent the attack of coryza and neuralgic pain,
h) The fresh stem of the pepper plant heated over a hearth or steam and the juice extracted and mixed with a little salt and used as an ear drop in the luke warm state cures ear ache and heals oozing from the ear.
i) Two teaspoons of black pepper powder and one teaspoon of cumin powder are boiled in a litre of water. After the volume is reduced to half a litre, add juice of one or two lime and little salt for taste. Flavour them with a few curry leaves and mustard seeds. This drink, which is most relishing and carminative, removes all sorts of neuralgic pains and colds and is useful in all debilitated conditions even during and after fever,
j) A mixture of black pepper powder, curd and jaggery is given orally against sinusitis and rhinitis at the initial stage,
k) Grind 3 gms. of black pepper with the juice of *Tulsi (Ocimum tenuiflorum)* leaves. Take it repeatedly to eliminate cough and sputum. A very small dose of this may be given to children for the same effect.
l) Take the paste of black pepper powder, honey or sugar candy and butter daily to eliminate chronic cough,
m) Toast one spoon of black pepper and grind with *Tulsi* leaves., boil the paste with one cup of water and allow to cool. After sweetening, drink the liquid thrice a day for stimulating digestion,
n) Take equal parts of black pepper and ginger and boil with eight glasses of water. Reduce the volume and take 1 or 2 spoons of this extract with honey 2 or 3 times a day to control several types of fever,
o) Grind a few black pepper corns with one teaspoon of saltless butter. Take this preparation in small repeated doses against food poisoning, vomiting and diarrhoea.
p) Pepper in combination with *Cissampelos pareira* has been claimed to be useful in birth control when given immediately after delivery (Tiwari *et al.* 1982).

The above are a few of the varied uses of pepper. As the world of medicine is now accepting the natural product to be safe in treating diseases, there is every possibility that pepper will see further heights as a valuable remedy for many illnesses.

PEPPER IN COOKING

Pepper is today an indispensable ingredient in cooking and occupies a proud place in the cuisines of both East and West. It is used practically in all types of curries, meat and vegetables and most of the fish preparations. The consumer preference for pepper corns is more among the Western people as they relish the presence of pepper in every meal either in ground form, as dried corns or as green pepper (in all cooking and catering literature the world “pepper corn” is used to designate dried black pepper). But it all started in the Indian cuisine, which is one of the richest in the world, being a diverse amalgam of Portuguese, Dutch, French and English cultures. Indian cookery is an art in itself. In every Indian kitchen, pepper plays a versatile and mobile role in the spice box, which contains in its slots, other spices like turmeric, cardamom, cinnamon bark, chillies, cumin, mustard, etc. Pepper is always used in the kitchen to correct or improve a made dish and sometimes directly shifted to the dining table in a fresh ground form. Pepper powder is the only spice served on the dining table, and in flights and fast food restaurants. The most insipid dish can be made sensorilly attractive by a subtle blend of flavouring and seasoning, especially with the pungent taste and spicy aroma of pepper. This goes well with the Indian vegetarian cooking style, which is a number of styles tied together with multitude of herbs and spices. In Western cuisine, black pepper finds use in the preparation of clear soups, cream cheese dips, in most of the savouring dishes and in some cakes and biscuits. Whole pepper corns are added to certain meat dishes, fish preparations, soups and pickles, while ground pepper finds use in salads, eggs and gravies. In addition, pepper is indispensable in making the universally popular salad dressing, viz. the French dressing. In Indian cuisine, pepper is also an essential ingredient in *garam masala* or curry powder, which is a blend of dried and powdered spices, used as such or in combination with other seasoning. Moreover, in most of the households in Kerala and Western Karnataka, spikes of green pepper are used in a number of dishes.

The following is a list of well-known dishes, wherein pepper is used as one of the essential ingredients.

Beverages

Pepper tea, pepper coffee, rasala, pepper milk shake, spicy watermelon juice.

Pickles/Chutneys

Pickled cherries, pickled port of beef, pepper spike pickle, coconut chutney, fresh coriander chutney, green pepper chutney.

Sweets and Snacks

Quick banana pudding, pepper biscuits, vegetable crispies

Soups

Mushroom soup, mixed vegetable soup, cream of vegetable soup, clear dal soup, etc.

Meat dishes

Pepper steak, black pepper pot roast, black pepper fried chicken (and in most other meat dishes).

The recipes of some of these delicious items are given below:

Pepper tea

Pepper corns (12 crushed pepper corns for two cups of tea), sugar and milk to taste.

Method: Put water to boil, when it is just hot, add pepper, pour the boiling water over tea and stir well, after 2 minutes, strain, add sugar and milk to individual taste.

Pepper milk shake

Milk—500 ml, Sugar—10 teaspoons, pepper corns (Finely powdered—10), cashew nuts (finely cut & fried—12).

Method: Boil milk and sugar stirring for about 20 minutes until it thickens a little; chill, garnish with pepper powder and cashew nuts before serving. This can be served hot also.

Pepper spike pickle

Green pepper spike—1 kg, vinegar—500 ml, garlic—1 (big), green chillies—10, ginger—2 inch piece, salt—½ cup, turmeric—1 teaspoon, oil—2 tablespoons.

Method: Wash the pepper spikes, wipe, and sprinkle over with salt and set aside for sometime. Peel and slice garlic and ginger, slit green chillies. Heat oil, add garlic, ginger and green chillies, remove pan from fire, add turmeric, stir well, add vinegar and salt. Bring to boil, remove, cool and add prepared pepper spikes. Pack and store in air tight jars.

Pepper biscuits

Wheat flour—3 cups, salt—1½ tea spoon, baking powder—1 teaspoon, fat—4 tablespoons, pepper—1 teaspoon, water—1 cup (slightly less), sugar—1½ teaspoon.

Method: Sieve wheat flour and baking powder; add salt and freshly powdered pepper; add fat and water and knead into a smooth dough, cool and cut into biscuits and bake till light brown.

Note: These biscuits can also be deep fried. Addition of one teaspoon of dry ginger and one tablespoon of sugar and substitution of half the water with milk can also be done.

Mushroom soup

Mushroom—100 g, onion—200 g, milk—400 ml, water—600 ml, cornflour—10 g, butter—20 g, tomato—50 g, pepper powder—5 g, nutmeg powder—5 g.

Method: Chop onions and mushrooms and roast lightly in butter in a pan, cut tomato in boiled water for three minutes; peel the skin, smash it and strain; mix water and milk together, and boil; mix corn flour in slightly hot milk and add to the boiling milk in low fire, add roasted mushrooms, tomato juice, pepper and nutmeg powder and stir. When it starts thickening, remove from fire.

Pepper steak

Rump steak—225 g, black pepper corns to taste, salt, potato chips, broccoli and cabbage.

Method: Take steak out of refrigerator well in advance of cooking it. Rub fat in several places to prevent steak curling up as it cooks. Crush pepper corns coarsely in a mortar, pat pepper corns firmly on both sides of the steak and leave for 30 minutes at room temperature to develop flavours. Light grill at maximum temperature and heat for 20 minutes before cooking. Grill steak. Transfer to a hot plate, sprinkle with salt and serve immediately. Garnish with potato chips, broccoli and cabbage.

Pepper pot roast

Bottom round of beef—2 kg, tomato paste—180 g, bay leaf—1 small, pepper corns—1½ teaspoon, salt—1½ teaspoon, minced onion—1 teaspoon, ground pepper—½ teaspoon, potato—8 small, carrots—6 medium.

Method: Brown meat on all sides in heavy kettle, add tomato paste, 1½ cups water, bay leaf, whole pepper, salt and minced onion. Cover and simmer three hours, basting frequently. Add ground pepper, potatoes and carrots, continue cooking 30 minutes until meat in tender.

Pepper fried chicken

Chicken—1 broiler, milk—1 cup, ground pepper—2½ teaspoon, flour—1½ cup, fat for deep frying milk (for gravy)—1¾ cup, salt to taste.

Method: Place chicken in a shallow dish. Combine one cup milk, one teaspoon ground pepper and ½ teaspoon of salt and pour over chicken. Cover and refrigerate for two hours. Combine ½ cup of flour, remaining pepper and salt. Cut chicken and coat with flour mixture and refrigerate again for one hour. Cook chicken in deep fat for 15–20 minutes until brown and tender and set aside.

Make cream gravy the following way: Place ¼ cup of fat for deep frying on a saucepan. Blend in ¼ cup for flour, add milk till medium thick, stir and cool. Add salt and pepper (remaining ½ teaspoon). Add gravy to fried chicken pieces and serve with naan or chapathi.

Commercial Formulations

Many commercial formulations of pepper like white pepper products, green pepper, canned green pepper, green pepper in brine, pepper oil, pepper oleoresin, etc. are readily available but are still to find consumer acceptability in the market. The latest spices processing technology which involves encapsulation of the flavouring component viz; spice oils and oleoresin is ready for commercial exploitation.

White pepper

White pepper is preferred to black pepper in some Western countries. It is used as table pepper and also for cream soups, white pickles and sea food salad, casseroles of chicken, egg, fish, etc. It is also used as an ingredient in sauces like mayonnaise and white sauces when the black specks from the skin of black pepper is unseemly.

Green pepper

Green pepper products have now become a favourite in France, Germany and other European countries. Slightly immature corns are preferred for preparing various products due to its high piperine and pepper oil level, which give a biting taste and characteristic flavour along with softness. These qualities make it ideal for garnishing meat dishes. The major products include green pepper in brine, canned green pepper, dehydrated green pepper, freeze dried green pepper, green pepper paste, etc, as mentioned earlier. Canned green pepper is not much popular, due to, its high cost of processing, while the consumer acceptability of green pepper in brine and pepper paste are ever on the increase. Brazil, India and Malaysia are the major producers of these products. Most of the green pepper is used by the catering sector to be served with meat dishes such as steaks and by the food manufacturing industry in a variety of food products including certain types of cheeses.

Pepper oil, oleoresin and encapsulated flavours

The largest use of pepper oleoresin is in flavouring meat. The other end uses are for preparing pickles, sauces, gravies, dressings, chutneys, soups and snacks. Meat is being prepared in most of the countries as a neutral product and pepper has been a traditional ingredient in giving it a flavour. Thus oleoresin goes for the same end use as pepper.

The spray drying technique developed by RRL Thiruvananthapuram, India for encapsulation of oleoresin is a newly emerging technology. The encapsulated flavour powder is used in a variety of products such as dry beverage mixes, cake mixes, infant desserts, soup mixes, dusting on potato chips, nuts etc.

CONCLUSION

Just by looking at the varied uses of pepper, one realises that pepper indeed is the king of spices. No other spice—in fact very few crops—can be put into so many uses—both in the area of cooking and health care. Further efforts in product development may open up new vistas in pepper uses. At least in the orient there is a visible shift towards herbal medicines in health care and pepper, no doubt, going to play an important role in this area. One thing is definite—Pepper is going to be the king of spices for many more decades to come.

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10. FUTUROLOGY OF BLACK PEPPER

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THE BACKGROUND

Area under pepper cultivation ranged from 3.71 to 4.04 lakh ha during 1992–96 in ten major producing countries with India leading (1.84 to 1.98 lakh ha) followed by Indonesia (0.98 to 1.29 lakh ha) and Brazil (0.21 to 0.35 lakh ha). These ten major pepper producing countries are Brazil, India, Indonesia, Malaysia, Thailand and Sri Lanka [International Pepper Community (IPC) countries]; Vietnam, China (P.R.), Madagascar and Mexico (Non IPC countries). The other countries where pepper is grown on a lesser scale are Cambodia, Brunei Darus (Asia and Pacific Region), Fiji, Samoa, Micronesia (South Pacific Region), Mexico, Guatemala, Honduras, St. Lucia (Latin American Region); Malawi, Zimbabwe, Benin, Kenya, Cote di Voire, Cameroon, Ethiopea and Zambia (Africa Region). The total global production ranged from 1.76 to 2.39 lakh tonnes during 1991–1996 with an average annual production of 2.00 lakh tonnes. The rate of growth in area is 0.97 per cent in the IPC countries with the highest growth rate in Sri Lanka (6.68%) followed by India (1.75%). The rate of growth in area is more in the non IPC countries (8.70%), more pronounced in Vietnam (17.63%) followed by China (P.R.) (14.50%). There is significant reduction in area under pepper in Thailand (5080 ha during 1990, 2390 ha during 1996), Malaysia (11250 ha during 1990, 8800 ha during 1996), and Madagascar. There is remarkable decrease in production in Indonesia (61,000 mt during 1991, 39,200 mt during 1996), Malaysia (29,000 mt during 1991, 12,000 mt during 1996), and Brazil (50,000 mt during 1991, 19,500 mt during 1996). The reduction in production is more pronounced in Latin American Region consisting Brazil, Mexico, Guatemala, Honduras and St.Lucia. The economics of pepper producing countries especially Brazil, Malaysia, Thailand and Indonesia are gradually moving away from Agriculture sector to Industrial sector. Pepper farming being labour intensive and labour becoming scarce and costly, the shift is mainly due to economic reasons. India is the only country maintaining or even marginally increasing pepper production over the years. New production centres are emerging in Vietnam, China (P.R.), Africa, Pacific Islands, Latin America and Caribbean Islands where the cost of labour is relatively low at present. The Caribbean island states like Guadeloupe, St. Martin, Saba, St. Eustatius, Nevis, Mom serrat, Dominica, Anguilla, St. Barts and St. Kitts are climatically suitable for black pepper cultivation. As a tropical crop, pepper cannot be cultivated in the temperate zones and these countries have to depend on countries of tropical zones for pepper. The use of pepper in addition to traditional use in food industry is also spreading to other aspects of human life like for beverages, cosmetics, perfumes, medicines, insecticides, fungicides and painting industries. The other biological advantage of pepper is that there is no replacement for pepper products. Synthetic colour and flavour are not preferred and natural product is always demanded by the food industry. Thus the demand for pepper is rising every year and pepper consumption in developed countries is also increasing.

Pepper export is a main source of foreign exchange in major producing countries like India, Indonesia, Malaysia, Brazil, Sri Lanka and Thailand. About 78.8 per cent of total production is exported on a global basis. The domestic consumption is only 23.1 per cent of total production. The export earnings of producing-exporting countries (IPC countries) from pepper total US$ 250 million per year. Asian Region consisting India, Indonesia, Malaysia, Thailand, Sri Lanka, Vietnam and China (P.R.) leads with an earning of US$ 250.9 million per year followed by Latin America Region (US$ 44.5 million) and Africa Region (US$ 4.126 million). Quantity wise, Indonesia leads with an export of 43,742 mt/year followed by India (29,894 mt/year), Malaysia (19,196 mt/year) and Vietnam (16,402 mt/year).

Pepper reaches restaurants/homes in more than 42 countries spread over six geographic regions. USA is the major importer (42,276 mt/year) followed by Germany (16,096 mt/year), Netherlands (12,393 mt/year), France (8890 mt/year) and Russia (7000 mt/year). There is also re-export of pepper from a few importing but non-producing countries like Singapore (37,281 mt/year). The re-export is mainly in packed and value added forms. The world demand for black pepper is increasing at the rate of 2.7 per cent per annum (1.85 lakh mt during 2000 AD and 2.10 lakh mt during 2005 AD).

THE PRESENT

The present state of knowledge on pepper—in all its aspects are presented in the various chapters of this volume. The following are a few points selected from this treasure house of knowledge to highlight some of the major achievments as well as gaps.

Main biotic production constraints of black pepper are *Phytophthora* foot rot, *Fusarium* wilt, stunt disease caused probably by a virus, slow decline mainly caused by the burrowing nematodes, incidence of pollu beetle and scale insects. Non biotic constraint is mainly drought. Being a vine crop demanding support, type of living or non-living standards also affects pepper productivity.

Phytophthora foot rot (quick wilt) is a serious disease and is the major cause of vine death in all pepper producing countries. Some *Phytophthora* tolerant lines are in pre release trial at Indian Institute of Spices Research (IISR), Calicut. In Malaysia one high yielding line tolerant to foot rot was released *(Semongok emas)*. The Indonesian vareity *Natar*-1 is also reported to be tolerant to foot rot.

Pepper cultivars rich in piperine, oleoresin and essential oil are in great demand. Evaluation of germplasm resulted in identifying a few high piperine and oleoresin lines as well as high oil lines. *Kottanadan, Kumbhakodi, Kuthiravally* and *Nilgiri* are rich in piperine and oleoresin, where as *Balancotta, Kaniyakadan* and *Kumbhakodi* are high in essential oil. Pepper cultivars are also categorized on the basis of piperine, oleoresin and essential oil content. Berry size is also an important criteria for pricing of whole pepper. White pepper has demand in selected markets in Europe and Japan. Indonesia has the monopoly on white pepper. Chemical quality of white and black pepper in a few selected popular cultivars has been worked out.

Drought is another production constraint in majority of pepper growing tracts in the states of Kerala, Karnataka, Tamil Nadu and Andhra Pradesh (India). Evaluation of pepper germplasm against moisture stress resulted in identifying a few promising *Karimunda* lines viz. KS 69, KS 51 and KS 114. These lines are now being evaluated for yield and other characters. Pepper lines are also collected from farmers' plots, which have shown promise during periods of severe drought. These lines are also being evaluated. Drought does not appear to be a major constraint in other producing countries.

Plant parasitic nematodes are a limiting factor in pepper production and productivity. Apart from feeding and damaging the host root system, they are also responsible for rendering the plants susceptible to attack by several fungal pathogens. *Radopholus similis* and *Meloidogyne incognita* are the primary incitants of "slow decline" disease in pepper. They along with *Phytophthora capsici* cause havoc in pepper gardens. Yield losses varied from 38.5 per cent to 64.6 per cent in *R. similis* inoculated pepper plants, alone or in combination with *M. incognita*. A cultivar *Pournami* is found field tolerant to *M. incognita*. No source of resistance to *R. similis* has been reported. From Sri Lank one line (PW14) is reported to be resistant to nematode.

Thirty four species of insects are recorded on the crop in India and many in other producing countries. Among these, *pollu* beetle (*Longitarsus nigripennis Mots.*), top shoot borer *(Cydia hemidoxa Meyr)*, scale insects (*Lepidosaphes piperis* Gr and *Aspidiotus destructor* Sign) and leaf gall thrips (*Liothrips karnyi* Bagn.) are serious in India. *Piper* taxa such as *P. colubrinum, P. betle, P. hymenophyllum., P. attenuatum, P. barberi, P. mullesua, P. arboreum, P. longum* and *P. chaba* are relatively resistant to *pollu* beetle. Some of the cultivars that have shown high degree of tolerance to *pollu* beetle are being yield evaluated.

In the area of tissue culture and biotechnology, protocols for micropropagation and callus regeneration are available now. Protoplast isolation and culture met with partial success. We have to go a long way if we want to use biotechnological techniques in pepper in any meaningful way.

Crop management technologies are available in most countries for getting high production, but their adoption level is very low in countries like India.

THE FUTURE—A CRYSTAL GAZING

The pepper production and trade in the past were growing at a rate of 2.7 and 3.6 per cent on an average respectively. Taking this as the average annual growth rate in demand, it has been estimated that the world demand for pepper will be around 280,000 mt by 2020 AD and by 2050 the demand may touch 360,000 mt. This means the present production should be doubled in the next 50 years. What are the prospects for such increases? There cannot be any substantial area increase except perhaps in China and Vietnam and marginally in India and Indonesia. Area under pepper is decreasing in Malaysia, Thailand and Brazil. The rich pepper producing countries such as Thailand and Malaysia are moving away from labour intensive agriculture and Brazil is following suite. And they are becoming more and more industrialised and pepper cultivation will decline there in the coming decades. This means that the future pepper production and trade will be controlled by India, Indonesia, China and Vietnam.

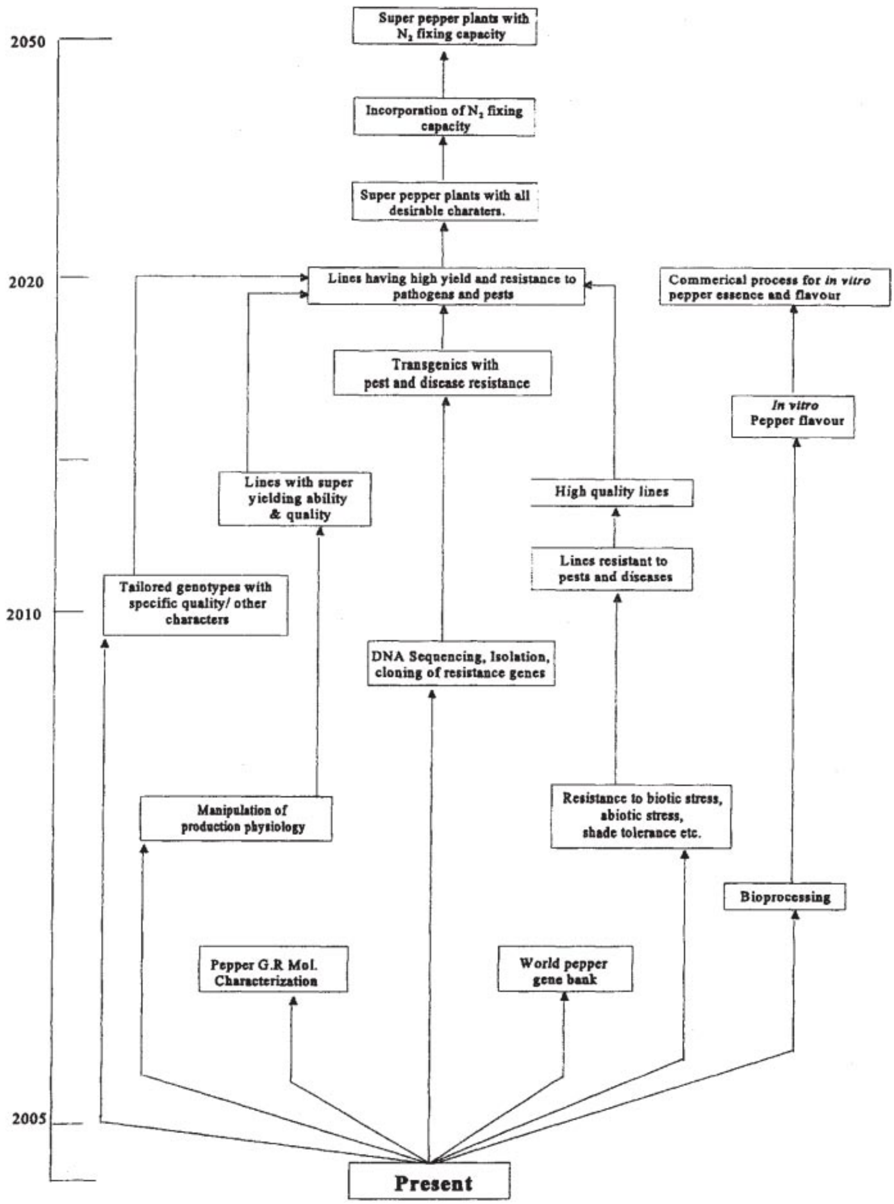
As land availability decreases in the coming decades, the countries have to depend more on productivity increase per unit area to sustain the trade. A production target, on a global scale, of 1–1.5 mt per ha is sufficient to meet the world demand from the present area of roughly 4 lakh ha. In order to meet the future challenges the R & D efforts of the countries need tuning up. In this area Indian Institute of Spices Research in India has drawn up a futuristic perspective plan. The emphasis here are:

1. Breeding high yielding, high quality cultivars that are resistant to *Phytophthora* foot rot, burrowing nematode, pollu beetle and the little leaf virus
2. Developing high yielding and disease and pest resistant cultivars that are responsive to low input and low management levels and tolerant to heat and drought
3. Evolving integrated high production technology combining both nutrient, pest and disease management
4. Evolving cultivars suitable for specific end uses
5. Collection and Conservation of genetic resources, their enhancement and characterization.

To achieve these aims, various lines of research have been indicated (IISR, 1997). These aims are equally applicable to other producing countries as well.

Looking for a Pepper Ideotype

The dream of developing a genotype having all the yield and quality contributing factors will remain a dream unless concerted efforts are made to translate the dream into reality. In the context of the 21 st century science nothing should be impossible. The pepper plant of our dream will probably have small leaves on a small statured vine, long spikes, very short internodes, high spiking capacity, regular yielding habit, bold fruits, high dry recovery, high quality, resistant to *Phytophthora, Fusarium,* nematodes, insect pests and drought, wide adaptation and capable of performing well even under minimal management (!). The crystal gazing can be raised to the level of having super pepper varieties with all the above characters and in addition having the N_2 fixing capacity. That will be simply marvellous and will be a challenging dream for young scientist to try and fulfil. Scheme 10.1 gives some of the future approaches that the scientists may persue.



Scheme 10.1 A crystal gazing chart on pepper research.

The above dreams are difficult to fulfil but not unattainable. At the center of diversity for black pepper, many genotypes having valuable genes might be existing. Intensive survey, collection and characterization (biological, chemical and molecular) can give the future pepper workers a wealth of materials for future use. Gene sequencing, now a laborious and high tech work can become much faster and simpler. The first decade of 21st century may probably witness the total sequencing of the genomes of black pepper and the resistant species *P. colubrinum*. Then the scientists can pick out and clone various genes for resistance for introduction into pepper. Production of transgenics, incorporating the needed genes from other sources can create the super pepper combining all the attributes listed above. Surely biotechnology is going to play a significant role in the years to come, and it can create a pepper plant that is immune to the dreaded diseases and insect pests and for specific end use. But then nature is very dynamic and can come up with strains adapted to parasitize our wonderful pepper plant and the race between nature and man will continue.

Human kind will become more and more health conscious in the years to come and organically grown spices will be in great demand in the coming decades. Medicinal uses of pepper are getting attention especially of piperine coated antibiotics. Pepper has a definite role in nature medicines. Biofertilizers and biopesticides will play greater roles in pepper production. Efficient and "super active" biopesticides and biofertilizers will have to be developed for this purpose and biotechnology can come to our help. Much of the pepper in the coming decades will be organically grown "clean spices". Highly potentiated VAM fungi can be created for use in pepper and this in turn will supplement the production of organically grown spices.

Scientists will unravel the mysteries in production physiology and ways and means will be evolved to manipulate the metabolic path ways, so as to develop lines having high metabolic efficiency and source to sink relationships. Genotypes with super efficiency and tailored properties can be created and pepper plants can be modified into a programmed factory. By mid 21st century we can hope for such a pepper plant having even the N_2-fixation capacity incorporated in it!

The future will witness remarkable advancements and diversification in the field of post harvest technology and product development. Imaginative product diversification efforts will lead to lots of entirely novel products for the consumer market. High flavour and low pungency pepper type will be used to flavour a variety of liquors, milk, fruit juices, sweets, various processed foods and bakery items and thus pepper will continue to reign supreme in the world of spices.

In another area, advances in bioprocessing can one day create *in vitro* produced pepper flavour. May be the next generation will witness harvesting pepper flavour from bioreactors. If this process is turned out to be cheap, the pepper cultivation may be in jeopardy. But human preferences for "natural spices" and "clean spices" may not, let us hope, make such a thing happen.

Science is advancing to areas hitherto unknown and today's dreams are tomorrow's realities. Let us hope and try to translate some of these crystal gazings into realities in the years to come. Anyone involved in this work will be reminded of the beautiful lines of Robert Frost:

"..........The woods are lovely dark and deep
But I have promises to keep
And miles to go before I sleep
And miles to go before I sleep........"

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11. CONCLUSIONS: CONSTRAINTS AND YIELD GAPS IN BLACK PEPPER

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Pepper is not cultivated intensively in India, probably because this is a crop that has evolved with the people of the region and its cultivation is taken rather casually. "Plant and forget" has been the policy of most growers. Efficient agrotechnology has not been evolved to suit the major production systems or areas and there are serious production constraints. Many of the constraints indicated here may be equally applicable to other pepper growing countries as well.

CONSTRAINTS

Technological Constraints

An efficient and dynamic research back up is required for increasing and sustaining productivity of any crop, pepper is no exception. The following research gaps affect adversely the production and productivity of pepper.

i) *Area and climate specification*
Areas having ideal soil and climatic factors for pepper to achieve high productivity have not been demarcated. Based on climatic and soil factors attempts should be made to demarcate areas not conducive for establishing pepper gardens. This will pre-empt the spread of pepper to areas of low productivity, avoiding losses to growers and locking up of precious land in unproductive farming.

ii) *Nutrition and nutrition management*
No information is available on the nutritional requirements for major production areas, or cropping systems or soil types. There are more than one dimension to this constraint:

a) Little is known on the optimum nutrient requirements for pushing up the yield level in the major pepper growing areas like Idukki and Wynad.
b) Nothing is known on the effects of increasing the number of applications from the present two to 4–5 splits, starting from June, though the cloudy weather and continuous rains in June–July can be negative factors here.
c) Ironically the present fertilizer recommendations have come out of trials from non-representative areas and from monocropping. Even in these cases only NPK requirements are given, neglecting totally the other elements. In India, pepper is

grown mostly as a mixed crop or intercrop, and nutrient management for such systems are not available.

d) Drought, together with the harvest operation, imposes a stress on the plant. A dose of fertilizer followed by a couple of irrigation will save the plant from this stress. Moreover, currently, fertilizer application starts only after getting the monsoon rains. By that time the floral differentiation might have already advanced; so that at the time of floral bud initiation the plant faces a nutrient stress. This in turn affects the spike production and yield. A dose of fertilizer after the harvest followed by irrigation ensures adequate nutrient concentration at the time of floral bud formation. But, there are other practical problems here,—nonavailability of labour, higher input cost, acute scarcity for water for irrigation etc. At the same time if information is available, the same may be useful to situations where the above problems do not exist.

e) The present fertilizer schedules are blanket recommendations without taking into consideration the inherent fertility status of the soil. Now, the growers or the extension workers do not know what should be the fertilizer schedule in an area with a particular mean fertility level. Such fertilizer schedules are available to growers is Brazil and Indonesia.

f) What is the fertilizer required to produce one kg of pepper? The recommendations are optimum levels for giving a reasonably high-yield. But if a grower is prepared to invest more for getting higher yield, he has no choice and little is known in this line. The only information available (Anon. 1996) has come from some preliminary studies from KAU. According to this, additional nutrient requirement for an increase of one kg of pepper is 6.35 g N, 6.33 g K, 1.18 g Ca, 0.47 g Mg, 0.44 g P, 0.29 g S, 42.82 mg Fe, 34.45 mg Mn and 4.2 Zn. This requires verification under field testing in different locations, together with aspects like lime requirement.

g) In India, various live standards are used for trailing pepper, and here, unlike in the case of nonliving standard, there is an interaction between the pepper-standard root systems. This interaction differs depending on the type of standard. Evidently a single fertilizer schedule is not applicable in all these cases. Separate schedules for major pepper—standard combinations are needed to manage the yield levels under such systems.

h) The area of micronutrient nutrition is totally neglected by the pepper agronomists in India. The yield reduction caused by micro nutrient deficiency has not been assessed so far.

iii) *Varieties*

No research work has gone in for developing location-specific varieties. As a result the same varieties are grown in all regions irrespective of their adaptability. High yielding varieties, ideally suitable for various regions and different cropping patterns can help boost up the yield of pepper.

iv) *Diseases and insect pests*

The most serious constraint facing pepper production is disease. The foot rot and slow decline diseases have caused wide spread damages, dipping the productivity to very low levels. No effective management strategy exists. Integrated management—integrating cultural, chemical and biological controls—seems to be useful in reducing but not eliminating the incidence of these diseases, and not supported by published results from large scale trials. Disease still continues to be the major constraint.

Cultivars resistant to foot rot and slow decline (pepper yellows) do not exist, though tolerance to *Phytophthora* foot rot has been claimed in certain instances, but in such cases their field performance and adaptability have not ben ascertained so far. Management of burrowing nematode is also difficult, though biocontrol agents do help to some extent. The little leaf disease, caused probably by a strain of Badna virus is becoming a major threat, seriously limiting productivity.

Insect pests-especially pollu beetle, which is endemic to India—can cause high crop loss, up to 40–45 per cent in certain cases in plains. Two rounds of sprays at the correct stages of flowering and fruit development are required to control this pest, but this practice is not followed by growers due to a variety of reasons. Efficient, alternate biological control measures are to be developed.

v) *Drought*

Along with diseases, drought is creating havoc to pepper gardens in many areas. A three year study in one district, has put the total loss to 43 per cent plants due to the combined effect of drought and diseases (Prabhakaran 1994).

The acute scarcity for drinking water in major pepper areas of Idukki, Wynad and Kannur districts, as well as in many other areas, rules out the possibility of irrigating the crop. Developing drought tolerant, high yielding lines is the only solution, no such variety exists right now, though a few tolerant lines are under evaluation.

vi) *Degraded soil—living plant*

Tropical evergreen forest soils are notoriously poor in nutrients, and that sustainable crop production is not possible in such soils for more than a short period. One study indicates that the sustainability of a tropical evergreen forest soil is only for a short span of three years, in comparison with 65 years in temperate prairie and six years in a tropical semi arid thorn forest (Tiessen *et al.* 1984). The soil system in the Western Ghat forests is very fragile; with high rainfall, steep gradients, a maze of rivulets, all leading to massive soil erosion. In fact, soil systems in most pepper growing areas are so degraded and are incapable of sustaining the productivity. All major pepper plantations are developed in the high range hill slopes, where soil erosion is rampant. No effort has ever been made to understand the nature and extent of damages caused, and nothing is being done, even now, to prevent the havoc. Thus, most pepper growing soils are in a state of degeneration or degradation and rapid decline of pepper in such soils are inevitable. Introduction of a vigorous organic farming programme coupled with soil conservation is essential to save the pepper growing soils.

Socioeconomic Constraints

Pepper is essentially a marginal farmers' crop, and they are economically so weak, that they cannot go in for an input intensive production programme. "Plant and forget" is their style and even the planting materials are often of poor quality. The inability of these small farmers to invest capital prevents them from adopting the recommended fertilizer and plant protection measures. They are getting little help from extension agencies and from financial institutions. Moreover many pepper growing tracts are not easily approachable. The acute scarcity for drinking water in many hilly terrains prevents them from giving life saving irrigation to young pepper vines in summer or making water available even for spraying programmes. In fact, the marginal farmers—who constitute the majority of the pepper farming community—do not get any benefit from the technological advancements made by R & D agencies.

The acute scarcity for farm labour poses another problem for pepper production. Agricultural labourers, as a class, is vanishing and in many areas harvesting of pepper poses a serious problem. Added to the scarcity is the high cost of labour. Even when the labour is available, the entire pepper crop is harvested at one time, selective harvesting of mature spikes is not done. This in turn leads to a mixture of immature, mature and ripe fruits, thereby leading to an overall reduction in quality.

Yet another facet of this socioeconomic constraint is the fluctuating market demands and prices year after year. The unsteady price levels discourages the farmers from adopting proper maintenance of their pepper plants.

The first pepper collection point from the village farmers is the village vendors. Sometimes the green pepper as such is sold to the vendors. The farmers have to take whatever price the vendors offer, they have no bargaining power at all, and no regulated market exists. Added to this the village vendors often ensnare the poor growers by advancing money for the standing crop, and they have no option but to give the product to the same vendors at throw away prices. The grower is always at a disadvantageous position. Naturally the disgusted growers pay no attention to the crop.

The Extension-cum-Educational Constraints

There is no proper, organized extension service for pepper cultivation (as it exists in the case of rubber, cardamom, coffee or tea). The government agencies existing are confined mostly to other food and commercial crops. In order to implement the much needed developmental measures an intensive and dynamic extension service is required. Even, many of the technological knowhow already available have not found their way to the farmers' fields because of this extension gap. The socially, financially and educationally backward pepper growers are to be taught about the scientific method of pepper cultivation and this requires an effective implementing agency, backed up by dynamic research programmes.

Prasad (IISR 1998) has carried out a study among pepper growers in Kerala to find out the constraints faced by them. The results of this study showed that most of the farmers belong to the low income group and the major constraints faced by them in pepper production are the following:

1. Non availability, high cost and even ignorance about improved cultivars
2. Ignorance about the package of practices for the crop
3. High labour cost and non availability of labour for various farm operations

4. High cost of organic manure (and their non availability) and also chemical fertilizers
5. Disease incidence and lack of measures to control or even contain them. Phytosanitation is costly, labour intensive and shortage or even nonavailability of materials at critical periods makes phytosanitation impractical in most cases, (except perhaps in the case of organized farmers or plantations). Added to this, continuous rains during the monsoon season—when the disease problems crop up—make spraying at the correct stage difficult. The high cost of fungicides and nematicides makes phytosanitation impossible for the poor farmers. There is also almost total ignorance among them about the various aspects of disease management
6. Poor financial status of the growers, lack of resources for adopting the package of practices.

An earlier study (Chandran *et al.* 1991) pointed out that among the various constraints facing the farmers, the inadequate and untimely supply of inputs was rated as the most frequent, followed by death of plants due to foot rot and slow decline, and nonavailability of high quality planting material of improved cultivars. Crop failures lead farmers to acute financial crisis, and they loose interest in further pursuing the crop.

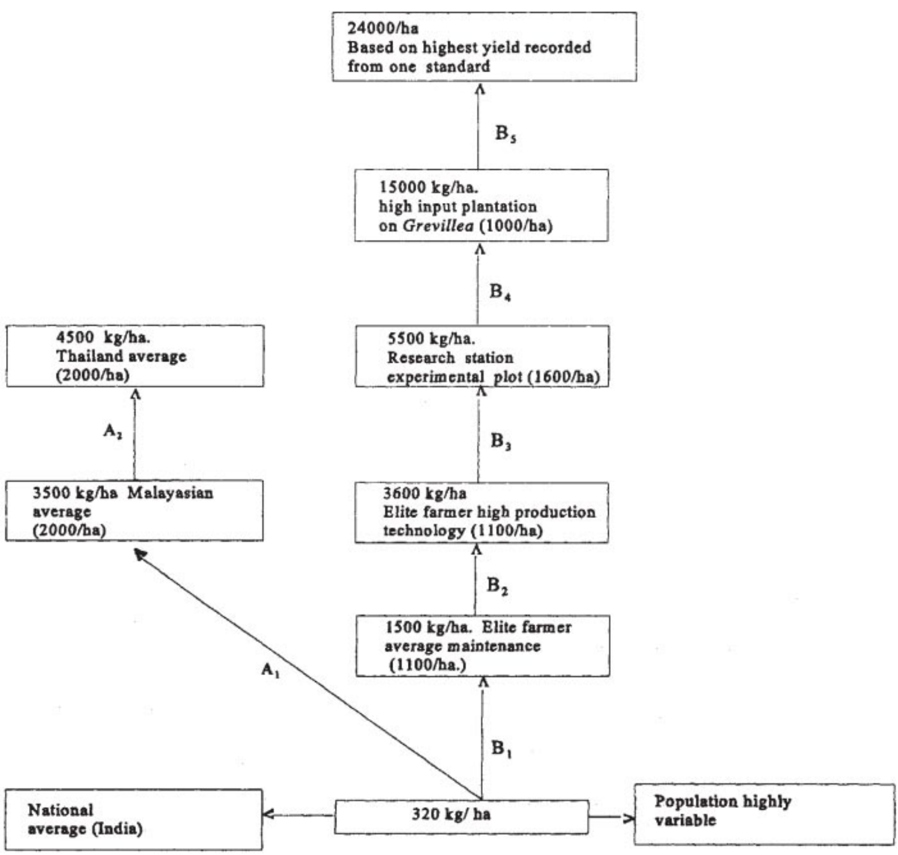
These constraints perceived by the farmers can be removed only through aggressive extension programmes for which the present extension agencies are not geared up to.

YIELD GAPS IN PEPPER

In spite of the fact that pepper has originated in Kerala (India) and that it was under cultivation for centuries, the yield of pepper in India, is one of the lowest in the world mainly because intensive cultivation practices were not in vogue, and people have been growing pepper in a casual way (plant and forget!) as in the case of many other crop plants. As a result there is a very wide yield gap existing between the productivity in India and that of other countries—320 kg/ha (India) to 4500 kg/ha (Thailand). However, there are many cases, where the yield levels have gone up considerably, touching around 50 kg fresh harvest per plant. Such high yields are possible when tall trees such as *Grevillia robusta,* are used as standards along with high yielding varieties such as *Panniyur*-I, *Subhakara, Pancbami* etc. One such case is in the private plantations under the management of M/s Consolidated Coffee Ltd, in Pollibetta, Coorg Dist of Karnataka. From one of the estates, they were harvesting regularly, on an average, 40–45 kg fresh fruits per standard, from a coffee-pepper mixed stand, where pepper is planted on *Grevillia robusta*. This yield figure works out to be around 15,000 kg/ha (dry pepper). In 1997 the harvest touched 72 kg (fresh) per standard in certain cases (private communication), when the yield touched 24,000 kg/ha (dry). The highest yield reported (142 kg-fresh), is from a *Panniyur*-I plant that was trailed on a forest tree in Manjushree estate in Gudalur (private communication). But such yields are not realisable on a unit area basis. However, this brings out the important point that pepper under good management and when trailed on tall trees, never reaches an yield plateau.

The situation is different when pepper is trailed on nonliving standard or on small trees such as *Erythrina, Garuga* or *Glyricidia,* where the height is restricted to about 3m (non living) to about 4–6 m when trailed on the above trees. Almost all small holders use one of these trees as standards. Under such situation the yield reaches a plateau in 5–6 years and then comes down after about 12–15 years. But due to the severe disease incidence many plants may not reach this stage.

At the IISR experimental station, pepper plants trailed on *Erythrina* recorded an average of 14 kg fresh in certain plots, which works out to be around 5600 kg/ha (dry). Many elite farmers have attained an yield figure of 2–3 kg (dry) per standard. Thus the gaps existing between the national average, elite farmers, research institutions and plantations under superior management are staggering (Scheme 11.1).



Scheme 11.1 Yield gaps in pepper production (Figures in parenthesis represent plants per hectare.)

Gaps A_1 and A_2 indicate the gaps existing in national average yield between India and Malaysia and Thailand. The genetic quality and production potential of the cv. Kuching of Malaysia and Thailand is much lower than that of Panniyur 1, Karimunda or Kottanadan. The use of varieties with higher production potential could easily push up Thailand's yield to much higher levels. This yield gap is essentially a technological gap-the casual way of cultivation in India vs. the intensive production technology in Thailand and Malaysia.

The gaps B_1 to B_5 are the components of the gaps existing between the national average at one end and the highest production reported from one plant on the other extreme. The average grower often gets a mean yield of 1–1.5 kg dry pepper per standard and an yield of 1500 to 2000 kg ha^{-1} is easily achievable just by following the package of practices. In many areas, farmers harvest around 10 kg fresh yield from pepper grown on *Erythrina, Ailanthus* etc. An yield level of 3300–3600 kg ha^{-1} has been achieved by the elite growers by following the high production technology. Third gap exists between the yield realized by the elite farmer and that in a research station. By using the high yielding, improved varieties, an yield level of up to 8000 kg ha^{-1} has been achieved from a population of about 1600 vines ha^{-1}, trailed on *Erythrina*. This is actually a realizable yield by using high yielding improved varieties. The final yield gap exists when high yielding varieties are trailed on tall trees such as *Grevillia robusta* under superior management. Under such a situation an yield level of 15,000–24,000 kg ha^{-1} is possible from a population of about 1000 plants ha^{-1}.

Bridging the yield gaps involves:

Use of elite, improved varieties, adoption of HPT practices (phytosanitation, balanced nutrition, pest control, appropriate cultural practices including soil and water conservation strategies etc.), use of tall standards, especially *Grevilla robusta* to obtain long columns of pepper of 10 m or more leading to an efficient vertical harvest of solar energy; alleviation of moisture stress through irrigation etc. The constraints outlined in the previous section are all important, and steps have to be taken to remove them for achieving higher production and productivity and to push up the national average to the levels of that of Malaysia or Thailand and even to levels far higher than that.

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12. OTHER ECONOMICALLY IMPORTANT SPECIES OF *PIPER*

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Though black pepper (*Piper nigrum* L.) is the most important species in the genus *Piper,* there are a few others having great economic importance. They include the betel leaf *(P. betle),* long pepper *(P. longum)* Java long pepper *(P. chaba= P. retrofractum),* tailed pepper *(P. cubeba)* and *Kava (P. methysticum)*. In addition some species are ornamental foliage plants. *P. clusii* is the West African pepper and is used as a spice by the local people. Ashanti or Benin pepper *(P. guineense)* is yet another species used by local tribes. *P. hispidinervium,* a native of Brazil, is a rich source of safrole.

In this chapter brief descriptions are presented on *Piper* spp. other than black pepper, which are of much economic importance.

THE BETEL LEAF (*Piper betle* L.)

A perennial climber, like black pepper, probably originated in the Indo-Malayan region, and known to occur only under cultivation. Cultivated extensively in India, Bangladesh, Pakistan, Malaysia, Indonesia, etc. for its leaves which are used as masticatory, for chewing (together with lime, betel nut and with or without tobacco). It is a dioceous plant, propagated exclusively by stem cuttings. Stems are semi woody, green or pinkish green, climbing on support trees by means of adventitious roots arising from nodes as in the case of pepper. Leaves are highly variable among cultivars, 5–20 cm long, ovate to broadly ovate or cordate, often with unequal bases, tip acuminate or acute, entire, glabrous and shining, yellowish green to bright green depending on the cultivar. Flowering rare, mainly because the plants are replanted in every 4–5 years under cultivation. Old plants (8–10 years) flower, spikes cylindrical and pendulous. Usually male or female plants only occur in any given locality, probably because the local cultivar might have developed from a single source. As such mixed populations of male and female vines are not normally found. Fruits are observed only rarely.

It is generally believed that the cultivated betel plants are male plants selected over a period by the growers. Much variations exist in all characters including the taste and aroma of leaves. The variability is highest in India. Tamil Nadu, Karnataka, Andhra

Pradesh and West Bengal are the major producing states in India. A total of 43,000 ha is cultivated and the annual production in India is worth around Rs.7000 millions. Many cultivars are known in Indonesia and Malaysia also, some of which are reported to have distinct flavours. In Philippines, three varieties are commonly grown. Leaves produced under high fertility are larger in size and less pungent and spicy; under less favourable conditions the leaves become smaller and more spicy. A list of the more important cultivars common in India are given in Table 12.1.

Rawat *et al.* (1988) after analysing 85 different cultivars of germplasm for morphological and chemical characters identified five distinct varieties that differ in their morphology and chemistry. They are *Bangla, Desawari, Kapoori, Meetha* and *Sanchi*. *Bangla* is characterized by roundish to cordate leaf lamina with prominent basal lobes. *Desawari* has short, acuminate curved tip with cordate leaf base.

Table-12.1 Common cultivars of betel leaf in India.*

Sl. no	*Cultivar*	*Pungency*	*Keeping quality (days for 50% rotting)*
1	Bangla (Madhya Pradesh)	P	13
2	Bangla (Uttar Pradesh)	P	13
3	Bangla Nagaram (Uttar Pradesh)	P	13
4	Calcutta (West Bengal)	P	19
5	Calcutta Bengal (-do-)	P	17
6	Deshi Calcutta (-do-)	P	19
7	Deswari Mahoba (Uttar Pradesh)	MP	13
8	Ghanghatte (West Bengal)	P	13
9	Godi Bangla (Orissa)	P	13
10	Halisahar Sanchi (West Bengal)	P	13
11	Kakir (Bihar)	P	13
12	Kalipatti (Maharashtra)	P	13
13	Kappori (Bihar)	NP	10
14	Kappori (Orissa)	NP	10
15	Karapaku (Andra Pradesh)	P	13
16	Karpuri (Tamil Nadu)	NP	10
17	Kuljedu (Andra Pradesh)	NP	10
18	Maghai (Bihar)	P	13
19	Meetha pan (West Bengal)	Sweet	10
20	Nov Bangla (Orissa)	P	13
21	Ramtek Bangla (Maharashtra)	P	13
22	S.G.M.-1 (Tamil Nadu)	MP	13
23	Sachi pan (Assam)	P	13
24	Sangli Kapoori	NP	10
25	Tellaku (Andhra Pradesh)	NP	10
26	Vellai kodi (Tamil Nadu)	NP	10

MP=Mildly pungent; P=Pungent; NP=Non pungent.
* Source: Ann. Rep. AICRP on betel vine 1995–96, IIHR, Bangalore.

Kapoori has yellowish green leaves, narrow and ovate with characteristic veins running parallel to the mid rib. *Meetha* leaves are distinguished by the acute apex and yellowish spots on lamina. *Sanchi* has broadly ovate leaves with attenuate apex, having short channeled petiole, characteristically oriented towards the stem (Balasubrahmanyam and Rawat 1990).

Ganguly and Gupta (1974) classified 12 *Bangla* types into two groups distinguishable on the basis of morphology of leaves—those having roundish leaves, and those having elongated leaves (ovate-lanceolate). Similarly *Sanchi* is found to contain two morphotypes distinguishable on the basis of taste, texture and general morphology. Leaf anatomy showed the typical structure of the *Piper* leaf in all the five varieties.

Chromosome number reports on betel vine vary much; 2n=26, 32, 52, 58, 62, 78 and 195 have been reported but the most frequent number is 2n=78 for the majority of cultivars and varieties, thus betel is a hexaploid (Jose and Sharma 1988).

Betel vine is cultivated often in a very intensive way under irrigation and high levels of nutrient application in order to speed up foliage development and growth. Improved cultivation practices were evolved and promoted with technical back up (Balasubrahamanyam *et al.* 1992). Though the recommended dose is only 150 kg N and 100 kg each of P and K/ha, farmers often use much more, and added to this lot of organics are also being used. Such conditions unfortunately are also ideal for pests and disease development. Rahaman *et al.* (1997) after studying 27 genotypes concluded that two genotypes (*Kare Bangla* and *Adi Bangla*) have high adaptability and least influenced by environmental factors, and are therefore suitable for cultivation under wide environmental conditions.

Betel vine is affected by *Phytophthora* foot rot, and is the most serious disease. Screening of cultivars led to the identification of a few that are tolerant to *Phytophthora* foot rot (such as *Halisahar Sanchi, Pachaikodi* and *Karapaku*). Cv. *Simurali Bangla* is found resistant to bacterial leaf spot. Male clones of *Kapoori, Tellaku, Vellaivettala, Ambadi Badam* and *Kulgedu* are resistant to Powdery mildew. Cv. *Halisahar Sanchi* is having resistance to *Phytophthora* foot rot, anthracnose and bacterial leaf spot (Maiti 1994). S.G.M.I, a dwarf statured, high yielding selection is highly tolerant to anthracnose and reported to with stand wind, pests and diseases (Padmanabhan *et al.* 1995). Crop improvement work is so far limited to germplasm evaluation and selection. Efforts for cross breeding has just been initiated in India. Micropropagation protocols for betel vine has been standardized by Nirmal Babu *et al.* (1992) and by Aminudin *et al.* (1993). Betel vine can be successfully micropropagated in woody plant medium supplemented with 3 mgl^{-1} benzyladenine and 1 mgl^{-1} kinetin (Nirmal Babu *et al.* 1992).

Chemical Composition

Many reports exist on the chemical constitution of various types and varieties of betel leaves. The benzene extract of betel leaves yield *ß*-sitosterol, *?*-sitosterol, hentriacontane, n-triacontanol, stearic acid, chavicol and 3,5-dinitrobenzoate (Deshpande *et al.* 1970).

The betel leaf contain an essential oil varying from 0.10 to 1.0 per cent. *Sanchi* contains 0.19 per cent, *Kapoori* 0.1 per cent, *Desawari* 0.12 per cent, *Bangla* 0.16 per cent and *Meetha* 0.85 per cent of essential oil. About 52 compounds are identified in the betel leaf oil the composition of which varies considerably among the varieties (Balasubrahmanyam and Rawat 1992). The major constituents are: monoterpenes (*a*-thugene, sabinene, *ß*-pinene, *ß*-myrcene, *ß*-phellandrene etc.); sesquiterpenes (*?*-cadinene, *ß*-salinene, *ß*-elemene, transcaryophyllene, *a*-cubebene etc.); oxygenated compounds such as alcohols (linalool, *a*-terpineol, geraniol etc.); aldehydes (decanal, stearaldelyde); oxides (1,8-cineole, caryophylene oxide), phenols (eugenol, isoeugenol, chavicol, chavibetol); phenolic ethers (methyleugenol, methyl chavicol, anethole (safrole) and esters (eugenolacetate, methyl benzoate). The final aroma and taste depend on the contents and relative amounts of the various components (Nigam and Purohit 1962, Baslas and Baslas 1970, Balasubrahmanyam and Rawat 1990). Balasubrahamanym and Rawat (1990) noted significant chemical differences among the five major betel leaf varieties-namely *Sanchi, Kapoori, Desawari, Bangla* and *Meetha*. In the *var. Sanchi* the mono and sequiterpenes constitute about 34 per cent of the oil, while in other varieties the corresponding values are: *Kapoori* 16.94 per cent, *Desawari*—14.39 per cent, *Bangla*—nil, *Meetha*—33.24 per cent. Eugenol contents are: 13.1 per cent in *Sanchi,* 33.2 per cent in *Kapoori,* 20.47 per cent in *Desawari,* 63.56 per cent in *Bangla,* 18.92 per cent in *Meetha*. Phenolic ethers (mainly 1, *ß*-benzodioxole (5)-2-propenyl) are present to the extent of 22.75 per cent in *Sanchi,* 6.5 in *Kapoori,* 45.34 per cent in *Bangla,* 2.3 per cent in *Desawari* and is absent in *Meetha*. *Var. Meetha* contains 19.35 per cent anethole which accounts for its sweet taste. *Var. Bangla* contains 18.68 per cent of eugenol acetate, while *Kapoori* has 2.23 per cent methyl benzoate (Balasubrahmanyam and Rawat 1990). Variations are noted within a variety itself. Sarma *et al.* (1983) noted that in *Bangla* types the amount of eugenol varied from 82.2 per cent in *Desi Bangla* and 90.5 per cent in *Rantek Bangla*. The National Institute of Nutrition at Hyderabad (Gopalan *et al.* 1984) reported that betel leaves contain 230 mg calcium, 40 mg phosphorous, 7.0 mg iron, 0.07 mg thiamine, 0.03 mg riboflavin, 0.7 mg niacin, 5 mg vit. C, and 5760 mg carotene per 100 gm of leaves.

Blanching (Bleaching) of Betel Leaves

Fresh betel leaves are usually used for chewing. In some areas leaves are subjected to a process of blanching or bleaching before they are marketed. The bleaching process consists of dipping the leaves in water and stalking them in a dark warm room. For bleaching only mature leaves are used because tender leaves undergo rotting rapidly. In commercial bleaching 25–30 kg of leaves are bleached at a time by packing them in baskets lined with jute matting. Leaves are arranged in vertical layers in a circle leaving a space in the center for aeration. The leaves are sprinkled with water (the quantity should be controlled) and covered with a moist gunny bag. The leaves gradually turn to yellow to yellowish white. After 5–6 days, leaves are taken out, bleached ones are sorted out rejecting the rotten ones, and the rest rearranged in the

Table-12.2 Essential oil composition (%) of bleached leaves of two *Bangla* lines.*

Compound	*Jaganathi Bangla*		*Tamluk Bangla*	
	Bleached	*Control*	*Bleached*	*Control*
Linalool	0.12	0.08	0.44	0.23
Chavicol	–	0.09	0.31	–
Safrol	0.86	0.18	–	–
Eugenol	64.30	64.00	46.14	63.66
Methyl eugenol	0.23	0.07	–	0.11
β-Caryophyllene	3.34	3.37	4.70	1.19
L-Lunalene	1.05	1.23	1.33	1.12
Germacrene D	5.93	6.15	5.96	–
Ψ-Elemene	3.80	–	–	4.98
Eugenyl acetate	4.12	3.84	5.25	5.03
f-Cadinene	1.89	1.81	3.08	3.05
Sesquiterpene alcohol	Traces	–	–	Traces
Phytol	–	–	–	0.18
Essential oil	0.01	0.01	0.01	0.01

* Source: Ann. Rep. AICRP on betel vine 1995–'96; IIHR, Bangalore.

basket and is allowed to remain for another one week to 10 days. The whole processes takes 15–20 days. The yield of bleached leaf is about 50 per cent. The leaves are then dried in shade to remove surface moisture, packed and marketed (Anon. 1969). This bleaching process lead to some changes in the chemical composition of the essential oils (Table 12.2).

Uses

Betel leaf is most extensively used for chewing in all South Asian countries and by many people in the far east countries. Leaves are chewed with arecanut and lime, and with or without tobacco. The essential oil from leaves is used in respiratory catarrh and also as an antiseptic. In some areas leaf juice is used in eye afflictions. Aqueous extract of leaves is believed to be useful in throat inflammation and in the alleviation of cough and indigestion. The plant is considered by tribals as useful in treating madness, strangulation of the intestine, venereal sore, syphilis, dysentery and phthisis (Jain and Tarafder 1970). Betel leaf is also used in certain indigenous medicinal preparations. A cultivar called *Thulsi Vettila* is commonly used for this purpose in Kerala and parts of Tamil Nadu and Karnataka, though other varieties are also used in other parts of the country. This is an old land race having very small leaves, short stature and poor yield and hence has not much of commercial importance. This variety having the flavour of Thulsi *(Ocimum tenuiflorum),* is an ingredient in many indigenous medicinal preparations used in a variety of skin troubles, in headache, sinusitis, etc. The essential oil and the extract of leaves possess antibacterial activity against both gram negative and gram positive bacteria. The antiseptic activity is believed to be due to chavicol. Both leaf oil and extract showed antifungal activity. The oil is found to be lethal to protozoa in 1:10,000 dilution, inhibits the growth of *Vibrio cholerae* in 1:4000 dilution, *Salmonella typhossum* and *Shigella flexneri* in 1:3000 dilution, *E. coli* and *Micrococcus* in 1:2000 dilution. Steam distillate of the leaves showed activity against *Mycobacterium tuberculosis* in dilution of 1:5000 (Anon. 1969, Sathyavathi 1987).

Betel leaf chewing is an ancient practice in India and other countries of South and East Asia. In India this is associated with many religious and social practices as well. As a masticatory it is credited with many properties—it is aromatic, digestive, stimulant and carminative. Chewing leads to excitation of the salivary glands, a mild degree of stimulation is produced resulting in pleasant sensation of warmth and well being besides imparting a pleasant odour. The Central Nervous System (CNS) stimulant activity is due to the arecoline present in the betel nut and the red colouration is due to the action of lime on arecanut. The betel leaf has a synergistic effect on CNS. However excessive indulgence in chewing is liable to produce various afflictions of the mouth including carcinoma.

Betel leaves possess anti-oxidant action. When leaves are heated with fats and oils (especially ghee) rancidity is checked. Leaves are effective in preserving refined oils of ground nut, mustard, sesame, coconut and sunflower. This anti-oxidant action is due to phenols especially hydroxy chavicol (4-allyl pyrocatechol). The effect is comparable to well known anti-oxidants such as propyl gallate.

THE INDIAN LONG PEPPER (*Piper longum* L.)

A slender creeping plant with perennial woody roots occurring throughout India, Sri Lanka, Burma and Malaysia and other South Asian countries, but is most widely distributed in India. Long pepper fruits (dried) and roots are among the most important medicinal plants used in the Indian systems of medicines—*Ayurveda, Unani and Sidha*. (For botanical description see Chapter 2).

The long pepper sold in India appears to be derived from two or three species including an Indonesian species. Indian long pepper is the dried mature fruits (spike) of *P. longum*. In the Indian market the dried spikes of *P. peepuloides* are also sold as long pepper. The globoid spikes of *P. mullesua (P. brachystachyum)* is also sold as long pepper (Anon. 1969). The Indonesian or Java long pepper is obtained from *P. chaba (P. retrofractum)*. The spikes of these species are used for the same purpose, though they vary in their effectiveness. True Indian long pepper is derived from *P. longum,* from wild grown plants in Assam, West Bengal, Nepal, North Eastern regions, Bihar, Uttar Pradesh, Kerala, Tamil Nadu, Andhra Pradesh, etc. It is cultivated on a small scale in Tamil Nadu, Andhra Pradesh, Assam and West Bengal. In some parts, long pepper is grown for their root. Tissue culture protocols, both micropropagation and callus regeneration were achieved by many workers (Sarasan *et al.* 1993, Rema *et al.* 1996).

Chemistry and Pharmacology

The dried spikes of long pepper on steam distillation yield an essential oil (about 0.7–0.8%). This oil consists mainly of n-hexadecane, n-heptadecane, n-octadecane, n-nonadecane, n-ciocosane, n-hencosane, *a*-thujene, terpenolene, zingiberene, *p*-cymene, *p*-methoxy acetophenone, dihydrocarveol, phenyl ethyl alcohol, etc. On extraction with petroleum ether long pepper yield sylvatin, sesamin and dieudesmin. Stem of long pepper on extraction with petroleum ether yield triacontane, dihydrostigmasterol and two alkaloids—piperine and pipalartine (Atal and Banga 1962). Petroleum ether extract of roots yielded the alkaloid piperlonguminine (Sathyavathi 1987).

A pellitorine type of alkaloid (CH-isobutyl deca trans-4-dienamide) isolated from long pepper and *P. peepuloides* was reported to exhibit significant antitubercular activity against *Mycobacterium* (about 20% of the potency of streptomycin). The essential oil of long pepper showed antibacterial activity against *Bacillus, Mycobacterium Streptococcus, E. coli, Shigella, Salmonella* and *Vibrio chloerae*. Oil revealed antifungal activity against *Aspergillus, Trichoderma, Curvularia* and *Penicillium*. The oil exhibited insecticidal and insect repellent activities against stored grain insects.

Extract of long pepper effectively reduced passive cutaneous anaphylaxis in rats and protected guinea pigs against antigen induced bronchospasm. It did not have any effect on the total quantity of histamines in lungs, trachea and intestine or on release of histamines on antigenic challenge (Dhanaukar and Karandikar 1984). Anti-inflammatory activity was also reported (Sharma and Singh 1980). Long pepper in combination with *Emblica ribes* and borax was shown to cause reversible sterility in female rats and irreversible sterility in male rats (Sathyavathi 1987). Petroleum ether extract of long pepper produced respiratory stimulation in smaller doses and convulsion with larger doses in laboratory animals. Piperlongumine as well as the extract of whole plant of long pepper showed marked antispasmodic action in isolated tissues. The ether extract of the plant caused complete cessation of the frog heart beat for a short period, the effect could not be blocked by atropine (Sathyvathi 1987).

Uses

The most important use of long pepper is as a medicinal ingredient in the Indian systems of medicine—*Ayurveda, Sidha and Unani*. Both fruit and dried roots are extensively used.

A decoction of immature fruits and roots is used in chronic bronchitis, cough and cold. Fruit and root are used in palsy, gout, rheumatism and lumbago. Fruit is a vermifuge and also used after child birth to check post-partum haemorrhage. The fruit and root are used as antidots for snakebite and scorpion sting. The fruit is also used as a sedative in insomnia and epilepsy; as a cholagogue in bile duct and gall bladder obstructions; as an emmenagogue and abortifacient. It forms one of the ingredients in various compound preparations used for asthma, anorexia, piles, dyspepsia and also in snuffs used in coma and drowsiness. (Chopra *et al.* 1950, Nadkarni 1954, Anon. 1969). A compound preparation is also said to be useful in the treatment of leucoderma. The tribals consider the plant to be useful in splenic disorders, cholera, dysentery, cough, bronchitis, asthma, constipation, purpural fever and diarrhoea (Jain and Tarafdar 1970).

The roots of long pepper is also attributed with several medicinal properties. The extract is used in cough syrups and as a counterirritant in analgesics and for all other ailments where fruits are used.

JAVA LONG PEPPER (*Piper chaba* Hunter Syn *P. retrofractum* Vahl *P. officmarum* DC)

A glabrous, fleshy climber with adhesive roots; originally from Indonesia, now cultivated on a small scale in Indonesia, Malaysia and in certain parts of India (north eastern regions). The plant possess pronounced dimorphic branching. The orthotropic shoot bears small, cordate leaves, the fruiting lateral shoots have large lanceolate-acuminate leaves. The fruiting spikes are erect, cylindro-conic, widest at base, bright red when ripe, 2.5–7.5 cm long. The fruits are very small, laterally fused, seeds small. Probably an apomictic species as profuse fruiting is noticed in the absence of male plant. The mature spike is pungent, the spikes loose their pungency and quality on ripening. So harvesting has to be done when the spikes are mature but still green. Tissue culture of *P. chaba* has been standardized by Rema *et al.* (1995).

The petroleum ether extract of stem yielded piperine, pipalartine and *ß*-sitosterol (Mishra and Tewari 1964). The root yielded sylvatine and piperlonguminine (Patra and Ghosh 1974). Petroleum ether extract of the fruit yielded methyl piperate, (*?-d*-dihydropiperine, N-isobutyl-tridieca-13-(3-4-methylene dioxy phenyl) 2,4,12-trienamide, N-isobutyl docosa trans-2-trans-4-cis-10-trienamide-filfiline, N-isobutyl-decosa-trans-2-trans-4-cis-8-trienamide, piperine, *ß*-sitosterol, caryophyllene oxide and piperlonguiminine. Preliminary pharmacological study of aqueous and alcoholic extracts produced hypotensive and smooth muscle relaxant effect (Tewari *et al.* 1964). Alcoholic extract of stem exhibited antifungal activity. Alcoholic extract of roots enhanced the bioavailability of sulphadiazine (in dogs and rats) and tetracycline hydrochloride (in rats).

Fruits are used all over India as long pepper for the same purpose for which Indian long pepper is used. The fruits (spikes) are pungent and aromatic, stimulant, carminative, used in cough, cold and in hemorrhoidal affliction. It is also given in colic, tympanites and renal diseases.

CUBEB OR TAILED PEPPER (*Piper cubeba* L.)

P. cubeba is a climber, native of Indonesia, cultivated in Indonesia and Malaysia. Leaves glabrous, ovate-oblong with cordate or rounded base, fruit subglobose and stalked. This is a very distinct species having chromosome number of 2n=24 (Jose and Sharma 1984). The main centers of production are Java and Sumatra in Indonesia. Two other species yielding cubeb like fruits are *P. ribesioides* Wall and *P. sumatrana* DC.

Cubeb contains 5–20 per cent of essential oil and about 6–8 per cent resinous matter. The resinous matter contains several components including cubebin, cubebol and cubebic acid. The therapeutic value of cubeb is due mainly to cubebic acid. The essential oil contains many compounds such as d-sabinene, d-?[4] carene, 1,4-cineole, d-terpinen-4-ol, other terpene alcohols, l-cadinene, sesquiterpene alcohols, etc.

The essential oil of cubeb showed antibacterial activity against several bacteria such as *Bacillus subtilis, Vibrio cholera, Salmonella typhimurium, Clostridium diphthereae, Streptococcus pyogenes,* but has no effect on *E. coli*. Oil of cubeb exhibited anti-fungal activity against *Aspergillus, Trichoderma, Curvularia, Alternaria, Penicillium* and *Fusarium* (Rao and Nigam 1976). Oil of cubeb is used in lozenges for the relief of throat afflictions, for flavouring of certain liquors and cigarettes. The oil is also used in flavouring certain brands of sauces and also in perfumery to impart an exotic note.

KAWA—*Piper methysticum* G. Forst

Kawa is a native of the South Pacific Islands, and is the source of a narcotic drug widely used by the people of that land. It is a perennial shrub with broad, heart shaped leaves. The active principles are found in the roots and underground root stocks. The roots contain alkaloids such as methysticin, yangonin, dihydromethysticin and dihydrokawain. The Pacific Islanders have been using the roots of this plant for making the potent beverage called Kawa-Kawa. This plant and the beverage have played important roles in their social and religious ceremonies. Kawa-Kawa has been drunk to celebrate birth, marriage, to mourn death, to propitiate Gods, to cure illness, to remove curses etc. Its effect is non intoxicating, it does not dull mental processes, but it is a narcotic. It induces a euphoric state of tranquil-well being that eventually leads to a deep, dreamless sleep.

The roots and root stocks are handled in two ways:

(a) They are reduced to fragments and chewed to a soft mass especially by girls in a ceremonial way, often accompanied by song and dance, and the soft chewed mass is spit into a wooden bowl, mixed with water or coconut milk and kneaded by hand. The foamy mixture is allowed to stand a few hours, strained and consumed—in olden days only by men. The drink has a strong narcotic effect.
(b) The roots are grated and macerated in cold water or coconut milk and the liquid is filtered before drinking. This beverage is used by men and women alike. It has strong, stimulating, tonic effect but lacks the narcotic power of the chewed product.

The Kawa prepared by chewing has strong narcotic effect, it paralyzes the muscles, particularly the lower limbs, it increases the force, but decreases the rapidity of the hearts action and it first stimulates and later depresses respiration. Unlike alcohol the drug does not impair mental alertness. In small quantities it produces a euphoric state of short duration followed by tranquility. In larger quantities Kawa prepared by chewing disturbs vision (dilation of pupil and slower response to light) and muscle coordination and acts as a powerful hypnotic. When the drink is prepared by grating it is tonic and stimulant only and is often given to the sick and convalescent as well as to young mothers as a galactogogue.

Research has shown that the narcotic principle is liberated due to the strong emulsification during chewing and is not produced due to the action of saliva. Any emulsification process similar to chewing can set free the narcotic action. Chewed Kawa is a cerebral depressant, the drug apparently steadies the pulse, does not raise body temperature, is diaphoretic and counteracts obesity. The deep calm sleep induced by Kawa is not followed by a hang over. The substance is addicting and continued use leads to skin afflictions like exfoliative dermatitis, mainly due to the presence of dihydromethysticin (Lewis and Elvin Lewis 1977).

P. hispedinervium Trel.

This is a weedy species frequently found on degraded forests in Brazil, where it grows as thick bushes in extensive areas. This plant is very rich in safrole, a very valuable natural chemical of various industrial uses. The plant can be propagated through seeds or stem cuttings.

The safrole content of the essential oil from unselected stock in about 85 per cent and improvement to 90 per cent in believed to be possible (Coppen 1995). For oil extraction plants are harvested at 6–8 months intervals. For harvesting the shoots are cut above ground along with leaves, dried in shade and distilled. Safrole rich oil in highly prized in perfumery.

Ornamental Peppers

In addition to the above economically important species, there are a few that have found their way into the world of garden plants. They have attractive foliage and are valued for this purpose. The following are the important ones.

P. auritum HBK

A small tree or a large shrub with aromatic foliage, ovate to elliptic-ovate leaves, apex acuminate, base cordate, thinly pubescent on the upper surface, densely pubescent on the lower, petiole is winged. Produces long spikes about 18 cm. A Mexican species.

P. borneense N.E.Br.Herb.

An Indonesian species, herbaceous perennial, with stout pilose stem, elliptic to elliptic-oblong leaves, acute at apex and auriculate-cordate at base. The leaves are large, deep green above with silvery grey stripes, rugose, pubescent beneath. Spikes about 7 cm long. An attractive foliage plant.

P. decurrens DC.

A South American species occurring in Costa Rica to Colombia. A shrub, with stout, pale green stem with white spots and black lines. Leaves lanceolate, base cuneate to acute, slightly decurrent on petiole, green with metallic iridescence.

P. magnificum Trel. (Lacquered pepper)

Small, erect shrub having winged stem, leaves ovate to broadly elliptic or suborbicular, apex broadly acute, base cordate to auriculate, deep green above, glossy, bright maroon beneath. Petiole broadly winged. Origin is Peru, South America, now cultivated extensively as an ornamental foliage plant.

P. metallicum Hallier f.

An Indonesian species from Borneo, scandent herb, stem red when young with adventitious roots, leaves ovate, with red tinge when young, metallic deep green above when mature and reddish with silvery scale beneath, and with reticulate red veins.

P. ornatum N.E.Br. *(=P. crocatum)* Celebes pepper

A creeping/climbing shrub, from the Sulawesi island of Indonesia. Leaves broadly cordate to suborbicular, peltate, apex attenuate, base cordate, mottled green, pink and silver above, light maroon beneath.

P. porphyropbyllum (Lindl.) N.E.Br.

Species occurring in Malay peninsula and in Borneo, a creeping or weakly climbing shrub, stem wiry with hair, broadly cordate, apex shortly mucuronate, cordate to auriculate at base, dark green above with red and white spots, flushed purple beneath.

P. rubronodosum Nichols

A South American species from Colombia. Shrub, with fleshy scabrous stem having reddish nodes, leaves deep green with silver grey patches especially when young, petioles tomentose.

P. rubrovenosum hort. ex Rodigas

A species from New Guinea, woody climber, leaves oblique elliptic to cordate, apex acute to acuminate, base cordate, dark green above, pale green below, coriaceous marked by irregular pink lines above.

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ANNEXURE I
ISO DRAFT STANDARDS FOR BLACK PEPPER

The International Standards Organization (ISO) has developed standards for black and white pepper and pepper products. These standards are based on the inputs received from various exporting and importing countries and end users. The draft standards developed by ISO are reproduced below.

Pepper (*Piper nigrum* Linnaeus), whole or ground—Specification

Part 1: Black Pepper

1. Scope

This part of ISO 956 specifies requirements for black pepper, (*Piper nigrum* Linnaeus), (see ISO 676), whole or ground, at the following commercial stages:

- ► Pepper sold by the producing country without cleaning or after a partial cleaning, without preparation or classification, called "non-processed (NP) or semi-processed (SP) pepper" in this part of ISO 959;
- ► Pepper sold by the producing country after cleaning, preparation and/or classification, called "processed (P) pepper", which can, in certain cases, be re-sold to the consumers.

When the term "black pepper" is used alone, it means that the specification applies to both types described, without distinction.

This part of ISO 959 does not apply to black pepper categories called "light"

Specifications of white pepper are given in ISO 959–2.

Recommendations relating to storage and transport conditions are given in Annex C, as a guide.

2. Normative References

The following standard(s) contain provisions which, through reference in this text, constitute provisions of this part of ISO 959. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 959 are encouraged to investigate the possibility of applying the most recent editions of the standards listed below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 676:1982, Spices and condiments—Nomenclature-First list.
ISO 927:1982, Spices and condiments—Determination of extranaeous matter content.

ISO 928:1980, Spices and condiments—Determination of total ash.
ISO 930:1980, Spices and condiments—Determination of acid-insoluble ash.
ISO 939:1980, Spices and condiments—Determination of moisture content—Entrainment method.
ISO 948:1980, Spices and condiments—Sampling.
ISO 1108:1980, Spices and condiments—Determination of non-volatile ether extract.
ISO 1208:1982, Spices and condiments—Determination of filth.
ISO 5498:1981, Agricultural food products—Determination of crude fibre content—General method.
ISO 5564:1982, Black pepper and white pepper, whole or ground—Determination of piperine content-Spectrophotometric method.
ISO 6571:1984, Spices, condiments and herbs—Determination of volatile oil content.

3. Definitions

For the purposes of this part of ISO 959, the following definitions apply.

3.1 Black pepper: Berry of *Piper nigrum* Linnaeus having an unbroken pericarp.
3.2 Black pepper, non-processed or semi-processed: Pepper that has not undergone any treatment or has solely been partially processed by the producing country before being exported, and is in conformity with the requirements of this part of ISO 959.
3.3 Black pepper, processed: Pepper that has been processed (cleaning, drying, preparation, classification, etc.) by the producing country before being exported and is in conformity with the requirements of this part of ISO 959.
3.4 Black pepper, ground: Black pepper obtained by grinding whole berries without any added matter.
3.5 Grey pepper: Commercial name sometimes given to ground black pepper.
3.6 Light berry: Berry that has reached an apparently normal stage of development but the kernel of which does not exist.
3.7 Pinhead: Berry of very small size that has not developed.
3.8 Broken berry: Berry that has been separated in two or more pieces.
3.9 Extraneous matter: All materials other than black pepper seeds, irrespective of whether they are of vegetal (e.g. stems and leaves) or mineral (e.g. sand) origin. Light berries, pinhead or broken berries are not considered as extraneous matter.

4. Requirements

4.1 *Description*

Whole black pepper is the whole dry berry of *Piper nigrum* Linnaeus, generally picked before ripening. Seeds of black pepper have a diameter of 3 mm to 6 mm and are of a brown, grey or black colour with a wrinkled pericarp.

Ground black pepper is obtained by grinding whole berries, without any added matter.

4.2 *Odour and flavour*

The flavour of the black pepper when it is ground shall be characteristic, strongly sharp and very aromatic. The product shall be free from extraneous odours and flavours, including mouldy and rancid odours. The appearance of berries has no direct relation to their flavour. Small berries can be more aromatic than berries of better appearance or larger size.

4.3 *Absence of mould, insects, etc.*

Black pepper shall be free from mould and living insects and practically free from dead insect fragments and rodent contamination visible to the naked eye (corrected, if necessary, for abnormal vision) or with magnification if necessary in certain specific cases. If the magnification used is greater than 10 X, this fact shall be mentioned in the test report. Furthermore, in the case of ground black pepper, impurities shall be determined according to the method described in ISO 1208.

4.4 *Physical characteristics*

Whole black pepper shall meet the requirements given in Table 1.

Table 1 Requirements for physical characteristics of whole black pepper.

Characteristic	*Requirements*		*Reference test method*
	Pepper NP or SP	*Pepper P*	
Extraneous matter, % (m/m) max.	2.5	1.5	ISO 927
Light berries, % (m/m) max.	10	3.0	Annex A
Pinheads or broken, % (m/m) max.	7	4.0	Physical separation and weighing
Bulk density, g/l, min	450	490	Annex B

In addition, especially in the case of ground pepper, it is recommended that a microscopic test be carried out (see annex D).

4.5 *Whole pepper categories*

Grading of whole black pepper is based on the commercial appellations adopted by the producing country, and in particular:

- the place of production
- the extraneous matter content, light berries, pinheads and broken berries;
- its bulk density.

Annex E gives, as an indication, the main producing countries and the most frequently used commercial appellations.

4.6 *Chemical characteristics*

The whole or ground black pepper shall meet the requirements given in Table 2.

5. Sampling

Sample the black pepper using the method described in ISO 948.

Samples of whole black pepper shall be ground so that all material passes through a sieve with apertures of 1 mm. The material thus ground shall be used for determining the characteristics given in Table 2.

Table 2 Requirements concerning chemical characteristics of black pepper, whole or ground.

Characteristic	*Requirement*			*Reference test method*
	Pepper NP or SP	*Pepper P*	*Ground pepper*	
Moisture content % (m/m) max.	14.0	12.0	12.0	ISO 939
Total ash, % (m/m) max, on dry basis	7.0	5.0	5.0	ISO 928
Non-volatile ether extract, % (m/m) min., on dry basis	6.0	6.0	6.0	ISO 1108
Volatile oils, ml/100 g, min., on dry basis	2.0	2.0	1.5	ISO 6571
Piperine content, % (m/m)min.	4.0	4.0	4.0	ISO 5564
Acid-insoluble ash, % (m/m) max., on dry basis	–	–	1.0	ISO 930
Crude fibre, insoluble index, % (m/m) max., on dry basis	–	–	17.5	

6. Test Methods

The pepper samples shall be analysed to ensure conformity with the requirements of this part of ISO 959, following the methods described in International Standards referred to in tables 1 and 2 and in annexes A, B, C and D of this part of ISO 959.

7. Packing and Marking

7.1 *Packing*

Black pepper shall be packed in clean, sound, sealed packages, made of a material which does not affect the product.

7.2 *Marking of whole or ground pepper*

The following particulars shall be marked on each package or on a label attached to the package:

a) name of the product and the trade-name, if any;
b) name and address of the manufacturer or packer, or trade-mark;
c) code or batch number;
d) net mass;
e) grade of the product (if classified) according to national standards;
f) producing country;
g) destination by the name of port or town;
h) any other information requested by the buyer, such as year of harvest and date of packaging;
i) a possible reference to this part of ISO 959

7.3 *Labelling*

In the case of small packages intended for retail sale, Labelling shall be signed and dated according to regulations in force concerning labelling and food commodities.

ANNEX A (Normative)

Determination of percentage of light berries in black pepper

A.1 Reagent

Hydro-alcoholic solution, of relative density d 20/20=0.80 to 0.82 (If the temperature is different, a correction factor is to be used)

The alcohol used in the preparation of this solution can be ethanol, denatured alcohol previously rectified, or propanol-2-ol.

A.2 Procedure

A.2.1 *Test portion*

Weigh, to the nearest 0.01 g, 50.0 g of sample, from which the extraneous matter has been previously removed, into a glass beaker of 600 ml.

A.2.2 *Determination*

Add 300 ml of the hydro-alcoholic solution (A.1) to the glass beaker and mix the contents with a spoon. Leave the product standing for 2 min, then withdrew the floating berries with the spoon. Only berries floating in the surface shall be removed and not those that remain in suspension some distance below surface of the hydroalcoholic solution. Repeat the standing and removal operations of berries floating until no more berries float after two successive stirring.

Dry the berries removed on blotting paper to eliminate excess liquid, then spread them in dry air on a piece of paper or tile or other absorbent material. Leave the berries for 1 h and weigh to the nearest 0.01 g.

A.3 Expression of Results

The percentage by mass, of light berries in the sample is: $m_1/m_0 \times 100$ Where m_0 is the mass, in grams, of the test portion; m_1 is the mass, in grams, of the light berries removed.

ANNEX B (Normative)

Whole black pepper: Determination of apparent bulk density

B.1 Scope

This annex specifies a method of determination of the apparent bulk density of whole black pepper.

B.2 Principle

Weighing a volume, exactly measured, of 1 l (1 litre) of pepper.

B.3 Apparatus

B.3.1 Apparatus, consisting of:

- ► cylinder, of capacity 1 l or a cylinder of greater capacity, but equipped with apparatus allowing leveling of the product to the 1 l level.
- ► hopper, of capacity greater than 1 l and equipped with a gate
- ► device, for fixing the hopper above the cylinder at a certain distance, to allow free fall of the product into the cylinder from a constant height.

However, for routine control and when the apparatus described is not available, it is possible to use a cylinder of 1 l capacity and a funnel.

B.3.2 Balance

A special balance allowing the cylinder to be hooked to one side of the beam and equipped on the other side with a suitable plate serving as tare.

B.4 Procedure

B.4.1 Determination

Weigh the empty cylinder, if necessary. Place the cylinder on a horizontal plane and set the hopper on it with a fixing device. Pour the pepper into the hopper until it is filled. Open the gate and allow the pepper seeds to flow freely into the cylinder until the level slightly exceeds the upper level or the 1 litre level, according to the apparatus used. Level the pepper, according to the case, to the upper level of the cylinder with a ruler, or to the 1 litre level with a suitable device with which the cylinder is equipped. (In this latter case remove the excess seeds.) Remove the hopper and its support, then weigh the cylinder filled with the pepper.

B.4.2 Number of determinations

Carry out three determinations.

B.5 Expression of Results

B.5.1 Method of calculation

The apparent bulk density of pepper, expressed in grams per litre, is given by the mass of pepper contained in the cylinder. Take as the result, the arithmetic mean of the three determinations if the repeatability conditions (see B.5.2) are satisfied. Otherwise, carry out three further determinations. If the former conditions are still not satisfied, take the arithmetic mean of the six determinations as the result.

B.5.2 Repeatability

The difference between the results of two determinations carried out in rapid succession by the same analyst shall not exceed 5 g per litre.

B.6 Test Report

The test report shall specify the method used and the result obtained. It shall also mention all operating details not specified in this part of ISO 959, or regarded as optional, together with details of any incidents which may have influenced the results. The test report shall include all information necessary for the complete identification of the sample.

ANNEX E (Informative)

Main producing countries and current trade-names of grades
NOTE—This list is limited and is given for information only.

Producing countries	Trade-names of categories
Brazil..................................	ASTA (American Standards Trade Association) Type 1 Type 2 Type 3
India...................................	MG (Malabar garbled black pepper) MUG (Malabar ungarbled black pepper) TGEB (Tellichery garbled extra bold black pepper) TGSEG (Tellichery garbled special extra sold black pepper)
Indonesia.............................	Grade or ASTA (American Spices Trade Association) FAQ (Fair Acceptable Quality)
Madagascar...........................	Madagascar black pepper
Malaysia..............................	Standard Malaysian black No. 1 (Brown label) Sarawak special black (Yellow label) Sarawak FAQ Black (Black label) Sarawak Field Black (Purple label) Sarawak Coarse field black (Grey label)
Sri Lanka.............................	Grade 1 special Grade 1 Grade 2 FAQ Grade 3 Grade 4
Thailand............................	Grade 1 Grade 2 Grade 3
Cameroon...........................	Cameroon black pepper
China................................	Grade 1 Grade 2 Grade 3

Part 2: White Pepper

1. Scope

This part of ISO 959 specifies requirements for white pepper (*Piper nigrum* Linnaeus), (see ISO 6761), whole or ground, at the following commercial stages:

- semi-processed (SP) pepper;
- processed (P) pepper

When the term “white pepper” is used alone, it means that the specification applies to both types, without distinction.

This part of ISO 959 does not apply to white pepper categories called “light”.

Specifications of black pepper are given in ISO 959–1.

Recommendations relating to storage and transport are given in Annex C, as a guide.

2. Normative References

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 959. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 959 are encouraged to investigate the possibility of applying the most recent editions of the standards listed below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 676:1982, Spices and condiments—Nomenclature—First list.
ISO 927:1982, Spices and condiments—Determination of extraneous matter content.
ISO 928:1980, Spices and condiments—Determination of total ash.
ISO 930:1980, Spices and condiments—Determination of acid-insoluble ash.
ISO 939:1980, Spices and condiments—Determination of moisture content—Entrainment method.
ISO 948:1980, Spices and condiments—Sampling.
ISO 1108:1980, Spices and condiments—Determination of non-volatile ether extract.
ISO 1208:1982, Spices and condiments—Determination of filth.
ISO 5498:1981, Agricultural food products—Determination of crude fibre content—General method.
ISO 5564:1982, Black pepper and white pepper, whole or ground—Determination of piperine content—Spectrophotometric method.
ISO 6571:1984, Spices, condiments and herbs—Determination of volatile oil content.

3. Definitions

For the purposes of this part of ISO 959, the following definitions apply.

3.1 Black pepper: Berry of *Piper nigrum* Linnaeus, having an unbroken pericarp.
3.2 White pepper: Pepper obtained from berries of black pepper from which the outer pericarp has been removed by the process described in 4.1
3.3 White pepper, semi-processed: Pepper that has undergone a partial treatment by the producing country before being exported and meets the requirements of this part of ISO 959.

3.4 White pepper, processed: Pepper that has undergone a treatment (cleaning, drying, preparation, grading, etc.) By the producing country before being exported and meets the requirements of this part of ISO 959.
3.5 White pepper, ground: White pepper obtained by grinding the whole white berries without any added matter (particularly whitening agents).
3.6 Black berry: Berry of dark colour generally consisting of a black pepper berry, the pericarp of which has not been fully removed.
3.7 Broken berry: Berry that has been separated into two or more pieces.
3.8 Extraneous matter: All materials other than white pepper seeds, irrespective of whether they are of vegetable (e.g. stems and leaves) or mineral (e.g. sand) origin). Black and broken berries are not considered as extraneous matter.

4. Requirements

4.1 *Description*

4.1.1 Whole white pepper is obtained in two ways as follows:

- ► from black pepper of *Piper nigrum* Linnaeus, using the whole dry berry generally picked before maturity and removing the outer pericarp, with or without preliminary soaking in water. If necessary, drying is carried out afterwards;
- ► from the whole ripe berry of *Piper nigrum* Linnaeus, removing the outer pericarp by the same procedure described above.

Berries of white pepper are almost spherical grains of diameter 3 mm to 5 mm, showing a smooth surface, slightly flattened at one pole and a small protuberance at the opposite.

Berries generally have vertical scores going from one pole to another, of a slightly darkened colour. The colour of white pepper varies from matt grey to brownish to pale ivory white.

4.1.2 Ground white pepper is obtained by crushing whole white pepper, without any added matter.

4.2 *Odour and flavour*

The flavour of white pepper when it is ground shall be characteristic, slightly sharp and very aromatic. The product shall be free from extraneous odours and flavours, including mouldy and rancid odours. The appearance of berries has no direct relation to their flavour. Small berries can be more aromatic than berries of better appearance or larger size.

4.3 *Absence of mould, insects, etc.*

White pepper shall be free from mould and living insects and practically free from dead insects, insect fragments and rodent contamination visible to the naked eye (corrected, if necessary, for abnormal vision) or with magnification if necessary in certain specific cases. If the magnification used is greater than 10 X, this fact should be mentioned in the test report. Further more, in the case of ground white pepper, impurities shall be determined according to the method described in ISO 120.

4.4 *Physical characteristics*

Whole white pepper shall meet the requirements given in Table 3.

Table 3 Requirements for physical characteristic of whole white pepper.

Characteristic	*Requirements*		*Reference test method*
	Pepper SP	*Pepper P*	
Extraneous matter, % (m/m) max.	1.0	0.8	ISO 927
Broken berries, % (m/m) max.	4.0	3.0	
Black berries, % (m/m) max.	15.0	10.0	Physical separation and weighing
Bulk density, g/l, min.	600	600	Annex B

1) These values do not apply to “Samarinda” pepper, which always contains 20% black berries.

4.5 *Whole pepper categories*

Grading of whole white pepper is based on the commercial appellations adopted by the producing country and in particular

- the place of production;
- the extraneous matter content in black or brown berries;
- the appearance, namely the size of berries;
- its bulk density

Annex C gives, as an indication, the main producing countries and the most frequently used commercial appellations.

4.6 *Chemical characteristics*

The whole or ground white pepper shall meet the requirements given in table 4.

5. Sampling

Sample the white pepper using the method described ISO 948.

Samples of whole white pepper shall be ground so that material passes through a sieve with apertures of 1 mm. Material thus ground shall be used for determining characteristics given in Table 4.

Table 4 Requirements concerning chemical characteristics of white pepper, whole or ground.

Characteristic	*Requirements*			*Reference test method*
	Pepper NP	*Pepper P or SP*	*Ground pepper*	
Moisture content, % (m/m) max.	15.0	15.0	15.0	ISO 939
Total ash, % (m/m) max. On dry basis	3.5	3.5	3.5	ISO 928
Non-volatile ether extract, % (m/m) min, on dry basis	6.5	6.5	6.5	ISO 1108
Volatile oils, ml/100 g, min on dry basis	1.0	1.0	0.7	ISO 6571
Piperine content, % (m/m) min.	4.0	4.0	4.0	ISO 5564
Acid-insoluble ash, % (m/m) max., on dry basis	–	–	0.3	ISO 930
Crude fibre, insoluble index, % (m/m) max., on dry basis	–	–	6.0	ISO 5498

6. Test Methods

The pepper samples shall be analysed to ensure conformity with the requirements of this part of ISO 959, following the methods described in International Standards referred to in tables 1 and 2 and in annexes A and B of this part of ISO 959.

7. Packing and Marking

7.1 *Packing*

White pepper shall be packed in clean, sound, sealed packages, made of a material which does not affect the product.

7.2 *Marking of whole or ground pepper*

The following particulars shall be marked on each package or on a label attached to the package:

a) name of the product and the trade-name, if any;
b) name and address of the manufacturer or packer, or trade-mark;
c) code or batch number;
d) net mass;
e) grade of the product (if classified) according to national standards;
f) producing country;
g) destination by the name of port or town;

h) any other information requested by the buyer, such as year of harvest and date of packaging
i) a possible reference to this part of ISO 959

7.3 *Labelling*

In the case of small packages intended for retail sale, labelling shall be signed and dated according to regulations in force concerning labelling of food commodities.

ANNEX A (NORMATIVE)

Whole White Pepper: Determination of Apparent Bulk Density

A.1 Scope

This annex specifies the method of determination of the apparent bulk density of whole white pepper.

A.2 Principle

Weighing a volume, exactly measure, of 1 litre of pepper.

A.3 Apparatus

A.3.1 Cylinder of capacity 1 litre or a cylinder of greater capacity, but equipped with apparatus allowing leveling of the product to the 1 litre level;

► hopper, of capacity greater than 1 litre and equipped with a gate;
► device, for fixing the hopper above the cylinder at a certain distance, to allow free fall of the product, into the cylinder from a constant height.

However, for routine control and when the apparatus described is not available, it is possible to use a cylinder of 1 litre capacity and a funnel.

A.3.2 Balance

A special balance allowing the cylinder to be hooked to one side of the beam and equipped on the other side with a suitable plate serving as tare.

A.4 Procedure

A.4.1 Determination

Weigh the empty cylinder, if necessary.

Place the cylinder on a horizontal plane and set the hopper on it with a fixing device. Pour the pepper into the hopper until it is filled. Open the gate and allow the pepper seeds to flow freely into the cylinder until the level slightly exceeds the upper level or the 1 litre level, according to the apparatus used. Level the pepper, according to the case, to the upper level in the cylinder with a ruler, or to the 1 litre level with a suitable device with which the cylinder is equipped. (In this case remove the excess seeds.) Remove the hopper and its support, then weigh the cylinder filled with the pepper.

A.4.2 Number of determinations

Carry out three determinations.

A.5 Expression of Results

A.5.1 Method of calculation

The apparent bulk density of pepper, expressed in grams per litre, is given by the mass of pepper contained in the cylinder. Take as the result, the arithmetic mean of the three determinations if the repeatability conditions (see A.5.2) are satisfied. Otherwise, carry out three further determinations. If the former conditions are still not satisfied, take the arithmetic mean of the six determinations as the result.

A.5.2 Repeatability

The difference between the results of two determinations carried out in rapid succession by the same analyst shall not exceed 5 g per litre.

A.6 Test Report

The test report shall specify the method used and the result obtained. It shall also mention all operating details not specified in this part of ISO 959, or regarded as optional, together with details of any incidents which may have influenced the results. The test report shall include all information necessary for the complete identification of the sample.

ANNEX B (Informative)

Recommendations for Storage and Transport

B.1 The packages of pepper shall be stored in covered rooms, well protected from sun, rain and excessive heat.

B.2 The store shall be dry, free of unpleasant smells and protected against penetration of insects and vermin. The ventilation shall be regulated so that good ventilation is ensured during the dry period and ventilation can be fully stopped during the damp period. Suitable provisions shall be taken to allow fumigation in the store.

B.3 The packages shall be handled and transported in such a manner that they are protected from rain, sun, or other excessive heat sources from unpleasant smells and all contamination, particularly in the holds of ships.

ANNEX C (Informative)

Main Producing Countries and Currents Trade-names of Grades

NOTE—the list is limited and is given for information.

Producing countries	Trade names of categories
Thailand....................	Premium Special Standard
Sri Lanka..................	Grade 1 special Grade 1 Grade 2 FAQ (Fair Acceptable Quality) Grade 3 Grade 4
Indonesia..................	Grade of ASTA (American Spices Trade Association)
Malaysia....................	Standard Malaysian White No. 1 (Cream label) Sarawak special White (Green label) Sarawak FAQ White (Blue label) Sarawak course field White (Grey label)
Brazil........................	Type 1 Type 2 Type 3
China........................	FAQ (Fair Acceptable Quality)