Nutritional Characteristics of Sorghums from Queensland and New South Wales for Chicken Meat Production

RIRDC Innovation for rural Australia

Australian Government

Rural Industries Research and Development Corporation

Nutritional Characteristics of Sorghums from Queensland and New South Wales for Chicken Meat Production

by Dr Rider A Perez-Maldonado and Dr Hugh D Rodrigues

November 2009

Nutritional Characteristics of Sorghums from Queensland and New South Wales for Chicken Meat Production
Publication No. 09/170
Project No. DAQ-326A

Researcher Contact Details

Dr Hugh D Rodrigues
Research Scientist
Queensland Primary Industries and Fisheries (QPIF)
Department of Employment, Economic Development
and Innovation
Pig Research Centre
280 Grindle Road
Wacol QLD 4076

Phone: 07 3406 8495
Fax: 07 3406 8494
Email: hugh.rodrigues@dpi.qld.gov.au

In submitting this report, the researcher has agreed to RIRDC publishing this material in its edited form.

Foreword

Sorghum (*Sorghum bicolour* (L) Moench) is an important cereal providing energy and nutrients to sustain humans and livestock world wide. Sorghum grain represents a major component of Australian dryland cropping systems of the north-eastern regions with about 60% of the crop grown in Queensland and the remainder in northern New South Wales. At current prices, sorghum is cheaper than wheat and maize and is highly used by the chicken meat industry. It represents substantial savings by replacing wheat or maize in poultry diets and generating substantial revenues to the Queensland/Australian economy.

Early cultivars of sorghum contained considerable anti-nutritional factors such as polyphenolic compounds and fungus contaminations that lowered sorghum nutritional value with significantly depressed growth, poorer feed and energy utilisation and sometimes with toxic effects when fed to poultry. However, Australian plant breeding programs have paid considerable attention to reduce these antinutritional factors in sorghum cultivars producing modern varieties well adapted to low rainfall and poor soil conditions which are able to improve its nutritional value and safeness when feeding livestock.

In many areas of Australia improved Australian sorghum is the preferred grain instead of wheat for poultry feeding. This is due to its apparent metabolisable energy (AME) consistency and lower price. It was recently pointed out that in chicken meat production based on sorghum diets, the breast yield variability can be large and the feed conversion ratio (FCR) slightly depressed compared to values obtained on wheat-based diets. This difference equates to 2 to 3% additional feed cost ($2-3 million) and needs to be addressed. Together with the loss in revenue due to variability in carcass composition, this poor FCR results in a significant loss to this very competitive Australian industry. This project was proposed to address these production differences and to provide the basis for research in other livestock industries particularly pigs.

This project supports the environmental sustainability of the poultry industry by delivering more accurate technical data regarding the nutritional quality of sorghum grain, such that nutritionists would be able to formulate diets of high digestibility which in turn will reduce unwanted nutrients flowing into the environment.

This project was funded from industry revenue which is matched by funds provided by the Australian Government.

This report, an addition to RIRDC's diverse range of over 1900 research publications, forms part of our Chicken Meat R&D program, which aims to support increased sustainability and profitability in the chicken meat industry through focused research and development.

Most of RIRDC's publications are available for viewing, downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Peter O'Brien
Managing Director
Rural Industries Research and Development Corporation

Acknowledgments

---

[1] Now known as Queensland Primary Industries and Fisheries (QPIF), Department of Employment, Economic Development and Innovation.

Abbreviations

AA	Amino acid
AME	Apparent metabolisable energy
ANF	Anti-nutritional factors
CP	Crude protein
CT	Condensed tannins
DM	Dry Matter
DAA	Digestible amino acid
DPI&F	Department of Primary Industries and Fisheries, Queensland[2]
FCR	Feed conversion ratio
FI	Feed intake
LWG	Live weight gain
PRDC	DPI&F QLD, Poultry Research and Development Centre of DPI&F
PGLP	Premium Grain Livestock Program

---

[2] Now known as Queensland Primary Industries and Fisheries (QPIF), Department of Employment, Economic Development and Innovation.

Contents

Tables

Figures

Executive Summary

What the report is about

This report provides technical information from the 2.5 year research project on the evaluation of Australian sorghum grains for chicken meat production.

Why the research is important

Sorghum is the fifth most important cereal in the world and the third most important cereal crop in the USA. In Australia sorghum is the most promising grain of the low rainfall and poor soil condition regions of north-eastern Queensland and northern New South Wales in which 720,000 ha are devoted to sorghum producing 2 million MT/year. About 1/2 million MT of sorghum is utilised by the chicken meat industry due to its availability and lower price. Sorghum represents $7-9 and $18-20 million in savings by replacing wheat or maize in poultry diets respectively. Sorghum grain generates about $150 million/year to the Queensland and Australian economy.

However it has been observed that Sorghum can have a lower feed conversion ratio than wheat costing the chicken meat industry $2-3m/year. This project investigated this reduction in performance of broilers on Sorghum diets.

Who the research is targeted at

The present research is directed to the poultry industry stakeholders, particularly nutritionists, feed industry manufacturers research-scientists, plant breeders, extensionists and research funding bodies. This report may also be applicable to developing regions of the world in which sorghum grain represents the main source of energy for animal production.

Background

In Australia, early cultivars of sorghum contained considerable anti-nutritional factors (ANF) such as polyphenolic compounds and fungus contaminations that lowered sorghum nutritional value with significantly depressed growth, poorer feed and energy utilisation and sometimes with toxic effects when fed to poultry. However, Australian plant breeding programs have paid considerable attention to reduce these ANF in sorghum cultivars producing modern varieties which are able to improve its nutritional value and safeness when feeding livestock. In areas of Australia, improved Australian sorghum lines are the preferred grain for chicken meat production compared to wheat due to its apparent metabolisable energy (AME) consistency and lower price. However, it was recently pointed out that breast-meat yield variability is large and the feed conversion ratio (FCR) slightly depressed compared to values obtained on wheat-based diets. This difference equates to 2 to 3% additional feed cost ($2-3 million) and needs to be addressed. Together with the loss in revenue due to variability in carcass composition, this results in a significant loss to this Australian industry. This project was proposed to address these production differences.

Aims/objectives

1. The characterisation and nutritional evaluation of sorghum obtained from various regions in Queensland and New South Wales.

2. Precise assessment of nutritional variability of sorghum found in different regional ecosystems.

3. Detailed nutritional information of main grain sorghums in terms of chemical composition, AME, digestible amino acid, main ANFs (condensed tannins and ergot), their interactions and the resultant chicken meat growth performance.

4. Comparison of the value of sorghum-based diets with wheat-based diets for chicken meat with regards to performance and carcass variability.

5. Provision of data to link these results with the Premium Grain Livestock Program group to enable development of near infra red calibrations on AME and feed intake.

6. Provide practical solutions to improve the nutritional value of sorghum and to reduce breast-meat yield variability.

Methods used

A total of 38 sorghum samples were collected over two harvest periods: year 1 (2004-2005) and year 2 (2005-2006) from various areas of NSW and Qld. Each grain was chemically analysed for ANF such as condensed tannins (CT) and ergot contamination. The AME, ileal digestibility of amino acids (AA), starch, nitrogen (N), and CT were determined including their affects on sorghum nutritional value in poultry diets.

Next, pilot studies in metabolism cages evaluated broiler growth performance for each sorghum sample collected. A control wheat-based diet with added xylanase enzyme was included in each pilot study for comparing bird performance between grains. The relationship between sorghum grain AME intake and live weight gain (LWG) and between grain AME intake and FCR during the starter and grower/finisher period were calculated and plotted and compared with grain feed efficiency obtained in wheat-based diets.

Broiler performance parameters were compared between pilot studies conducted on the 2004 and 2005 harvested sorhgums. The effect of AME determination methods, feed preparation and bird age were compared on broiler performance. The effects of adding commercial xylanase and phytase feed enzymes and synthetic cystine on selected sorghum-based starter diets were compared with wheat-based diets.

Finally, selected sorghums were evaluated in semi-commercial experiments with various feeding strategies to improve sorghum utilisation with emphasis in the starter phase period (0-21 d) in comparison to current industry standard wheat-based diets.

Results/key findings

Except for the lysine and histidine levels, the sorghum overall chemical composition between years of evaluation was consistent. However within each harvest year, the composition varied quite widely and was related to sorghum cultivar and region of crop growth. The total phosphorus (P) level was consistent between years. But it was found that about 76% of the sorghum total P is bound in the grain in the form of phytate-P which is unavailable for utilisation and is excreted. A positive correlation (r= 0.70) was found between grain available P and the grain AME, which indicates that the high level found of phytate-P may also negatively influence AA, N, minerals and energy utilisation in poultry.

To investigate this situation pilot studies using birds in cages, investigated the effect of adding phytase on top of sorghum-based diets. This resulted in a significant improvement in bird production performance. In a subsequent experiment adding phytase to a diet formulated with lower available phosphorous (AvP) and calcium (Ca) in selected sorghum-based diets tended to improve bird LWG. However, the results were not consistent with the previous results obtained when phytase was added on top of diets. In a semi-commercial floor experiment, dietary treatments also examined a commercial phytase enzyme added to a commercial sorghum control diet, either on top of the diet, or added after reducing the Av. P and Ca formulated levels of the diet. The results showed that the overall performance of birds on both phytase treatments were not different from the performance of birds on the commercial sorghum control diet. These results may indicate an economical and environmental advantage to adding phytase to sorghum diets formulated with reduced Av. P and Ca levels. More work is needed to confirm this enzyme effect, since a negative control (sorghum diet with reduced Av.

P and Ca without enzyme) was not used in the experimental design and hence this enzyme response may be due to the Av. P and ca reduction only.

Total CT levels ranged between 1.3–12.0g/kg DM in 2004 and 1.6–8.5g/kg DM for 2005. Previous to this study it was considered that Australian sorghums did not contain CT. However, our results showed that CT was present in the grain and their effect on poultry protein and energy digestion (which has not been extensively evaluated in Australia) were studied with emphasis on AA digestibility and the negative effect of CT in much younger birds (0-7 and 7-14 d old). During metabolism studies a strong inverse relationship was found between AME and the grain free-CT ($r = -0.725$) and bound-CT ($r = -0.773$) fractions. This negative CT effect on energy utilisation was evident only in young chickens (14-21 d old). During this study, it was calculated that the reduction in AME in younger birds (14-21 d) was about 0.9-1.0 MJ/Kg DM when compared with AME values obtained in older birds (22-28 d). Such a difference in AME will have a significant nutritional consequence particularly during the bird starter phase (0-21 d old). Normally in Australia, AME values, which are obtained with older birds (22-29 d), are used to formulate diets for birds between 0-21 d. We concluded that the AME content of Australian sorghum has been overestimated by about 1 MJ/Kg DM. In addition, we found that it was bird age and not method of preparation that was the main aspect that influenced sorghum AME results. Another strong relationship found was between sorghum CT content and tryptophan digestibility ($r = 0.673$) which was found in this study to be the second limiting AA due to its lower content and digestibility value.

In regards to sorghum protein, it was found that its digestibility was 15% and 11 % lower in 2004 and 2005 respectively than determined in wheat grain. The low protein digestibility was associated with low cystine (52% and 53%), threonine (58% and 68%), tryptophan (64% and 78%) and histidine (64% and 73%) for 2004 and 2005 respectively. Cystine and tryptophan were nominated the first and second limiting AA due to their consistent lower availability. Arginine which has been indicated by other reports to be the first limiting AA was found to be at adequate levels in this study. More importantly, cystine, a major sulphur AA component in the crude protein (CP) of sorghum, with a determined digestibility value of about 52.5%, suggests the α-kafirins (which are rich in cysteine) are one of the main factors responsible for the lower protein digestibility of Sorghum. It is suggested by others that the low CP digestibility of sorghum may also influence its starch variability and its digestibility. However, in our study the lower protein digestibility was not highly correlated with sorghum starch digestibility. We found that sorghum starch digestibility value does vary considerably among cultivars (2004 = 85.3%, range 71.3-92.9; and 2005 = 92.0% range 84.6-97.9), hence there's an opportunity for improving its digestibility in cultivars which exhibit lower to middle digestibility. Starch digestibility improvement can be achieved by using external enzymes additives, which have been shown to improve starch digestibility in other grains.

The metabolism broiler cage evaluations consistently indicated that in general during the starter period (0-21 days), independent of sorghum variety or region of cultivation, birds offered sorghum-based diets exhibited a poorer FCR than birds in the control wheat diet, which had a superior LWG than those given the sorghum treatments. This poor FCR at 21 d was strongly linked ($r = 0.704$) with the total intake of CT from sorghum. This was supported by the good performance achieved by birds offered sorghum diet which had the lowest sorghum CT content. All this suggests the importance of CT as an ANF present in Australian sorghum as CT are known to bind to digestive enzymes and reduce the digestion and availability of dietary compounds including AA in poultry. During the grower/finisher phase (22-42 d), the general trend was that birds consuming sorghum-based diets exhibited a similar FI, and LWG, and were as efficient as birds consuming wheat-based diets. The carcass evaluation at 43 d revealed that with the exception of four sorghum-based diets in 2004 and one sorghum in 2005, all sorghum samples produced birds with similar breast-meat yield and similar fat pad value than birds consuming wheat based diets.

The broiler floor pen semi-commercial growth experiments, also showed that during the starter period (0-21 d), birds consuming wheat-based diets had a significantly higher LWG equivalent and a better FCR than birds on sorghum diets (FCR 1.397 vs. 1.433). During the grower/finisher period, birds on

sorghum diets consumed similar energy and had a LWG similar to birds on the wheat diet, with some sorghum cultivars exhibiting a superior LWG with the lowest FCR which agreed with the results obtained during the same growth period during metabolism cages studies. The results of both the previous metabolism cage studies and the current floor pen studies conducted during this project make it apparent that the main limit to birds fed sorghum growing as well as those on wheat-based diets only occurs during the starter period (0-21 d) when birds somehow were not able to efficiently utilized sorghum energy.

With experimental data obtained in this study, it is believed that ANF (condensed tannins, phytate-P, reduced AA digestibility or a combination of all these) in sorghum affected its potential energy value and use in younger birds. Selected feeding strategies were undertaken with two selected sorghum samples to improve grain energy utilisation, particularly during the starter phase (0-21 d). With these two sorghums, the AME value was reduced by 0.8 MJ producing similar FI and LWG as birds consuming the wheat diets. Similarly the FCR of birds fed on these two energy reduced sorghums tended to be better when compared with birds offered other sorghum diets. The strategies applied during this study were discussed and linked with results obtained in the previous experiments that showed low energy utilisation, poor utilisation of starch and the decreased digestibility of the protein during the starter growth period. The studies on feed strategies also discusses the bird energy utilisation linked with tannin-protein complexes factors. Using the reduced energy strategy in selected sorghums also confirms that during the grower/finisher period these two sorghum samples and all other sorghum diets produced an excellent bird performance as expected. Therefore any restriction of sorghum energy utilisation appears to be confined to the starter period only.

Implications for relevant stakeholders

Industry nutritionists

- Chemical analyses of sorghum samples were consistent over 2004 and 2005. Therefore the data reported here can be valid for at least the next seven years.

- Within year of evaluation, there was a consistently large variability between regions and cultivars, so any extrapolation of data needs to be taken with care.

- The total bound P as phytate-P, which represented about 76% of evaluated sorghum samples, may negatively influence AA, N, DM, minerals and energy utilisation, with a high correlation (r=0.70) between available P and sorghum AME.

- The lower cystine and tryptophan digestibility of Sorghum samples was associated with their levels of CT and this may affect bird performance in sorghum-based diets, particularly during early bird growth.

- The reduction in AME found in young birds (0-21 d old) was negatively correlated with the free CT (r=0.725) and bound CT (r= -0.773) fractions found in sorghum grain. It was proposed that AME will continue to reduce as birds are younger.

- Such an AME difference have a significant nutritional consequence particularly during the bird starter phase (0-21 d old) growth period. Normally in Australia AME values, which are obtained with older birds, (22-29 d) are used to formulate diets for birds between 0-21 d.

- We demonstrated that the sorghum AME value was reduced when bird age was reduced by one week and that there was no influence of method of feed preparation. It was calculated that for a one week bird age reduction, sorghum AME was reduced by about 0.8-1.0 MJ. It may be possible that use of this adjusted grain energy value may also improve carcass composition as the energy/protein ratio in the diets will be more balanced. However more research is needed to investigate the potential effect of CT on AME determined in much younger birds (0-7 d old and 7-14 d old) and when fed these sorghum-based diets.

Sorghum breeders

- With CT found in sorghum grain it raises concerns about the nutritional value of sorghum in poultry.

- There may be some sorghums lines with low phytate-P.

Recommendations

- Nutritionists are recommended to update their databases with values obtained in this report.

- Prior to dietary formulation, chemical analysis of sorghum grain is needed at least for N, but an overall mean value for other parameters such as P, phytate-P, AME, starch, and amino acids can be used with acceptable results.

- It is recommended that sorghum breeders use international accepted methods for CT determination in important sorghum lines.

- There is a need for reducing CT levels in sorghum lines.

- There is a need to evaluate the negative CT effect in younger birds (0-7 and 7-14 d old) and its interaction with energy, and the utilisation of other nutrients.

- The addition of phytase showed positive improvement in FI and LWG without negatively affecting FCR. But subsequent experiments with the use of enzymes and selected AA were not conclusive. Thus it is recommended to continue poultry research on the response of various enzymes levels and types in combination with AA (cystine and trptophan) as indicated in the report.

- Due to age of bird and the negative CT effect, it is necessary for nutritionists to adjust the AME value by -0.8 MJ to be applied in the formulation of broiler starter diets in order to improve sorghum utilisation particularly during the early starter period.

- The adjustment of AME in sorghum grain diets was linked to a reduction of fat and increased breast meat yield. However more research is needed to investigate the potential effect of CT on AME determined in much younger birds (0-7 d old and 7-14 d old) and when fed these sorghum-based diets.

1. Introduction

In Australia sorghum grain is a major component of the dryland cropping system with production of about 2,000 tonnes from the north-eastern regions of the continent with 60% of the crop grown in Queensland (Qld) and the remainder in northern New South Wales (NSW). Approximately 0.3 Mt of sorghum is used by the chicken meat industry. With sorghum price on average approximately $50-60/tonne cheaper than wheat and $65-75/tonne cheaper than maize, its use in poultry diets can present savings of $6-8 million and $16-18 million if used to replace wheat or maize in poultry diets.

1.1   Historical view

Historically sorghum was believed to contain considerable anti-nutritional factors (ANF) with known toxic effects when fed to poultry (McClymont and Duncan, 1952). The major cause of this problem was the effect of tannins as demonstrated by Connor *et al.,* (1969). They showed depressed performance in crossbred cockerels offered diets of high-tannin sorghums (25 g/kg) compared with low-tannin (1 g/kg) sorghums. The digestibility of essential AA in high-tannin sorghums has been reported as about 20 % lower than in low-tannin sorghums (Anon, 1989). Recently, it has been pointed out that Australian plant breeding programs have paid considerable attention to selecting for low-tannin cultivars producing varieties with approximately zero tannin content (Walker, 1999; Bob Henzel, sorghum breeder at Hermitage Research Station, personal communication, 2004). It is therefore expected and believed by industry that Australian grain sorghum currently does not pose a tannin problem in the feeding of livestock.

In many parts of the world, when compared with maize, low-tannin sorghums have similar nutritional value and offer an excellent alternative ingredient for preparing diets for the production of non-pigmented poultry products (Leeson and Summers, 1991; Nyachoti *et al.,* 1997).

In many areas of Australia, sorghum is the preferred grain instead of wheat for poultry feeding, due to its apparent metabolisabe energy (AME) consistency and lower price. It was recently pointed out that for chicken meat production using sorghum-based diets, the breast yield variability is large and the feed conversion ratio (FCR) is slightly depressed compared to values obtained on wheat-based diets. This difference in production equates to an additional 2-3% in feed cost and consequently needs to be addressed. Previous Australian research investigating the reasons behind this poorer FCR and breast-meat yield variability included grain AME determinations, the addition of essential amino acids with extra digestible lysine in combination with the addition of enzymes from various sources in the diets. Unfortunately all these have not completely resolved the problem.

1.2   Other toxins

Ergot, a fungi affecting sorghum that contain toxic substances, have been found in all sorghum producing regions in Qld and NSW. Broiler chick growth trials carried out at DPI&F, Poultry Research and Development Centre (PRDC) demonstrated that 25g ergot/kg diet significantly depressed growth with a poorer FCR and AMEn (Mannion and Blaney, 1998). This project examined if ergot is a contributing factor for the observed poor performance with sorghum-based diets.

1.3   Condensed tannin (CT) determination

Various authors have already reviewed the nutritional aspects of sorghum grain for poultry feeding (Walker, 1999; Nyachoti *et al.,* 1997; Gualtieri and Rapaccini, 1990). Interestingly, the values reported for sorghum CT were normally expressed as catechin equivalents percent, measured with the Vanillin-HCl assay. Hence it is believed that most breeding programs conducted on sorghum cultivars that aimed to eliminate CT have used this assay for CT determinations. A major criticism directed at this

Vanillin/HCL method as the technique for CT evaluation, is that the standards used (catechin and tannic acid) to calculate the CT content in plant material bear little relation to the forms of CT that are usually found in plant tissue (Perez-Maldonado, 1994; Mole and Waterman, 1987; Muller-Harvey *et al*., 1988). The use of Butanol/HCL in combination with extracted purified standards from the plant or tissues being evaluated is the more universally accepted technique for CT evaluations (Perez-Maldonado and Norton, 1996; Perez-Maldonado, 1994; Porter *et al.,* 1986; Hagerman and Butler, 1989; Hagerman, 1991). It would therefore appear appropriate that a more detailed CT evaluation using this technique is needed to confirm if Australian sorghum cultivars are indeed low-tannin or whether they contain sufficient polyphenolic compounds to exert negative effect on poultry performance.

1.4   Condensed tannins and drought

Condensed tannins and other phenolic compounds, which are present in sorghum grain, can rapidly increase within plant tissue particularly if environmental conditions are adverse; including the prolonged drought periods experienced during 2000-2007 in Australia. In Australia, CT has not been extensively evaluated for its effect on poultry protein digestion. It is proposed that during drought conditions, the CT levels in sorghum cultivars may have changed and are now present in moderate levels in the grain. Additionally during feed processing and pelleting, the heating of phenolics including CT (free fraction) from sorghum grain may form complexes mainly with plant proteins rendering them unavailable for utilisation. Carbohydrate complexes can also be formed rendering them also unavailable during digestion, with further complexes between free CT fraction and the host digestive enzymes reducing their activity and efficiency. Complexes can also be formed between CT from sorghum and other plant protein ingredients. Recent advances in knowledge on the effects of CT and their interaction in the digestive system with nutrients and microflora host, indicate that these theories need to be investigated.

1.5   Research benefit

The major benefit of the research was to provide the Australian poultry industry with a comprehensive sorghum characterisation and a regional evaluation of at least three major sorghum cultivars representing at least 60% of all sorghum production regions (including white sorghum cultivar). Sorghum grain is the main summer grain crop in most regions of Qld and plays a key role in providing feed grains to the beef, dairy, pig and poultry industries. It is a good rotation crop that tolerates heat and moisture stress and performs better than maize on soils with marginal potassium levels. The 1994-98 average for Queensland was 450,000 ha yielding 1.8 t/ha generating about $126 million/year to the Queensland/Australian economy. The proposed research will primarily benefit the chicken meat industry but will also provide information which can be the basis for further research with potential value to other animal industries.

1.6   Chicken industry

The Australian Chicken Meat Industry in Australia has a retail value in excess of $3.6 billion, producing around 420 million birds to yield 700,000 tonnes of chicken meat annually. During 2005, the annual per capita consumption of chicken meat in Australia increased to 38.4 kg, overtaking beef and it is expected to increase at 3-4% annually. At current prices, sorghum is approximately $50-60/tonne cheaper than wheat and approximately $65/tonne cheaper than maize. It is estimated that the Australian chicken meat poultry industry use of sorghum is about 0.4-0.5 Mt/annum representing savings of $8-10 million by replacing wheat and about $18-20 million by replacing wheat or maize in poultry diets.

The slightly poorer FCR performance of sorghum-based diets when compared with wheat-based diets represents a significant 2 to 3% additional feed cost ($2-3 million) to the chicken meat industry.

Together with the additional loss in revenue due to variability in carcass composition, this results in a significant loss to this very competitive Australian industry.

1.7   Objectives

This research project had the follow objectives:

- The characterisation and nutritional evaluation of sorghums obtained from various regions in Queensland and New South Wales.

- Precise assessment of nutritional variability of sorghum found in different regional ecosystems.

- Detailed nutritional information of main grain sorghums in terms of chemical composition, AME, digestible amino acid, main anti-nutritional factors (condensed tannins and ergot) and the resultant chicken meat growth performance.

- Comparison of the value of sorghum-based diets compared with wheat-based diets for chicken meat with regards to performance and carcass variability.

- Provision of data to link RIRDC results with PGLP group to enable development of NIR calibrations on AME and feed intake.

This research study also supports the environmental sustainability of the poultry industry by delivering more accurate data regarding the nutritional quality of sorghum grain, enabling nutritionists to create and formulate precise diets which in turn would reduce costs, nutrient wastage and nutrient and its flow into the environment.

2. Grain sampling and chemical composition

2.1 Introduction

In 2004, data from the NSW Department of Primary Industries (Agnote DPI 473, 2004) indicated that the main sorghum varieties available for planting in Australia for 2004-2005 were: **Hylan**: Enforcer, Armour, Dominator, Liberty; **Pioneer**: 85G83, Bonus MR, Hi-Bred; **Pacific Seeds**: MR Bounty, MR Buster, MR Maxi, MR 43, MR 32, MR Goldrush and MR Pacer.

In 2005 as a result of drought, which considerably reduced subsoil moisture levels, the production of grain sorghum declining by 6 percent to 1.7 million tonnes (Australian Crop Report June 2005). Therefore, during this year fewer varieties were available for collection. The following table represents the main areas in Qld and NSW from which major cultivars were obtained.

Table 1   Main production areas, markets and harvest periods in Qld and NSW from which major cultivars were obtained for this study

Area	State	Town	Area	Market	Harvest
Liverpool Plains	NSW	Gunnedah		Sydney	Mid-February
North West NSW	NSW	Moree, Boomi	Goondiwindi	Sydney and Brisbane	Mid-February
North East NSW	NSW	Yellarbon	East Texas	Sydney and Brisbane	Mid-February
Southern Qld	North Downs	Kingaroy	Kingaroy/ Jandowa		
Southern Qld	Western Downs	Condamine Moonie Roma Dalby		Qld	Early March
	Central Downs	Clifton Pittsworth Dolby/Bowenville		Qld	Early March
Central Qld	Qld	Emerald		Qld	Early January & late April-May

Sorghum grains can vary in their chemical and physiological characteristics depending on variety and regional growing conditions. One of the most notable physiological characteristics is grain colour, which can range from white, cream, red and brown. Usually the grain colour in sorghum has been linked to its tannin content, a compound which has been categorized as a major antinutritional factor (ANF) in sorghum.

It has been reported that white sorghums cultivars (lighter seed coat) contain less tannin and are superior in nutritional values than those sorghums of a darker seed colour (Nyachoti *et al*., 1997). It is generally assumed that high tannin sorghums have lower nutritional value than maize in broiler diets, because tannins can reduce bird feed intake, weight gain and feed efficiency (Kumar *et al*., 2007).

Australian plant breeding programs for sorghum have paid considerable attention to developing low-tannin cultivars, producing varieties with approximately zero tannin content (Walker, 1999; Bob Henzel, sorghum breeder at Hermitage Research Station, personal communication, 2004). Consequently it is expected that Australian sorghum should currently pose no tannin problems when used in the feeding of livestock. Thus the characteristic of various sorghum cultivars in terms of their nutritional value were evaluated with broiler chickens during two years corresponding to 2004-2005 and 2005-2006 sorghum crop cycle.

2.2   Materials and Methods

2.2.1   Collection periods

Grain sorghum samples were collected in two rounds; the first corresponding to the January-June 2004 harvest season (Table 2) and the second during a similar period in the 2005 harvest season (Table 3). There were a greater range of varieties collected from Qld (12) than from NSW (5).

2.2.2   Grains types and amounts supplied

Quantities of about 600-1200 kg of grain sorghum were received at PRDC in bulk bugs with appropriate identification for variety, harvest date and site. Sorghum samples were obtained from the two main Australian breeder companies (Pioneer and Pacific Seeds) who supplied at least two main grain sorghum cultivars representing major regional sorghum areas in Qld and NSW as described in the Tables below.

Grain sorghums cultivars MR 43 and MR Buster are currently the main modern major cultivars used in Australia and were included as a part of this project and they represent about 60% of the total cultivars of sorghum planted in Australia and were included as a part of this project. However a number of other important cultivars were also studied, these included Hyland, and Pioneer. All sorghum samples from this study were collected through Phil Albury from Phil Brodie Grains (Toowoomba). During 2004-2005, additional sorghum grain samples were also obtained from the Premium Grain for Livestock Program (PGLP) group and evaluated within the project to ensure that the project results provided as much information as possible and also to help test the accuracy of PGLP NIR calibrations for AME and feed intake.

This additional work was conducted to provide a 'proof of concept' that diets formulated using grains selected on the basis of AME intake result in differences in bird performance and/or cheaper diet formulation.

2.2.3   Grain samples evaluated

Therefore during year 1 (2004-2005) seventeen (17) sorghum samples were collected from various areas of NSW and Qld with additional samples (seven) provided by PGLP group (see Table 2) totalling 24 samples. During year 2 (2005-2006) fourteen (14) samples were collected from various regions in NSW and Qld (see Table 3). Therefore a total of 38 sorghum samples representing main sorghum areas were collected and evaluated during this study.

2.2.4   Grain testing

At arrival at PRDC sorghums samples were labelled and stored inside a commercial shed suitable for grain storage. Sub-samples of each grain were collected and sent for chemical analysis which included an initial proximate composition (dry matter, nitrogen, phosphorous, calcium), full AA profile, gross energy, and starch. Antinutritional Factors (ANF) such as condensed tannins and ergot contamination were also determined in all cultivars. These analyses were conducted at the facilities of DPI&F's Queensland ARI laboratories, the University of Queensland (School of Land and Food Sciences

laboratories), and Sydney University, which each used their own internal approved internal analytical procedures/methods.

2.2.5 Analytical methods

Proximate analysis was undertaken according to the methods of the AOAC (1975, 1980, and 1984). Gross energy, was determined using a LECO AC-350 automatic calorimeter (LECO Corporation, St. Joseph MA, USA) on pelleted (~ 1000 mg) samples. Instrument was calibrated using AR grade benzoic acid. Nitrogen (N) was analysed by a combustion method (Sweeny 1989) using an ELEMENTAR Rapid N analyser. The instrument was calibrated using AR grade aspartic acid. Dry Matter was determined by heating to constant weight at 105°C under an atmosphere of Nitrogen using an automated LECO Thermo-gravimetric TGA 701 Analyser (LECO Corporation, St Joseph Michigan USA). The ash content was determined by further heating the dry samples in the Thermo-gravimetric Analyser at 610 °C to constant weight in an atmosphere of oxygen. Phosphorus was measured by a colorimetric method (A.O.A.C. 1980) following ignition at 610°C for 3h and concentrated HCl digestion. Crude fat was determined by soxhlet extraction using petroleum ether (boiling range 40-60°C) for 16 hours, (Kent-Jones and Amos, 1957). Calcium was measured by atomic absorption flame spectroscopy using a nitrous oxide-acetylene flame. Samples were prepared by igniting at 610°C for 3 hours followed by a concentrated HCl digestion. Samples were further diluted in KCl to prevent interference caused by ionisation of calcium (A.O.A.C. 1984). Crude Fibre was determined by the method of AOAC (1975) adapted for the Fibertec 2021 Fibrecap System (Application Sub-Note ASN 3801) by FOSS TECATOR.

Analyses of AA were performed by reversed phase high performance liquid chromatography (waters HPLC) after hydrolysis with 6M hydrochloric acid at 110 °C for 18 h under reflux conditions (Spackman *et al*., 1958; Finlayson, 1964) and derivatisation with AccQ, Fluor reagent, 6-aminoquinolyl-N-hydroxysuccinimidyl carbamate (Waters AccQ, Tag method). Cystine and methionine were determined as cysteic acid and methionine sulphone, respectively, using the same method as above, following performic acid oxidation (Moore, 1963).

Condensed tannins were measured by the Butanol/HCl method by Dalzell and Kerven, (1998).

Analysis of ergot in sorghum grains during 2004 and 2005 harvest years was performed at the Animal Research Institute by de method developed by Blaney *et al.,* (2003).

2.3   Results and Discussion

The sorghum grain collected by PRDC from Qld and NSW during 2004 and 2005 season are listed in Tables 2 and 3 respectively. The results of the chemical analysis showing the grain composition for the 2004 and 2005 harvest periods are presented in Tables 4 and Table 5 respectively. Mean values and range of data related to chemical composition for both years are presented in Tables 6 and 7 respectively.

The present study revealed that Pacific Buster and Pacific MR 43 from both Qld and NSW were the most predominant grains (14 out of 21 sorghums in 2004 and 9 out of 14 in 2005). Relevant varieties from Pioneer and Hyland were also included in the collection with all sorghum varieties showing red, red-brown colour except for Hylan Liberty which is white. Studies by Boren and Waniska, (1992) have shown that the belief that tannin content was related to darkness of seed colour was not necessary true and also indicated that the colour of sorghum seed coat is not an adequate measure of tannin content. Therefore, Waniska *et al*., (1992), developed qualitative tests to enable quality control personnel to rapidly detect sorghums that contain tannins.

The chemical analysis of varieties within years (Tables 4 and 5) showed that sorghum grain varied quite widely in chemical composition. Although the mean value for crude protein (CP) content between years was consistent (11.7 and 11.6 for 2004 and 2005 respectively), the range of values

varied widely (Tables 6 and 7). Literature reports of CP levels within sorghum varieties vary significantly and can range from 7.2 -15%, and are most likely to be between 10-13% (Gualtieri and Rapaccini, 1990; Nyachoti *et al.*, 1997; Walker, 1999; Dicko *et al.*, 2006). The CP levels in the present study, ranged from 9-14% in 2004 and from 8-13% in 2005. In the present study, there was considerable variation in the amount of CP within varieties and between regions. For example in 2004, Pacific Buster CP ranged from 9.1-12.9 %, while Pacific MR 43 showed lower variability with levels ranging from 11.6–13.5 %. It would appear that within varieties, some regions (North Down region in Qld) produced sorghums with the lowest CP content as shown during 2004 for the varieties Hylan liberty (white sorghum) and Hylan dominator (red sorghum). The sorghum chemical composition review by O'Brien (1999) reported significant genotype differences in CP and also in tannins.

Table 2   Sorghum varieties and location collected during 2004-2005 season

Area	State	Towns	ID	Area sown	Variety	Kg
Liverpool Plains	NSW	Gunnedah	11	55%	Pacific Buster	1035
Liverpool Plains	NSW	Gunnedah	12	10%	Pacific MR 43	1100
North West NSW	NSW	Moree, Boomi/ Goondiwindi	1	18%	Pacific MR 43	1201
North West NSW	NSW	Moree, Boomi/ Goondiwindi	2	35%	Pacific Buster	980
North East NSW	NSW	Yellarbon/East Texas	3	20%	Pacific MR 43	929
North East NSW	NSW	Yellarbon/East Texas	4	35%	Pacific Buster	1058
South Qld	North Downs	Kingaroy/Jandowae	5	3%	Hylan Liberty	683
	North Downs	Kingaroy/Jandowae	6	10%	Hylan Dominator	422
	Western Downs	Dalby/Warra	7	10%	Pioneer Bonus	1080
	Western Downs	Dalby/Warra	8	2%	Pioneer 85G83	960
	Central Downs	Clifton	9	22%	Pacific MR 43	1000
		Pittsworth	10	34%	Pacific Buster	1060
		Dolby/Bowenville	13	2%	Hylan Liberty	1096
Central Qld	Qld	Emerald	15	38%	Pacific MR Buster	1120
Central Qld	Qld	Emerald	16	20%	Pacific MR 43	720
	Western Downs	Dalby	14		Pacific MR 43	902
	Western Downs	Dalby	17		Pacific MR 43	873
	Qld (2000)	Biloela	18		Pacific Buster*	200
	Qld (2000)	Biloela	19		Pac. Buster-micro	200
Wheat	NSW (2002)	Wagga Wagga	20		H45*	200
Wheat	NSW (2000)	Narrabri	21		Oxley*	1000
Wheat	NSW (1999)	Narrabri	22		Waxy wheat*	200
Sorghum	Qld (2003)	Biloela	23		Waxy isoline*	200
Sorghum	Qld (2003)	Biloela	24		Normal isoline*	200

* These varieties were supplied by PGLP and used as connectivity varieties

In the present study, with the exception of lysine (in 2004), amino acid (AA) level in the grain was highly positive correlated (~0.90) to CP content in the grain. Therefore, it is expected that grains with higher CP content displaying larger AA values would need less AA from protein meals during diet formulation, and thus saving on ingredients cost. When sorghum was compared with wheat samples, wheat presented a higher CP (range 17-21%) and nearly double the AA values, except for leucine. This poorer AA level content of sorghum can be easily overcome by first formulating and preparing poultry diets using well balance protein meals (soybean meal) or by a combination of meals (such as

soybean, meat and bone, sunflower, canola meal) aided with supplementation of synthetic commercially available AA (lysine, methionine, and trytophan).

Total phosphorus levels ranged from 2–3.9 g/kg DM in 2004 and was consistent in 2005 with a range value 1.9-4.1 g/kg DM, while calcium was found in only trace amounts of less than 0.1% in both years. These values were found to be similar to expected values. All sorghum samples were analysed for phytate-phosphorus, representing 62% (40-74% range) and 78% (58-83% range) for 2004 and 2005 respectively. Literature reports have indicated that phytate-phosphorus forms a large percentage of total P, (accounting for 66-93% of the total P in the plant material) with concentrations affected by cultivar, climate, environment and processing factors (Selle *et al*., 2003). Phytate may negatively influence AA, N, DM, minerals and energy utilisation in poultry but this situation can be ameliorated by the use of phytase enzymes in poultry diets (Cowieson, 2006). Therefore, feed enzymes application has been a strategy proposed during growth experiments.

Table 3   Sorghum varieties and location collected during 2005-2006 season

Area		Pallet ID	Variety	Property ID	Kg
Southern downs	Qld	A	Pac. MR 43	L. Chandler	997
Lowood, Lockyer	Qld	B	Pac. Buster		1160
Western Downs	Qld	C	Pioneer 86G87	L. Gray	1118
Central Downs	Qld	D	Pac. Buster	C. Orr	1027
Lowood, Lockyer	Qld	E	Pac. Buster		1200
Central Downs	Qld	F	Pac. MR43	C. Orr	975
Dalby	Qld	G	Pac. Buster	D Brown	1042
Western Downs	Qld	H	Pioneer Bonus	P. Egan	985
Dalby	Qld	I	Pioneer Bounty	D Browne	1162
Southern Downs	Qld	J	Pioneer Bounty	L. Chandler	1053
Northern downs	Qld	K	Hylan Liberty	White sorghum	1000
Liverpool plains	NSW	L	Pac. MR 43		1000
Liverpool plains	NSW	M	Pac. MR 43		1000
Liverpool plains	NSW	N	Pac. MR Buster		1000

Although maize was not part of this study, sorghum is generally reported to have higher CP levels than maize with 8.8-12.2% but which has shown less variability between growing locations (Nyachoti *et al*., 1997; Walker, 1999).

The AA profiles of the experimental grains for 2004 and 2005 are presented in Tables 4 and 5 respectively. Sorghum has been reported to be deficient in lysine, methionine and threonine levels (Nyachoti *et al*., 1997; Walker, 1999). The AA profiles reported for the sorghum grains are similar to expected values (Ravindran *et al*. 1998; Rhône-Poulenc Animal Nutrition, 1993; Oduguwa *et al*., 2007). In comparison with maize, sorghum grains have similar levels of lysine, methionine and cystine, higher isoleucine and tryptophan and lower digestible protein levels. However as sorghum generally has a greater (2%) protein level, the essential AA availability from sorghum and maize are similar (Gualtieri and Rapaccini, 1990; Nyachoti *et al*., 1997; Walker, 1999; Oduguwa *et al*., 2007). In comparison with wheat, sorghum exhibited nearly half the amount in arginine, lysine, methionine, cystine, threonine, tryptophan and valine, and similar levels of phenylalanine and tyrosine.

Table 4   **Sorghum grains chemical composition (g/kg DM) 2004 harvest**

Analysis	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	20*	21*	22*
Dry matter (%)	88.3	88.1	88.3	88.2	87.1	87.7	88.6	88.2	87.8	87.6	87.0	87.0	88.6	89.2	87.1	87.3	89.2	91.1	90.5	90.2
Crude protein (%)	13.5	12.6	12.9	12.9	8.9	10.4	10.6	11.6	11.8	9.1	11.1	11.9	13.6	11.6	12.2	11.6	11.8	17.5	20.9	17.4
Total phosphorous	3.7	3.3	3.4	3.4	2.5	3.3	2.6	3.2	2.0	2.5	3.4	3.3	3.9	2.6	3.1	3.3	2.5	3.2	3.9	3.9
Phytate phosphorous	2.9	2.5	2.8	2.2	0.8	2.2	1.3	2.4	1.5	1.5	1.4	1.8	2.7	1.3	0.96	2.0	2.2	n/a	n/a	n/a
Free condensed tannins	6.4	6.4	5.9	5.2	1.3	6.1	8.5	11.2	5.6	5.8	7.9	8.6	1.5	9.4	6.2	7.1	8.7	0.3	0.3	0.3
Bound tannins	1.4	1.0	1.3	1.0	0	0.6	1.4	0.8	1.5	1.0	1.9	1.6	0.3	1.8	0.9	0.8	1.7	0.0	0.0	0.0
Total tannins	7.8	7.4	7.2	6.2	1.3	6.7	9.9	12.0	7.1	6.8	9.8	10.2	1.8	11.2	7.1	7.9	10.4	0.3	0.3	0.3
Crude fibre	20	19	21	20	23	19	21	17	19	18	18	19	19	20	19	19	20	27	28	28
Starch	657	612	640	612	640	667	595	605	643	645	634	641	627	636	633	631	606	n/a	n/a	n/a
Essential amino acids																				
Arginine	5.2	4.6	5.0	4.8	3.8	4.2	4.1	4.5	4.7	3.6	3.7	4.2	4.6	4.4	4.3	4.3	4.2	7.3	9.2	7.5
Leucine	16.6	16.0	16.7	16.4	10.4	12.8	12.8	14.0	14.2	10.5	13.6	14.7	16.6	13.9	15.4	14.1	13.8	9.8	11.7	10.0
Lysine	2.4	2.5	2.4	2.5	2.7	2.9	2.5	2.6	3.2	3.0	2.9	3.4	3.7	3.4	3.3	3.5	3.6	4.4	5.1	4.5
Methionine	1.1	1.3	1.4	1.4	1.0	1.0	1.1	1.4	1.1	1.4	1.5	1.7	1.8	1.7	2.0	1.4	1.4	2.6	4.2	3.2
Phenylalanine	5.8	5.0	5.2	5.1	3.0	3.7	3.8	4.4	4.1	2.8	3.6	3.9	4.6	3.9	4.1	3.7	3.6	6.2	7.3	6.0
Cystine	1.4	1.6	1.9	1.8	1.0	1.2	1.5	1.8	1.4	1.4	1.5	1.7	1.8	1.5	1.9	1.7	1.7	3.5	5.6	4.4
Histidine	2.1	1.9	2.1	1.9	1.2	1.5	1.5	1.7	1.7	1.2	1.4	1.6	1.7	1.6	1.7	1.5	1.5	3.0	3.5	3.1
Isoleucine	4.8	4.5	4.7	4.6	3.2	3.8	3.7	4.1	4.2	3.2	4.0	4.3	4.9	4.1	4.4	4.1	4.1	4.9	6.0	5.0
Threonine	3.3	3.1	3.3	3.1	2.3	2.6	3.2	3.6	2.9	2.2	2.6	2.8	3.3	2.8	2.9	2.7	2.8	4.3	5.1	4.0
Tryptophan	1.6	1.5	1.6	1.5	1.1	1.2	1.3	1.4	1.4	1.0	1.3	1.4	1.7	1.5	1.5	1.4	1.5	1.6	2.4	2.0
Tyrosine	4.3	3.6	3.8	3.7	2.1	2.7	2.7	3.2	2.9	2.0	2.5	2.8	3.3	2.8	3.0	2.6	2.6	4.2	4.9	4.1
Valine	5.8	5.5	5.8	5.7	4.0	4.8	4.7	5.1	5.3	4.2	4.9	5.3	5.9	5.2	5.5	5.2	5.2	6.1	7.4	6.3

Note: = 20, 21 and 22 are wheat samples, *= PGLP samples; Calcium was detected only in trace amounts (<0.1%); Ergot analysis reported values <0.01 ppm; n/a= not analysed..1= Pacific MR 43 (Moree, Boomi/ Goondiwindi); 2 = Pacific Buster (Moree, Boomi/ Goondiwindi); 3= Pacific MR 43 (Yellarbon/East Texas); 4= Pacific Buster (Yellarbon/East Texas); 5= Hylan Liberty (Kingaroy/Jandowae); 6= Hylan Dominator (Kingaroy/Jandowae); 7= Pioneer Bonus (Dalby/Warra); 8= Pioneer 85G83 (Dalby/Warra); 9= Pacific MR 43 (Clifton); 10= Pacific Buster (Pittsworth); 11= Pacific Buster (Gunnedah); 12= Pacific MR 43 (Gunnedah); 13= Hylan Liberty (Dolby/Bowenville); 14= Pacifc MR 43 (Dalby); 15= Pacific MR Buster (Emerald); 16= Pacific MR 43 (Emerald); 17= Pacific MR Buster (Dalby); 20= H45 (Downside Wagga Wagga); 21= Oxley (Narrabri); 22= Waxy Oxley (Narrabri)

Table 5   Sorghum grains chemical composition (g/kg DM) 2005 harvest

Analysis	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Dry matter (%)	89.1	88.9	89.2	89.8	88.6	89.5	89.2	89.9	90.1	89.5	89.1	89.1	90.1	90.3	89.9
Crude protein (%)	11.3	12.9	12.4	12.3	12.9	11.6	13.3	11.4	12.1	8.4	9.1	9.9	12.4	12.3	12.2
Total phosphorous	2.5	2.9	1.9	3.5	2.7	2.6	4.1	2.5	2.8	2.5	2.3	3.4	2.9	2.8	n/a
Phytate phosphorous	1.4	1.8	1.1	2.9	1.8	2.7	3.0	1.7	2.5	2.2	1.8	3.4	2.4	2.3	n/a
Free condensed tannins	6.1	5.6	4.8	4.4	5.7	4.9	5.6	5.5	4.1	5.5	1.6	4.5	7.0	8.5	n/a
Bound tannins	0.7	0.7	0.6	0.5	0.8	0.7	0.5	1.0	0.5	1.0	0.2	0.8	1.0	1.2	n/a
Total tannins	6.8	6.3	5.4	4.8	6.6	5.5	6.1	6.5	4.6	6.5	1.8	5.3	8.0	9.6	n/a
Starch	679	623	677	678	644	532	689	675	657	617	700	644	606	655	n/a
Essential amino acids															
Arginine	4.2	4.6	4.2	4.6	4.6	4.3	4.7	4.3	4.3	3.1	3.3	3.7	4.1	4.1	8.7
Leucine	12.7	15.1	15.6	14.1	15.8	13.5	15.4	13.3	14.2	9.2	10.1	11.3	15.5	15.2	11.8
Lysine	1.9	1.9	1.9	1.9	1.9	1.8	2.2	1.9	1.9	1.5	1.7	1.8	1.9	2.0	3.7
Methionine	1.9	1.8	1.6	2.2	1.9	1.6	1.9	1.4	1.7	1.1	1.2	1.1	1.6	1.7	2.8
Phenylalanine	5.0	5.8	5.8	5.6	6.0	5.2	5.8	5.2	5.4	3.6	3.9	4.4	5.8	5.5	8.4
Cystine	2.2	2.2	1.9	2.4	2.2	1.9	2.1	1.8	2.0	1.5	1.5	1.5	1.9	1.9	4.5
Histidine	2.1	2.4	2.3	2.4	2.5	2.2	2.5	2.2	2.3	1.6	1.6	1.8	2.3	2.3	4.1
Isoleucine	3.7	4.3	4.4	4.1	4.5	3.9	4.4	3.8	4.0	2.7	3.0	3.4	4.4	4.4	5.9
Threonine	3.0	3.5	3.5	3.3	3.6	3.2	3.6	3.2	3.3	2.4	2.5	2.7	3.4	3.4	5.0
Tryptophan	1.3	1.4	1.4	1.4	1.3	1.2	1.5	1.3	1.4	1.0	1.1	1.1	1.3	1.4	2.0
Tyrosine	3.5	4.3	4.3	4.1	4.5	3.8	4.3	3.9	4.0	2.6	2.8	3.0	4.3	4.1	5.5
Valine	4.6	5.2	5.4	5.0	5.5	4.7	5.3	4.7	5.0	3.3	3.7	4.2	5.2	5.4	7.2

A= Pac. MR 43, S Downs; B= Pacific Buster, Lowood, Lockyer; C= Pioneer 86G87, W Downs; D= Pacific Buster C Downs; E= Pacific Buster, Lowood, Lockyer; F= Pacific MR 43, C Downs; G= Pacific Buster, Dalby; H= Pioneer Bonus W Downs; I= Pioneer Bounty, Dalby; J= Pioneer Bounty, S Downs; K= Hylan Liberty, N Downs; L= Pacific MR 43, Liverpool Plains; M= Pacific MR 43, Liverpool Plains; N= Pacific MR Buster, Liverpool Plains.

In the present study, the mean starch content in both years was consistent with 63.1% DM and 64.8% DM (with a range value 60-68% DM and 53-70% DM) for 2004 and 2005 respectively (Table 6). These results agree with the recent work of Dicko *et al*., (2006) in which evaluation of 50 varieties of sorghum showed a starch mean value of 63% with a range variation 57-69%. Choct and Hughes, (2000) reported that sorghum starch content was higher than observed in wheat (65%), rye (60%) and barley (55%) but lower than maize (75 %) and rice (80 %). Since starch is considered to be about 70% of the total energy of the grain, variation of it in grain may be reflected in the AME values. It is reported that sorghum contains resistant starch, which can impair its digestibility and which has been associated with high tannin and to hard peripheral endosperm layer sorghum varieties (Rooney and Pflugfelder, 1986). Although this starch resistance may be desirable to address human obesity and diabetes via longer passage to the digestive tract (Beta *et al.,* 2000; Dicko *et al*., 2006), this characteristics may not be desirable for poultry nutrition. Contrary to expectations, Australian sorghum exhibited relatively high tannins levels, thus, digestibility of the starch may be compromised for normal bird growth.

Having tannins found in Australian sorghums (Tables 4 and 5) raises concerns on their impacts on the nutritional value of sorghum in poultry diets. There have been many reports which have expressed concern that tannins in sorghum grain are antinutritional factors (ANF). Tannins are a distinctive group of polyphenolic polymers of relatively high molecular weight (1000-20,000) which has the capacity to form complexes with carbohydrates, enzymes, starch, minerals and proteins (Porter, 1989; Beta *et al*., 2000; Perez-Maldonado, 1994). Tannins are usually classified into two main classes, the hydrolysable tannins and the condensed tannins (CT). In general, CT is also referred to as proanthocyanidins which describes the most widespread tannins found in the plant kingdom. CT may exist in two states; a form that is easily extractable with solvents (free tannins) and a form which may be bound to cell protein and/or carbohydrate components (bound tannins). Total CT levels found in our collection ranged 1.3–12.0 g/kg DM and 1.6–8.5 g/kg DM for 2004 and 2005 respectively. In 2004, Pioneer 85G8,3 a red colour sorghum, showed the highest CT level with Hylan Liberty, a white colour sorghum, containing the lowest level (~ 1.612 g/kg).

In 2005, Pacific buster from Liverpool plains (NSW) showed the highest CT levels (9.6 g/kg) with Hylan Lyberty (white sorghum) containing the lowest amount (1.8 g/kg). The only results clearly indicating a variety effect on CT levels was for Hylan Lyberty (white sorghum) which consistently showed lowest CT levels in both years. However, a significant variation occurred within varieties between regions in red or brown red sorghums. The CT levels range (g/kg DM) for 2004 and 2005 respectively for Pacific Buster was 6.2-9.8, and 4.8-9.6; Pacific MR 43 ranged between 7.1-11.2 and 5.3-8 and Pioneer ranged from 9.9–12 and 4.6-6.5. This variation within years and locations indicates that sorghum growing conditions have a significant effect on CT levels found in Australian sorghums. The literature also indicates that CT concentrations and its level in plant tissue varies with species, species within genera, plant part, plant age and maturity, soil fertility, seasonal changes, light intensity, heat, water stress and methods for tissue collection (Perez-Maldonado, 1994; Kleiner, 1991; Mole and waterman, 1988; Barry and Forss, 1983).

As new knowledge and understanding in poultry nutrition develops, there may be another aspect of CT and their effects on chicken gut microflora which may have consequences for poultry production.

The sorghum non-starch polysaccharides (NSP) fraction was not quantified during this study, as reports have indicated that this grain like maize contain low levels of NSP which are not detrimental to the nutritional quality of wheat, barley and other viscous grains (Walker, 1999; Choct and Hughes, 2000). For information, the NSP fraction has been described in detail by Dicko *et al.,* (2006) indicating that sorghum NSP are located in the pericarp and endosperm cell walls, with proportion in the kernel ranging from 2-7% depending on variety with arabinoxylans and β-glucans representing 55% and 40% respectively.

Sorghum has benefits as a feed source due to its adaptability to environmental conditions, economic feasibility and availability. Sorghum is already a significant grain crop of tropical and sub-tropical

regions in Australia and worldwide particularly in low income regions. However sorghum grain has had variable results when used as a feed source in poultry. This variability has been attributed to variety, region of growth and variety by region interactions affecting the grain chemical composition and in particular its CT content. As shown in our results examining the nutritional characteristics of 17 sorghum samples in 2004 and 15 sorghum samples in 2005, there is considerable variation within varieties that can be attributed to differences in soil, crop management and environmental growing conditions.

Table 6   Summary of the chemical analysis and amino acids mean results and (mean range) of 2004 and 2005 sorghum grain harvest

Evaluation (dry matter basis)	2004	range	2005	range
Dry matter (%)	88.10	(87-89.2)	89.5	(88.6-90.3)
Crude protein (%)	11.7	(8.9-13.6)	11.6	(8.4-13.3)
Total Phosphorous (g/kg)	3.1	(2-3.9)	2.8	(1.9-4.1)
Phytate phosphorous (g/kg)	1.91	(0.8-2.9)	2.2	(1.1-3.4)
Calcium (g/kg)	< 0.1		< 0.1	
Crude Fibre (g/kg)	19.5	(17-23)	n/a	n/a
Starch (%)	63.1	(59.5-66.7)	64.8	(53.2-70.0)
Free tannin (g/kg)	6.6	(1.3-11.2)	5.3	(1.6-8.5)
Bound tannins (g/kg)	1.1	(0-1.9)	0.73	(0.2-1.2)
Total tannins (g/kg)	7.7	(1.3-12)	6.0	(1.8-9.6)
Lysine (g/kg)	3.0	(2.4-3.7)	2.0	(1.5-2.2)
Methionine (g/kg)	1.4	(1-2)	1.6	(1.1-2.2)
Cysteine (g/kg)	1.6	(1-1.9)	1.9	(1.5-2.4)
Threonine (g/kg)	2.9	(2.2-3.6)	3.2	(2.4-3.6)
Tryptophan (g/kg)	1.4	(1-1.7)	1.3	(1-1.5)
Arginine (g/kg)	4.4	(3.6-5.2)	4.2	(3.1-4.7)
Histidine (g/kg)	1.6	(1.2-2.1)	2.2	(1.6-2.5)
Isoleucine (g/kg)	4.2	(3.2-4.9)	3.9	(2.7-4.5)

3. Bioassays: Apparent metabolisable energy content and digestibility determinations for amino acids, starch and condensed tannins

3.1 Introduction

During year 1 (2004-2005) 17 sorghum samples were collected from various areas of NSW and Qld with seven additional samples provided by the PGLP group (Table 2). During year 2 (2005-2006) 14 samples were collected from various regions in NSW and Qld (Table 3), totalling 38 sorghum samples representing the main sorghum areas of Australia.

The previous chapter described the results of the chemical composition of all sorghum samples collected. As more information is necessary to improve sorghum nutritional value and to formulate future dietary treatments, a follow up step for the evaluation of sorghum grain is necessary.

Therefore in this study several bioassays in all sorghum samples were undertaken to determine the apparent metabolisable energy (AME), and the digestibility of main nutrients which include, nitrogen, starch, amino acids, calcium, phosphorous and condensed tannins, a major antinutritional factor, found in nearly all sorghum grains.

The main objectives of this study were to undertake:

- AME determination in all sorghum samples

- Ileal digestibility determination of main sorghum grain nutrients

- Ileal digestibility of condensed tannins and its interaction with main nutrients

Additional experiments were undertaken in this study to complement the required information. These experiments compared PGLP and PRDC methods for AME determination, AME determination in association with different methods of feed preparation and AME determination using birds of different ages. Finally, all the obtained information, including the data from the previous chapter provided a major insight of the main factors affecting broiler performance when they are fed sorghum diets.

3.2 Materials and Methods

3.2.1 PGLP method for Apparent Metabolisable Energy (AME) used for 2004 grains

During 2004, to ensure connectivity with the PGLP group, the sorghum AME determination used the protocol as directed by PGLP with a number of additional sorghum and wheat samples provided by the PGLP to allow data connectivity between the two projects. Each grain sample was evaluated for AME and corrected for dry matter and nitrogen. In September 2004, male and female broiler chicks (COBB) were purchased locally as day old birds and reared from 0-22 d of age on litter under electrical heaters in separate-sex pens and were offered a commercial starter diet for 21 days. On day 22, all birds (weight 700-1000g) were randomly transferred into metabolism cages to obtain six birds/pen. For each dietary treatment, four pens containing the six birds were allocated with two replicated pens containing only males and two pens containing only females. In total there were 24 dietary treatments, which

were offered to each of four pens (6 birds/pen) in a completely randomised layout of 96 cages (2 replicates x 2 sex x 24 treatments).

During the seven days of the experimental period, the air temperature in the metabolism shed was gradually reduced from the range 26-24 °C to 24-22 °C.

The data from the AME determination was provided to the PGLP group to interpret the results regarding the connectivity analyses. For the purpose of this report only results of sorghum grains examined and obtained from the DPI&F collection will be will be presented.

AME–adaptation period

Dietary treatments were allocated to pens prior to a weekend for an initial adaptation period and data collection commenced on the following Monday with the bioassay continuing until the following Friday. On each day during the experimental period, drinkers and feeders were checked and temperature recorded. Prior to excreta collection, the total weight of aluminium trays used for excreta collection was recorded.

AME-diets

Cold pelleted diets were prepared containing (g/kg): sorghum (804), casein (155) limestone (11), di-calcium phosphate (20), salt (3), vitamins and minerals (5.0), and choline chloride (2.0). Feed samples and total excreta were collected and sub-sampled for gross energy determination using an AC-350 LECO adiabatic bomb calorimeter located at the Animal Research Institute (ARI).

3.2.2 Comparison of PGLP and PRDC methods for Apparent Metabolisable Energy (AME) determinations

The technical staff at PRDC presented concerns to RIRDC Chicken Meat management regarding the methodology used for the first sorghum AME evaluations. These were:

- that a significant amount of feathers were observed under the cage and fell into the excreta collection tray in birds which were 22 days (d) old at the beginning of the evaluation and that may have influenced results in the previous AME determination

- with regards to the use of whole sorghum grain in cold pellet diets (WGCP) and

- the use of casein as protein ingredient in the AME diets. Concerns were raised that the fine particles from casein and the minerals and vitamins did not mix uniformly during diet mixing and this may have not produced uniform pellets.

Additional time was provided to carry out some comparison between methods.

In Australia, AME determinations in grains are usually conducted with birds which are 22-28 d old and with the grain normally hammer-milled and the diets offered as mash. The AME (MJ/kg DM) data of the grain as so determined is then used in the formulation of broiler diets. There is however a concern that the AME values from birds age 22-28 d old, may inappropriate for formulating starter diets for much younger birds (0-21 d old). Therefore it was decided to re-evaluate the AME of selected sorghums samples using PRDC methodology to enable comparison with results obtained earlier using the standard PGLP methods (section 3.1.1). This entailed an AME undertaken using younger broilers (14-21 d old). Three sorghum samples from 2004 were prepared as whole grain cold press pellet diets and had AME determination carried out using the PGLP protocol but with the use of birds 14-21d old. The possible effect of the method of diet preparation was also investigated in this study with diets examined being prepared as either mash (M), cold pellet (CP), hot pellet (HP) and WGCP.

3.2.3 PRDC method for Apparent Metabolisable Energy (AME) used for 2005 samples

Due to difference in results obtained following comparison of the two AME methods, it was decided that AME determinations for 2005 sorghums, would use the PRDC methodology. Therefore AME of the 2005 sorghum samples were determined using classical total collection of excreta and measurements of feed intake (FI) over a 4 d period on four replicate cages of six male broiler chickens (16-21 d old) allowed to become accustomed to the test diets for an initial 3 d period. Diets were mixed, hot pelleted then crumbeled. The composition of diets were (g/kg): sorghum (968), limestone (14), dicalcium phosphate (6), salt (1), sodium bicarbonate (0.5), vitamins and minerals (5.0), choline chloride (1), lysine (2), methionine (1.5) and, threonine (1). Feed samples and total excreta produced were collected mixed and then and sub-sampled for gross energy and N determination using methods described previously.

3.2.4 Ileal digestible amino acid, nitrogen, starch and condensed tannins

Immediately following each AME determination, the same birds were utilised in a follow-up bioassay to determine the ileal digestibility of amino acids (AA), starch, nitrogen (N), and condensed tannins (CT).

- For the 2004 sorghums samples the ileal digestibility bioassay in all samples was evaluated using male and female broiler chickens aged 29-35 d.

- For the 2005 sorghum samples, ileal digestibility determinations in all samples were evaluated using male broilers age 22-29 d.

The bioassay procedure followed was that of Ravindran et al., (1998) and Ravindran et al., (1999). It is worth noting that the only difference in methodology for the ileal digestibility bioassay between years of evaluation was bird age, with older birds 29-35 d for the 2004 evaluation and younger birds 22-29 d for the 2005 evaluation.

Ileal digestibility – animals and housing

Birds were allocated to their respective metabolism cages and to their digestibility diets, which were offered *ad libitum* to each pen (6 birds/pen). Temperature and light was regulated accordingly to breeder guide manual.

Ileal Digestibility – diets

Ileal digestibility diet composition for sorghum samples were per kg: 944 g sorghum, 14 g vegetable oil, 16 g di-calcium phosphate, 2 g sodium chloride, 13 g limestone, 5 g vitamin and mineral supplement, and 1 g choline chloride. Chromium oxide was also added as an internal indigestible marker at 3 g/kg.

- For the 2004 sorghum samples, each assay diet was offered *ad libitum* to four replicate cages (2 cages with males and two cages with females) containing six birds (29 d old) per cage.

- For the 2005 sorghum, each assay diet was offered *ad libitum* to four replicate cages containing six male birds (22 d old) per cage.

Ileal Digestibility – digesta collection and analyses

After a five day experimental feeding period birds from each cage were euthanised by cervical dislocation and immediately opened to remove the digestive tract to enable collection of digesta from

the vitelline diverticulum (formerly Meckel's diverticulum) to 40-mm back from the ileo-caecal junction. Ileal digesta collected from birds within a pen was pooled and frozen immediately after collection and subsequently freeze-dried. Dried ileal digesta samples were mashed/crushed using a mortar/pestle and stored in airtight containers at –20 °C for chemical analysis. Feed and digesta samples were analysed for AA, CT, starch, and N, following current procedures at the ARI and the University of Queensland (UQ).

3.3   Results and Discussions

3.3.1   PGLP method for Apparent Metabolisable Energy (AME) used for 2004 grains

The AME contents of the sorghum cultivars determined by the PGLP procedure (2004 sorghum collection) are shown in Table 7 with mean values and range presented in Table 9. The mean value of 15.8 MJ/Kg DM (range 15.5-16.2) is consistent with values reported for Australian sorghums (Walker, 1999; Black *et al.,* 2005) in which total collection method with birds 22-28 d old were used. The statistical analysis on parameters evaluated (AME, intake, sex difference) indicated that the only significant difference (P<0.05) was found in AME values between sorghum (15.8 MJ/Kg) and wheat (13.90 MJ/Kg).

3.3.2   Comparison of PGLP and PRDC methods for Apparent Metabolisable Energy (AME) determination

The AME results comparing the bird age and method of preparation are presented in Table 10a showed that method of preparation did not influence (P>0.05) sorghum AME results. However from Table 10b it can be seen that the mean sorghum AME determined with younger birds (14-21 d) was 0.9 MJ/Kg DM lower compared to AME values obtained in older birds (22-28 d). Such an AME difference will have a significant consequence particularly during the starter phase (0-21 d old) especially if AME values obtained from older birds (22-29 d) are used to formulated diets for birds between 0-21 d. Consequently, experiments to examine impacts of these AME difference are needed to observe if during the starter phase, bird performance, and particularly FCR can be improved if sorghum diets are adjusted or formulated using AME values obtained with younger birds (14-21 d).

3.3.3   PRDC method for Apparent Metabolisable Energy (AME) used for 2005 grains

The AME contents of the 2005 sorghums determined using the PRDC procedure are shown in Table 8, with a summary of mean values and ranges presented in Table 9. The overall AME (MJ/Kg DM) value of 14.8 (range 14.3-15.6) was about 1 MJ/Kg DM lower than values obtained in the present study in the 2004 collection (Table 10b) as well as values reported in the literature (Walker, 1999; Black *et al.,* 2005). We concluded that the AME difference between each year was directly related to bird age. When AME determination and method of feed preparation was compared between younger (14-21 d) and older birds (22-28 d) we also found that the age of the bird and not the method of test diet preparation was the main factor influencing the realised AME value (Perez-Maldonado, *et al*., 2007). A report by Thomas and Ravindran, (2006) on the influence of bird age on AME over the first 21 days of life found that diets based on wheat or maize produced significant age effect on AME. The AME values were higher at day 3 and then declined during 5 to 9 days, before increasing at day 14 post-hatching. Thomas and Ravindran, (2006) concluded that during early bird age effects from yolk utilisation, sterile gut environment, changing gut flora, inadequate secretions of digestive enzymes affect energy utilisation. Farrell, (1999) also indicated that AME of similar diets or foodstuff is dependent on age of birds. Therefore further research is required particularly during early life of birds (1-7 d and 7-14 d old) to examine sorghum grain AME values in order to explain reasons for AME changes due to bird age and to provide strategies aimed at improving sorghum nutritional value on the early life period of birds.

3.3.4 Ileal digestible amino acid, nitrogen, starch and condensed tannins: Associations with AME

Bioassay results for N, AAs, starch and CT digestibility determinations are presented in Tables 7 and 8 from sorghum samples from 2004 and 2005 respectively. Theses are summarised and the ranges given for both years in Table 9. The results in this bioassay provide information on the nutritional characterisation of each sorghum cultivar, environmental effect and the interaction of CT on protein, starch and other nutrient digestibility. Comparison between cultivars, seasons, and regions differences was investigated.

In this experiment starch digestibility was found to be 85.3 % (range 71.3-92.9) and 92.0 % (range 84.6-97.9) for 2004 and 2005 sorghums respectively. It would appear that for the 2004 sorghums, Pacific Buster cultivars (Qld and NSW) were amongst the top three grains with regard to starch digestibility values (91, 92 and 92.9% respectively) whilst in 2005, Pacifc MR 43, Pioneer Bounty and Hylan Liberty cultivars had the three highest starch digestibilities (97.4, 97.6, and 97.9 % respectively). However in 2004 sorghums, Pacific Buster (Central Downs, Qld) had the lowest starch digestibility (71.3%); suggesting that there are digestibility differences within cultivars and regions and between years of collection. It was also observed that there was a large starch digestibility range found among sorghums cultivars in both years (Table 10). For example in 2004, there were three main groupings; low (71-78.4) middle (81.3-89.4) and high (90.4-92.9) whilst for the 2005 sorghum grains there was only two distinct digestibility ranges, a medium (84.6-88.8) and a high (95.3-97.9). This high starch variability displayed among cultivars and regions makes it difficult for any meaningful comparison.

In previous work, Connor *et al.,* (1976) found significant effects for variety, region of growth, and a variety by region interaction which was similar to that found here. The variability found in the present experiment suggests that there are opportunities for improving or manipulating sorghum starch digestibility in those cultivars exhibiting lower to middle range starch digestibility by the use of feed enzymes, which has been shown to improve starch digestibility in other grains (Choct and Hughes, 2000). There is however a need to better understand the specific characteristics of sorghum starch and its interaction with the protein molecules within the grain and other possible interactions with ANF such as phytate-P and CT. This is necessary in order to develop and deliver the correct strategy to improve starch digestibility.

The literature (Walker, 1999; Taylor, 2005; Black, 2005) indicates that sorghum starch granules are large spherical in form, measuring 10-16 microns with the majority found in the endosperm, enmeshed or embedded in protein bodies there. Black, (2005) suggested that the degree of starch granule encapsulation, the AA composition of the protein matrix, the nature of proteases and presence of ANF such as CT and trypsin inhibitors affect starch digestion in cereals. It has been suggested that the resistance to digestive action of the grain hard peripheral layer is responsible for the lower starch digestibility in sorghum (Walker, 1999). While other reports indicate that it is the cross-linked proteins (kafrin) in the sorghum matrix enveloping the starch granule that inhibit the access of amylase enzymes being the responsible for the grain low starch digestibility when compared with maize (Taylor 2005).

With regards N and AA digestibility it was found that protein digestibility was 68.5 % DM (range 62.7-74.8) and 77.3% DM (range 72.3-80.5) for 2004 and 2005 sorghum samples respectively (Table 9). This was consistently lower than values determined in wheat grain by about 15 and 11 % respectively. The low protein digestibility value of sorghum was associated with low cystine (52 and 53%), threonine (58 and 68%), tryptophan (64 and 78%) and histidine (64 and 73%) digestibility found for each year (2004 and 2005 respectively). Sorghum proteins are less digestible than those from other grains, due to the presence of α-kafirins which are proteins rich in sulphur AA and containing many disulphide bonds resistant to proteases enzymes during digestion (Black, 2005; Taylor, 2005).

Black *et al*., (2005) reported that protein inadequacy and arginine, as the first limiting AA, with both being responsible for the differences in the efficiency of available energy utilisation from sorghum relative to wheat-based diets, when the daily intake of AME was similar. But, in the current experiment, we found that for 2004 and 2005 sorghum samples, cystine and tryptophan were the first and second limiting AAs with cystine having a digetibilty value of only 52.5% and tryptophan being the lowest AA in the grain (1.35g/kg). Cystine is a major sulphur AA component in the crude protein of sorghum grains, and with a determined digestibility value of 52.5%. Our studies agreed with literature regarding α-kafirins (rich in cysteine) as one of the main factors responsible for the low protein digestibility and its influence on starch variability and its digestibility in sorghum.

However, if the protein matrix and bodies are poorly digested, which then influences starch digestibility (Taylor, 2005); then protein digestibility in our study should have been highly correlated with starch digestibility. But this was not observed, suggesting that there are differences in sorghum cultivars with regards to the components of the protein matrix and that other factors may also be affecting sorghum protein digestibility. This needs to be further investigated. Dicko *et al*., (2006), summarised studies which have shown that protein, protein-carbohydrate, protein-polyphenol and carbohydrate-polyphenol interactions are the main factors affecting protein digestibility.

Looking at a link between AA availability and tannin content, it has been reported (Gualtieri and Rapaccini, 1990) that low, intermediate and high tannin sorghums have reduced AA digestible levels of 22, 41 and 73% respectively. These finding were supported by Elkin *et al*., (1996) with a significant inverse relationship between tannin content and digestibility of AAs and true metabolisable energy (corrected for nitrogen). It was also noted that several sorghum varieties of similar tannin content had markedly different nutrient digestibilities, so they concluded that other factors apart from tannins may be involved for this variation.

In the present study, the 2004 sorghum samples showed little relationship between CT content and the digestibility of starch, N, AA and AME as determined in each grain. These results were obtained in bioassays using birds 22-28 d of age for the AME and 29-35 d of age for ileal digestibility of the nutrients. The same parameters evaluated in the 2005 sorghum however showed a strong inverse relationship between the AME and the grain free-CT ($r = -0.725$) and bound-CT ($r = -0.773$) fractions as shown in figure 1. These bioassays were conducted using younger birds (14-21 d and 22-28 d for the AME and ileal digestibility respectively). O'Brien, (1999) also has reported significant negative relationship between AME and tannic acid content.

Another strong relationship was found between sorghum CT content and tryptophan ($r = -0.673$) digestibility, which was found in this study to be the second limiting AA due to its lower content in the grain.

On the basis of the results here it can be speculated that bird age may play in important role in sorghum AME and the ability of CT to affect it with an apparent higher negative effect in younger birds. Fortunately, as birds mature this negative effect of sorghum CT became less significant as shown by the weak relationship between CT and AME values for 2004 sorghum.

Table 7 **The apparent metabolisable energy (AME), and digestibility of starch, nitrogen, essential amino acid, and condensed tannins determinations for 2004 sorghum grain and PGLP wheats**

Analysis	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	20*	21*	22*
Starch	88.2	92.0	87.0	92.9	87.6	78.4	83.9	89.0	77.1	71.3	81.3	76.9	87.0	86.9	91.0	90.4	89.2	88.3	75.3	84.7
Nitrogen	63.6	72.4	63.9	74.8	70.0	65.0	63.6	67.6	46.9	65.1	48.3	50.1	74.8	74.3	66.6	62.7	74.6	89.4	83.7	77.3
Arginine	65.9	76.2	58.3	75.2	67.5	67.1	66.8	69.2	58.3	67.6	56.0	67.2	78.3	75.5	74.2	74.9	83.2	82.0	80.2	68.7
Leucine	73.9	83.5	61.1	84.4	78.6	70.1	73.6	78.0	66.5	69.3	59.9	65.6	80.9	75.2	78.1	76.4	80.4	88.6	88.0	81.1
Lysine	70.2	75.9	63.2	75.3	67.6	66.8	71.2	74.2	60.1	77.2	51.4	70.7	76.9	73.9	70.4	75.2	82.2	80.0	77.8	64.0
Methionine	78.4	83.6	62.0	85.6	77.1	74.4	72.6	78.3	60.3	79.7	66.7	70.1	81.6	74.4	79.0	81.1	84.9	91.4	82.2	74.5
Phenylalanine	73.5	83.2	60.9	83.1	75.7	70.4	72.1	75.9	66.3	68.2	60.2	61.9	79.7	73.6	77.1	75.1	80.5	90.6	90.7	84.1
Cystine	51.9	57.8	22.8	58.0	47.7	47.9	39.1	49.4	23.1	48.3	21.5	25.9	62.9	51.8	49.8	47.9	63.1	87.0	79.9	66.0
Hisitdine	57.3	69.9	45.0	68.9	66.3	59.7	60.0	62.9	40.4	61.9	33.2	39.6	72.6	58.2	61.6	59.8	70.7	87.9	85.9	78.5
Isoleucine	68.9	79.2	57.7	79.2	71.6	65.7	66.8	71.5	57.5	67.0	52.9	60.3	77.1	68.8	71.4	69.2	76.9	87.1	86.7	78.1
Threonine	52.9	66.1	40.6	64.4	55.9	54.4	52.5	57.2	32.3	56.8	31.5	35.6	66.2	51.5	57.0	51.9	69.6	79.5	79.3	64.6
Tryptophan	57.6	69.5	36.8	61.0	60.0	65.0	63.8	63.3	29.4	59.8	45.6	53.7	74.9	57.0	50.5	69.2	76.0	82.1	71.4	67.5
Tyrosine	69.4	80.0	56.3	80.4	72.2	68.2	68.6	72.7	60.5	65.5	54.1	54.6	77.0	69.8	73.6	70.9	79.1	88.4	88.8	81.3
Valine	66.2	76.7	56.2	76.6	69.2	64.5	65.3	68.7	54.4	66.6	48.9	58.3	75.6	66.2	69.3	67.0	76.0	84.4	83.5	73.9
Free tannins	78.8	86.3	83.8	83.7	85.6	85.9	71.9	70.1	66.6	86.0	73.9	76.6	70.6	84.7	82.5	73.9	86.5	92.5	93.6	92.3
Bound tannins	38.6	39.6	33.5	42.3	84.6	23.2	26.6	21.4	21.4	49.0	24.1	20.0	64.4	65.2	51.3	26.9	58.0	95.0	90.5	96.0
AME DM	15.7	15.8	15.5	15.7	16.1	15.9	15.6	15.9	15.6	15.6	15.9	15.9	15.9	15.8	16.2	15.9	15.7	13	13.9	14.8
AMEn	15	15.2	14.8	15.1	15.5	15.3	15	15.1	15.1	15	15.2	15.2	15.2	15.2	15.5	15.2	15	12.3	13	13.9

*= PGLP wheat samples; 1= Pacific MR 43 (Moree, Boomi/ Goondiwindi); 2 = Pacific Buster (Moree, Boomi/ Goondiwindi); 3= Pacific MR 43 (Yellarbon/East Texas); 4= Pacific Buster (Yellarbon/East Texas); 5= Hylan Liberty (Kingaroy/Jandowae); 6= Hylan Dominator (Kingaroy/Jandowae); 7= Pioneer Bonus (Dalby/Warra); 8= Pioneer 85G83 (Dalby/Warra); 9= Pacific MR 43 (Clifton); 10= Pacific Buster (Pittsworth); 11= Pacific Buster (Gunnedah); 12= Pacific MR 43 (Gunnedah); 13= Hylan Liberty (Dolby/Bowenville); 14= Pacifc MR 43 (Dalby); 15= Pacific MR Buster (Emerald); 16= Pacific MR 43 (Emerald); 17= Pacific MR Buster (Dalby); 20= H45 (Wagga Wagga); 21= Oxley (Narrabri); 22= Waxy Oxley (Narrabri) ; AME (MJ/kg DM); AMEn (MJ/kg DM corrected for nitrogen).

Table 8   **The apparent metabolisable energy (AME), and digestibility of starch, nitrogen, essential amino acid, and condensed tannins determinations for the 2005 sorghum grain**

Analysis	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O wheat
Starch	87.3	84.6	86.9	88.0	88.8	87.6	88.1	96.6	95.3	97.6	97.9	97.4	96.3	96.2	77.8
Nitrogen	76.7	80.5	78.6	80.3	79.5	75.8	77.5	77.6	74.3	74.6	77.4	76.6	72.3	79.9	88.6
Arginine	81.0	83.1	79.2	83.6	82.8	80.4	80.8	79.2	77.3	79.3	79.0	81.4	79.5	80.3	83.2
Leucine	83.6	86.5	86.8	85.9	86.2	84.3	83.6	84.6	82.0	84.1	88.0	85.0	81.7	86.4	88.5
Lysine	73.4	79.9	74.9	81.1	81.1	73.7	80.7	78.5	75.2	77.4	73.9	78.1	70.5	78.3	77.6
Methionine	82.9	87.0	84.7	87.6	87.8	84.8	85.7	86.3	84.7	83.9	87.4	84.0	80.9	86.9	89.4
Phenylalanine	83.4	85.3	84.3	85.2	84.6	83.4	81.3	81.8	79.9	82.1	85.6	83.6	81.5	84.5	89.7
Cystine	50.0	58.8	49.5	58.3	60.1	52.0	56.3	55.3	52.9	38.0	55.3	45.5	49.0	62.3	78.9
Histidine	72.4	75.4	71.9	77.5	73.7	71.8	73.7	70.3	69.0	68.2	77.3	71.4	71.8	73.1	86.9
Isoleucine	79.3	82.8	82.3	82.6	82.2	79.4	79.8	80.0	77.7	78.8	81.9	80.4	76.8	82.4	86.7
Threonine	68.2	72.4	69.5	72.8	71.5	67.3	69.2	66.9	62.9	63.5	67.7	67.7	64.3	69.0	77.7
Tryptophan	77.3	82.6	77.7	79.5	78.9	79.4	76.8	77.1	76.1	73.4	83.5	77.3	74.3	74.0	82.8
Tyrosine	80.6	83.4	82.0	83.0	82.2	80.7	79.4	78.9	76.6	78.5	82.5	80.4	78.4	81.2	88.3
Valine	76.9	81.0	79.7	81.3	80.4	77.4	78.5	78.2	75.5	76.1	79.6	78.2	74.9	79.5	83.5
Free tannins	36.6	50.9	45.8	47.9	44.0	36.5	48.6	36.2	36.5	35.1	80.7	41.0	29.2	45.4	78.0
Bound tannins	17.6	56.3	39.4	51.6	52.2	57.2	53.4	37.1	40.8	41.6	84.4	44.9	20.0	62.4	23.0
AME (MJ/kg DM)	14.6	15.2	15.3	15.3	15.5	15.1	15.3	14.9	15.2	14.9	15.6	14.7	14.7	14.3	11.8
AMEn (MJ/kg DM)	14.3	14.9	15.0	15.0	15.2	14.8	15.0	14.6	14.9	14.7	15.3	14.6	14.4	14.0	11.4

A= Pac. MR 43, S Downs; B= Pacific Buster, Lowood, Lockyer; C= Pioneer 86G87, W Downs; D= Pacific Buster C Downs; E= Pacific Buster, Lowood, Lockyer; F= Pacific MR 43, C Downs; G= Pacific Buster, Dalby; H= Pioneer Bonus W Downs; I= Pioneer Bounty, Dalby; J= Pioneer Bounty, S Downs; K= Hylan Liberty, N Downs; L= Pacific MR 43, Liverpool Plains; M= Pacific MR 43, Liverpool Plains; N= Pacific MR Buster, Liverpool Plains. AME (MJ/kg DM); AMEn (MJ/kg DM corrected for nitrogen).

Table 9   Summary of 2004 and 2005 sorghums and wheat grains mean values and ranges for ileal digestibility of starch, nitrogen, essential amino acids, free and bound condensed tannins and AME Apparent Metabolisable Energy (corrected for dry matter and nitrogen, MJ/kg DM)

Digestibility %	Sorghum 2004		Sorghum 2005		Wheat 2004		Wheat 2005
Starch	85.3	(71.3-92.9)	92.0	(84.6-97.9)	82.8	(75.3-88.3)	77.8
Nitrogen	68.5	(62.7-74.8)	77.3	(72.3-80.5)	83.4	(77.3-89.4)	88.6
Arginine	72.4	(65.9-83.2)	80.5	(77.3-83.6)	77.0	(68.7-82.0)	83.2
Leucine	77.1	(69.3-84.4)	84.9	(81.7-88.0)	85.9	(81.1-88.6)	88.5
Lysine	73.6	(66.8-82.2)	76.9	(70.5-81.1)	74.0	(64.0-80.0)	77.6
Methionine	79.3	(72.6-85.6)	85.3	(80.9-87.8)	82.7	(74.5-91.4)	89.4
Phenylalanine	76.0	(68.2-83.2)	83.3	(79.9-85.6)	88.5	(84.1-90.7)	89.7
Cystine	52.0	(39.1-63.1)	53.1	(38.0-62.3)	77.6	(66.0-87.0)	78.9
Histidine	63.8	(57.3-72.6)	72.7	(68.2-77.5)	84.1	(78.5-87.9)	86.9
Isoleucine	71.8	(65.7-79.2)	80.5	(76.8-82.6)	84.0	(78.1-87.1)	86.7
Threonine	58.2	(51.5-69.6)	68.1	(62.9-72.8)	74.5	(64.6-79.5)	77.7
Tryptophan	63.7	(50.5-76.0)	77.7	(73.4-83.5)	73.7	(67.5-82.1)	82.8
Tyrosine	72.9	(65.5-80.4)	80.6	(76.6-83.4)	86.2	(81.3-88.8)	88.3
Valine	69.8	(64.5-76.7)	78.4	(74.9-81.3)	80.6	(73.9-84.4)	83.5
Free tannins	80.5	(66.6-86.5)	43.9	(29.2-80.7)	92.8	(92.3-93.6)	78.0
Bound tannins	46.4	(23.2-84.6)	47.1	(17.6-84.4)	93.8	(90.5-96.0)	23.0
AME (MJ/Kg DM)	15.8	(15.5-16.2)	14.8	(14.3-15.6)	13.9	(13.0-14.8)	11.81
AMEn (MJ/Kg DM)	15.2	(14.8-15.5)	14.5	(14.0-15.3)	13.1	(12.3-13.9)	11.38

Table 10a   Comparison of mean AME (MJ/Kg DM) values for different methods of test feed preparation: mash (M), cold pellet (CP), hot pellet (HP) and whole grain cold pellet (WGCP) from 2005 sorghum grains

AME 2005 sorghum

Bird age 14-21 d

	SG 1	SG 2	SG 3	Mean
M	14.7	14.9	14.9	14.8
CP	14.4	14.5	15.0	14.7
HP	14.9	14.8	14.9	14.9
WGCP	14.6	14.9	14.5	14.7

Table 10b   Comparison of AME derived with birds of different ages with three sorghum grains (SG) from 2004 and 2005 using whole grain cold press pellets

AME

	Bird age 22-29 d	Bird age 14-21 d	
	WGCP 2004	WGCP 2005	Difference
SG 1	15.7	14.6	1.1
SG 2	15.6	14.9	0.7
SG 3	15.6	14.5	1.1
Mean	15.6	14.7	0.97
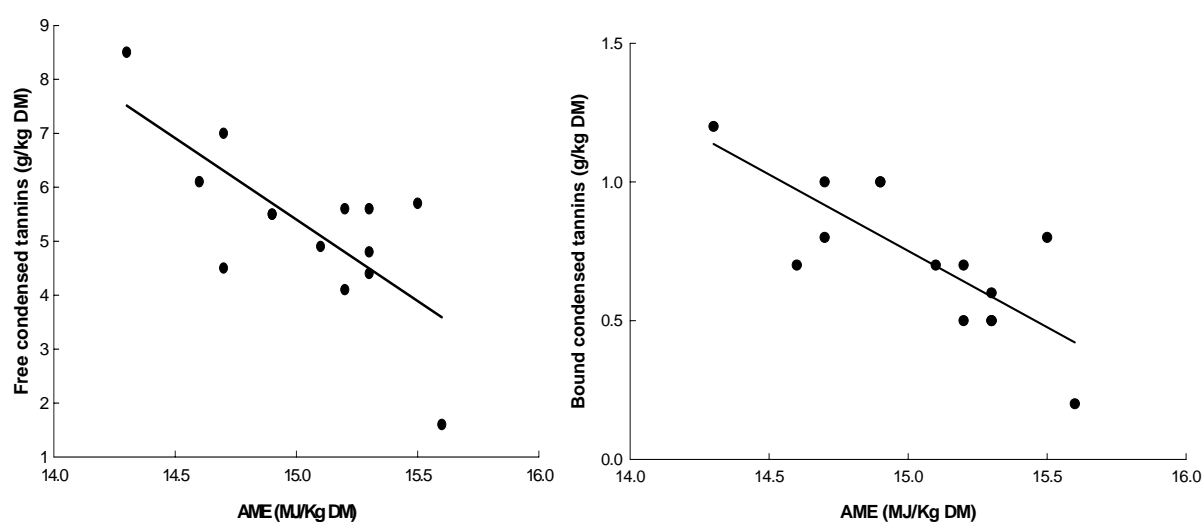
Figure 1   Relationship between 2005 sorghum AME values and free and bound condensed tannin content

3.3.5 The digestion of condensed tannins: Implications on nutrients digestibility

The mean values for the digestibility of free and bound CT from both the 2004 and 2005 sorghum samples in broiler birds of age 29-35 d old and 22-28 d old are shown in Tables 7 and 8 respectively. The mean and range digestibility values of CT for both these years are shown in Table 9.

There is little information available presently in the literature on the CT metabolism in the digestive tract and tissues of broiler chickens. Most work in CT digestion and metabolism has been undertaken using ruminants and radioactive labelled CT in which a model for tannin metabolism was developed (Perez-Maldonado, 1994). From the work with ruminants and plant tissues, it is now known that CT in plants exists in three major forms:

1. free tannins

2. protein-bound and

3. fibre-bound (Perez-Maldonado, 1994; Barry and Forss, 1983).

The present study investigated the digestibility of both free and bound CT in the small intestine with the aim of understanding CT metabolism in the chicken digestive system and its interaction with the other main nutrients. Therefore from the results obtained in broilers and with other published works on ruminants, an attempt will be made to understand how CT may influence broiler nutrient metabolism and digestion.

Studies with ruminants have shown that the interaction of CT with protein and fibre occurs in the rumen where complexes form, with evidence suggesting that a total CT loss of 24-73% in sheep fed shrub legumes such as leucaena, mulga and calliandra (Goodchild, 1989; Ahn, 1990). There is also evidence that free tannin can form complexes with plant protein and fibre with some free tannin also undergoing degradation/absorption in the rumen compartment. This degradation may also be aided by microflora population (Perez-Maldonado, 1994; Barry and Forss, 1983 Ahn, 1990; Shaw and Griffiths, 1980; Gronewoud and Hunt, 1984). Hackett, (1986) found in studies with rats and monkeys, that large accumulation of CT metabolites occurred in the liver, kidney and other tissues, before they were finally excreted, suggesting absorption of CT metabolites. In ruminants a substantial proportion of free CT binds with proteins and fibre and this is indicated by a significant net gain of CT-protein obtained across the rumen compartment. As only a small amount of protein-bound tannins appeared in faeces, this suggested that in ruminants, a substantial proportion of this fraction is dissociated and absorbed/metabolised during passage through the lower digestive tract. Work with ruminants has also shown that disruption of the free CT-proteins and CT-fibre complexes occurred in the duodenum by the action of the secretion of detergents (bile salts) thus liberating free CT to be absorbed/degraded in the small intestine.

In the present study, 80.5% and 44 % of the free-CT fraction in 2004 and 2005 sorghums samples respectively disappeared from the small intestine of birds fed these sorghums, with older birds being 55% more efficient at degrading/digesting these polyphenolic compounds. It is also possible that during transit, the majority of free-CT present may have interacted with either proteins or fibre dietary components to form a bound-CT fraction or simply may have undergone absorption/ degradation. From the data in ruminants on the fate of free-CT fraction, it can be speculated that in broilers, the free-CT fraction may have undergone degradation/metabolism before reaching the small intestine with older birds having greater degradation/ absorption than younger birds (as bird age was the main difference between evaluations). Since CT evaluation in excreta was not performed in the present studies, a total accounting of the free-CT fractions was not possible. However, from the work in rats (Shaw and Griffiths, 1980; Gronewoud and Hunt, 1984), it can be assumed that in broilers further free-CT degradation may had occurred in the ceacum (due to hindgut microflora) or else it was voided in the excreta. A possible interaction between free CT and the microflora may have some effect on

microflora population development and bird performance but this still needs to be investigated and proven.

In both the 2004 and 2005 sorghum samples, consistently only about 50% of bound-CT fraction disappeared in the small intestine, hence a substantial proportion of bound CT may be bound to proteins, enzymes, AA, fibre, or minerals component and thus limiting these nutrients from being digested/absorbed in the small intestine and utilised by the bird.

In the present study younger birds were found to be 55% less capable of degrading/ absorbing free-CT fraction. Similarly the AME in these younger birds was highly negatively correlated with free and bound CT fractions (see figure 1), and so it may be speculated that CT was responsible for the lower AME value observed in sorghums from the 2005 harvest when bird age was 14-21 d. If this assumption is correct, then one can assume that when birds were much younger (0-7 d or 7-14 d), a further sorghum AME reduction should be applied, due to the CT negative effect on AME related with age.

When all AME data obtained during this study (i.e. for both the 2004 and 2005 sorghum grains) was plotted (Figure 2), the regression line produced indicated a trend for a reduction of energy utilisation as birds get younger.
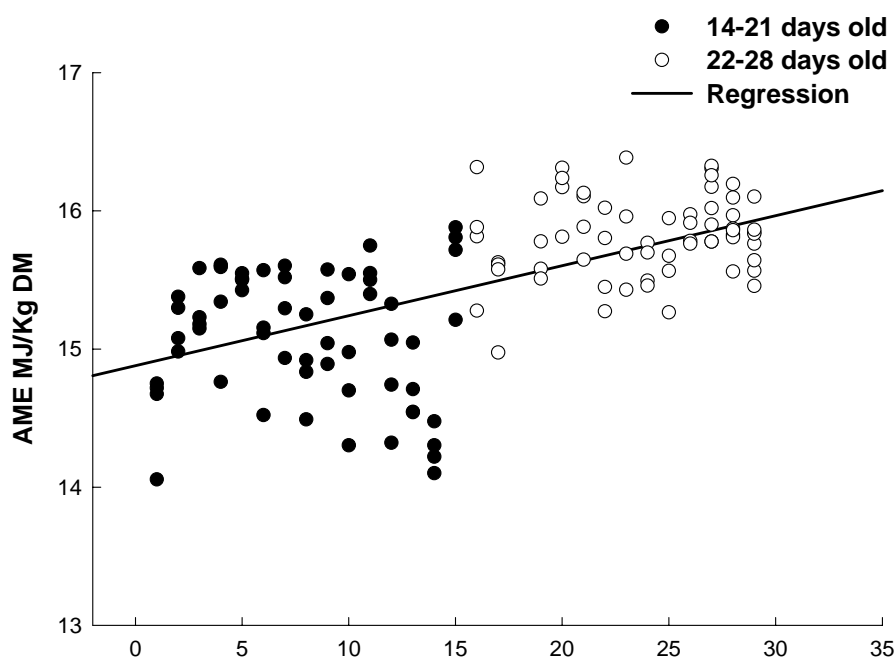
Figure 2   Relationship between sorghum AME (2004 and 2005 harvest combined) and bird age, each data point represent a cage with eight birds

In the present study we have demonstrated that a reduction in bird age at AME determination by one week reduced AME . In a previous experiment it was shown that the method of preparation was not as important as the age of birds in affecting sorghum AME values. It was calculated that one week reduction in bird age, lowered sorghum AME by about 1.0 MJ.

Practically this means, that an AME adjustment of bird age and effect of CT needs to be applied when formulating broiler diets in order to improve sorghum utilisation particularly during the early growth period. Additionally it may be possible that if this adjusted grain energy value is used it may also improve carcass composition as the energy/protein ratio in the diets will be more correctly balanced. It is recommended that more research is needed on sorghum to investigate the effect of CT on AME in much younger birds (0-7 d old and 7-14 d old).

Therefore, it would appear that at least four factors are affecting broiler performance when they are fed sorghum diets, and that these appear to influence the sorghum protein, starch digestibility and AME values in younger birds. These are:

1. The low cystine digestibility (52%) found in our study, which may be linked with the well known negative effect of sulphide bonds of the α-kafirin molecule.

2. The strong negative relationship of CT with lowering the digestibility of sorghum triptophan as found in the 2005 sorghum harvest.

3. The highly negative correlation found between AME in young birds and the free and bound-CT fractions in sorghum as shown in figure 1.

4. The high P-phytate content of sorghum which at 76% means that binding to this reduced availability of nutrients in sorghum.

4. Metabolism

4.1 Experiment 1 – Pilot trial evaluating chicken meat diets using different sorghums from 2004 harvest in various regions of Qld and NSW

4.1.1 Introduction

Previous work of chicken meat production using sorghum-based diets has indicated that anti-nutritional factors (ANF) found in sorghum has negatively effected bird performance which include significant breast yield variability and poor feed conversion ratio when compared to wheat-based diets.

During 2004 and 2005 more than 30 sorghum samples collected form NSW and Qld were evaluated for a chemical analysis and bioassays experiments (Chapters 2 and 3). It was found that at least four main aspects, contained in sorghum, can be linked to its ANF properties affecting protein, starch and energy digestibility. These are:

1. The lower sorghum cystine digestibility that may negatively effect the sulphide bonds of the α-kafirins.

2. The amounts of condensed tannin (CT) found in sorghum grain and their negative effect related to the lowering of the AA digestibility of triptophan as seen in young birds given 2005 sorghum grains.

3. The highly negative correlation found between AME and both the free and the bound CT fractions (see figure 1, chapter 3) indicating that CT may negatively influence AME in younger birds.

4. The sorghum high content of the P-phytate fraction which was found to be about 76% and this has been linked to reducing sorghum availability of nutrients.

The main objectives of this experiment are:

1. To investigate the nutritional characteristics for chicken meat production of sorghum varieties from Queensland and New South Wales (2004 harvest),

2. To evaluate the relationship between bird consumption of energy from Sorghum with bird performance during the starter and grower/finisher period,

3. To evaluate carcass fat and breast yield variability, and

4. By understanding these factors we aim to determine the cause of the reduced chicken meat performance related with feed efficiency and breast-meat yield variability.

4.1.2 Materials and Methods

Poultry house and measurements

This pilot experiment was conducted with birds kept in an insulated air-conditioned building in cages designed to house birds from 0-42 days. Birds were reared in cages for 42 days to monitor feed intake and live-weight gain. The poultry house is a fully insulated building that provides complete environmental control using an integrated air-conditioned system for heating or cooling to maintain bird comfort. It has artificial lights in which light intensity can be regulated to keep the birds calm.

- Cages for brooding chicks (from 0-21 d) measured 66 cm (L) x 35 cm (W) x 40 cm (H).

- Cages for rearing birds (from 21-42 d) measured 95 cm (L) x 70 cm (W) x 40 (H).

Every cage contains a nipple watering system and adjustable feeders to provide birds with food and water at all times. An air ventilation system connected with the existing air-conditioned unit was used in tandem to improve internal air quality aiding bird comfort and significantly reducing ammonia, carbon dioxide and humidity emissions. Electronic monitoring of the environment was conducted. Each cage housed 8 birds from 0-21 days with a stocking density of 27.7kg/m2. At day 21 birds were transferred to the follow up cages at 8 birds per cage to yield from 22-42 days a maximum stocking density of 30.1 kg/m2.

During the experiment temperature was gradually reduced from day 1 to day 42 according to breeder recommendations. There was a 23 h/d lighting period from 1-42 d. Chickens that died, or were culled during the first 72 h, were replaced by healthy birds. Any bird dying thereafter was not replaced.

At the beginning of the experiment, all birds were individually weighed and then assigned by stratified randomisation to their treatment cages to achieve 8 birds per cage. Then birds in each cage were bulk weighed at the start of the experiment, and on days 21 and 42. Birds that died or were culled and not replaced were individually weighed at the time of removal from the cage and feed residues recorded in affected pens.

Feed intake (FI) was measured for each pen for the starter period (0-21 d) and finisher period (22-42 d) by weighing each feeder plus contents at the start and end of each period and all feed issues during each growth period. Feed remaining in the feeder at the end of each period was discarded after weighing.

Performance variables measured were: FI, live weight gain (LWG) and feed conversion ratio (FCR). On day 43, three birds per cage were euthanised for evaluation of carcass quality, which included fat pad and breast-meat yield measurements, expressed as % of bird body weight.

Animals and diets

The present study evaluated production performance parameters and carcass quality in two age groups, 0-21 d (starter phase) and 22-42 d (finisher phase).

All sorghum samples collected during 2004 harvest period had been previously analysed for DM, N, P, available P, Ca, AA, AME, and CT (see Chapter 1, Table 4). The Protein meals used for the formulation of the diets were analysed for DM, N, P, and fat with other components obtained from PRDC and ARI database.

The control diet (starter-finisher) was formulated using wheat (at 632-692 g/kg), soybean meal (190-173 g/kg), meat and bone meal (52-34 g/kg), canola meal (60-30 g/kg), sunflower meal (30-20 g/kg) with a commercial xylanase enzyme also added according to industry practice. The remaining sorghum treatment diets used sorghum from 17 different Australian locations to replace the wheat fraction. Ingredients within the sorghum diets varied slightly depending on the sorghum chemical composition. All diets were supplemented with vitamins, minerals and amino acids. Birds were offered the dietary treatments as crumbled starter (containing 12.5 MJ AME and 127 g total lysine/kg) and pelleted finisher diets (containing 13.0 MJ AME and 110 g total lysine/kg) formulated (Feedmania Saltbush Agricultural Software) to achieve maximum production.

All experimental diets were formulated to contain similar calcium, available P, AME and with a similar total crude protein content to meet the minimum total AA requirements estimated as being required for maximum growth. Nutrient requirements used were based and adjusted on data from Baker et al., (2002).

The ingredient and chemical composition of the starter and finisher diets for the wheat control diet and all sorghum diets are presented in Tables 13 and 14 respectively.

Experimental design

In this study, 17 sorghum-based diets and one wheat based-diet were evaluated for broiler performance. The sorghum grains tested corresponded to the 17 collected sorghums from the 2004 harvest.

All diets were offered to Acres (n= 768) male broilers housed in 96 cages with five replicates per sorghum treatment and 11 replicates for the control wheat-based diet. The experimental unit was a cage of eight birds in a completely randomised layout of the 96 cages. Data were analysed using ANOVA and significant (P<0.05) differences between treatment means were determined using the Least Significant Difference test.

Ethical considerations

Before the commencement of each broiler experiment described in this project, animal ethics applications forms were submitted to the Animal Research Institute's Animal Ethics Review Committee. All submissions were approved and complied with the "Australian Code of Practice for the Care and Use of the Animals for Science Purposes" (the green code 6th Ed.), section 2.2.11. All stocking density in cages followed the stipulated in the Model Code of Practice for the Welfare of Animals – Domestic Poultry (4th Edition).

Table 11   Starter diet composition (g/kg as is basis) and calculated analysis using sorghums collected during 2004 harvest as primary grain

Ingredients	Diet A Wheat control	Diet B Sorg 1	Diet C Sorg 2	Diet D Sorg 3	Diet E Sorg 4	Diet F Sorg 5	Diet G Sorg 6	Diet H Sorg 7	Diet I Sorg 8	Diet J Sorg 9	Diet K Sorg 10	Diet L Sorg 11	Diet M Sorg 12	Diet N Sorg 13	Diet O Sorg 14	Diet P Sorg 15	Diet Q Sorg 16	Diet R Sorg 17
Starter																		
Wheat	632.03																	
Sorghum	---	632.8	625.4	623.1	628.0	576.5	600.0	589.2	609.7	609.2	569.5	599.4	617.9	629.3	615.6	610.5	611.6	610.6
Soybean meal	190.62	207.1	216.8	210.9	212.7	269.5	243.6	247.4	233.0	227.9	266.1	242.5	226.8	206.5	227.0	192.1	231.9	229.1
Canola meal	60.00	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	88.0	60.0	60.0
Meat & bone meal	51.47	52.03	51.84	51.98	51.92	50.82	51.32	51.27	51.53	51.63	50.91	51.35	51.64	51.77	51.64	50.67	51.55	51.61
Sunflower meal	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	38.64	30.00	45.00	30.00	30.00
Soybean oil	23.64	2.63	1.10	9.12	2.50	0.21	1.30	8.52	1.92	7.19	11.00	3.26	0.17	0.00	2.26	0.00	1.52	5.32
Salt	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium bicarb	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Cocidiostat	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vit/Min premix	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Lysine HCl	2.81	3.80	3.39	3.64	3.54	1.54	2.23	2.39	2.80	2.54	1.47	2.32	2.47	2.81	2.38	3.03	2.21	2.23
DL Methionine	1.40	4.20	3.91	3.73	3.79	3.92	4.04	3.76	3.59	4.04	3.52	3.66	3.53	3.49	3.61	3.23	3.71	3.63
Enzyme	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1000.3	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0
Crude protein	25.0	23.8	23.6	23.5	23.6	23.5	23.3	23.5	23.5	23.4	23.3	23.5	23.4	23.9	23.4	23.4	23.4	23.5
Lysine	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27
sulphur AA	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
Threonine	0.73	0.72	0.72	0.72	0.72	0.75	0.73	0.77	0.77	0.72	0.74	0.73	0.72	0.73	0.72	0.72	0.72	0.72
Isoleucine	0.82	0.84	0.84	0.84	0.84	0.85	0.84	0.84	0.84	0.84	0.84	0.85	0.84	0.85	0.84	0.83	0.84	0.83
Tryptophan	0.31	0.30	0.29	0.30	0.30	0.31	0.3	0.30	0.30	0.30	0.30	0.30	0.30	0.31	0.30	0.29	0.30	0.31
Arginine	1.42	1.35	1.34	1.34	1.34	1.45	1.4	1.40	1.39	1.38	1.43	1.37	1.34	1.33	1.37	1.33	1.37	1.35
Calcium	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Av P.	0.47	0.47	0.46	0.46	0.46	0.45	0.46	0.45	0.46	0.44	0.45	0.46	0.46	0.47	0.45	0.46	0.46	0.45
Ca/avP	1.79	1.79	1.83	1.83	1.83	1.87	1.83	1.87	1.83	1.91	1.87	1.83	1.83	1.79	1.87	1.83	1.83	1.87
AME Mj/kg	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

1= Pacific MR 43 (Moree, Boomi/ Goondiwindi); 2 = Pacific Buster (Moree, Boomi/ Goondiwindi); 3= Pacific MR 43 (Yellarbon/East Texas); 4= Pacific Buster (Yellarbon/East Texas); 5= Hylan Liberty Kingaroy/Jandowae); 6= Hylan Dominator (Kingaroy/Jandowae); 7= Pioneer Bonus (Dalby/Warra); 8= Pioneer 85G83 (Dalby/Warra); 9= Pacific MR 43 (Clifton); 10= Pacific Buster (Pittsworth); 11= Pacific Buster (Gunnedah); 12= Pacific MR 43 (Gunnedah); 13= Hylan Liberty (Dolby/Bowenville); 14= Pacifc MR 43 (Dalby); 15= Pacific MR Buster (Emerald); 16= Pacific MR 43 (Emerald); 17= Pacific MR Buster (Dalby)

Table 12   Grower/finisher composition (g/kg as is basis) and calculated analysis (%) using sorghums collected during 2004 harvest as primary grain

Ingredients/Diet Grower/finisher	A Wheat control	Diet B Sorg 1	Diet C Sorg 2	Diet D Sorg 3	Diet E Sorg 4	Diet F Sorg 5	Diet G Sorg 6	Diet H Sorg 7	Diet I Sorg 8	Diet J Sorg 9	Diet K Sorg 10	Diet L Sorg 11	Diet M Sorg 12	Diet N Sorg 13	Diet O Sorg 14	Diet P Sorg 15	Diet Q Sorg 16	Diet R Sorg 17
Wheat	692.28	-	-	-														
Sorghum	-	684.50	675.47	672.27	676.31	642.73	667.33	656.86	675.15	672.90	634.70	654.78	667.48	678.67	674.04	681.05	669.92	664.38
Soybean meal	173.01	199.77	210.90	205.25	208.41	248.00	221.42	223.55	212.65	206.67	244.25	231.66	221.43	212.51	212.20	216.23	218.18	218.43
Canola meal	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Meat & bone meal	33.59	33.54	34.41	34.35	34.20	35.67	34.19	35.97	34.59	38.03	35.79	33.80	34.29	32.67	36.18	34.82	34.27	36.27
Sunflower meal	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Soybean oil	34.48	12.38	10.73	19.48	12.47	7.17	8.75	16.49	9.83	15.33	19.19	12.27	9.69	8.50	10.75	1.01	10.12	14.53
Limestone	2.96	3.14	2.73	2.81	2.83	1.98	2.74	2.06	2.65	1.41	1.98	2.81	2.70	3.37	2.06	2.53	2.73	1.98
Salt	2.07	1.35	1.33	1.34	1.33	1.32	1.34	1.32	1.33	1.28	1.33	1.35	1.33	1.35	1.31	1.31	1.33	1.31
Sodium bicarb	2	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Cocidiostat	0.5	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vit/min pre-mix	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Lysine HCl	2.28	3.10	2.60	2.86	2.71	1.18	1.94	2.13	2.47	2.10	1.11	1.68	1.62	1.69	1.77	1.81	1.61	1.47
DL Methionine	1.04	3.86	3.54	3.34	3.39	3.73	3.85	3.55	3.32	3.80	3.28	3.33	3.12	3.05	3.28	2.89	3.39	3.27
Threonine	0.79	0.87	0.79	0.81	0.84	0.72	0.94	0.58	0.50	0.98	0.88	0.83	0.84	0.68	0.92	0.84	0.94	0.87
Enzyme	0.03																	
Total	1000.03	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0
Crude protein	22.8	21.7	21.6	21.5	21.6	20.8	20.6	20.8	21.0	21.0	20.6	21.2	21.4	22.1	21.1	21.4	21.1	21.3
Lysine	1.10	1.10	1.10	1.10	1.10	1.10	1.1	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
sulphur AA	0.86	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Threonine	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
Isoleucine	0.75	0.78	0.78	0.78	0.78	0.76	0.75	0.76	0.76	0.76	0.76	0.78	0.78	0.80	0.76	0.78	0.77	0.77
Tryptophan	0.28	0.28	0.27	0.28	0.28	0.28	0.27	0.27	0.27	0.27	0.27	0.28	0.28	0.29	0.28	0.28	0.28	0.28
Arginine	1.26	1.20	1.20	1.20	1.20	1.26	1.21	1.21	1.20	1.20	1.24	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Calcium	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Av P.	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Ca/avP	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
AME Mj/kg	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0

4.1.3 Results and Discussion

The production performance and carcass evaluations of broilers fed the diets with 2004 Sorghum samples or the control wheat diet over the starter period (0-21 d old) and grower/finisher period (22-42 d old) are presented in Table 15.

Note: Due to a lower growth responses in birds offered Diet 1, all diets in this experiment were checked for protein content and it was found that the content of Diet 1 did not reflect its assumed nutrient content, suggesting a fault in the diet, was therefore not included in the statistical analysis.

Bird performance

During the starter period (0-21 days), independent of sorghum variety and region of cultivation, birds fed diets with sorghums 2, 3, 4, 8, 12, 13, 15, and 16 exhibited similar (P>0.05) FI to that observed in birds fed the wheat diet. These sorghums which represent 50% of sorghum cultivars evaluated in this study, also exhibited the highest live weight gain (LWG). But this LWG (839-884 g/bird) was significantly lower (P<0.05) than birds given the wheat control diet (921 g/bird). As a result, the feed conversion ratio (FCR) of birds in the control wheat diet (1.270) was significantly lower (P<0.05) than those given the sorghum diets (range: 1.406-1.508).

During the grower/finisher phase (22-42 d), birds given diets with sorghum exhibited a similar FI, and LWG (P>0.05) to that of birds given the control wheat-based diet (Table 15). With the exception of birds given sorghum diet 15 (which showed the worst FCR of 1.966); birds consuming the diets based on sorghum converted as efficiently as those birds fed the wheat-based diets and in the case of sorghums diets 8, 10, and 14 conversion was more efficient (P<0.05) than birds consuming wheat-based diets.

This result clearly indicates that during the later growth period (22-42 d) birds were able to improve their starter phase performance, ending with a similar overall LWG at 42 days.

As a consequence of the better performance during the grower/finisher phase, with the exception of sorghum diets 10, and 15, the overall 42 d performance showed that broilers consuming 88% of the sorghum-based diets were as efficient as birds consuming wheat based diets.

The carcass evaluation at 43 d revealed that when fed most sorghum based diets all birds were found to have similar (P>0.05) breast-meat yield (% of BW) and similar (P>0.05) fat pad value (% of BW) to the birds fed the wheat diets. However with sorghum diets 2, 3, 4 and 8 birds exhibited higher (P<0.05) fat pad value of 0.24%.

Table 13 **Mean feed intake (FI), live weight gain (LWG), feed conversion ratio (FCR) in birds fed diets with either sorghum (grains 2-17) or wheat over periods 0-21, 22-42 and 0-42 d of age and final fat pad and breast-meat yield (% body weight)**

Treatment	Feed intake (g/bird)			Live weight gain (g/bird)			FCR (g/g)			Fat pad	Breast-meat
	Age days			Age days			Age days				
	0-21	21-42	0-42	0-21	21-42	0-42	0-21	21-42	0-42	(% BW)	(% BW)
Sorghum 2	1234[abcd]	4051	5285[abc]	874[bcd]	2236	3110	1.421[ghi]	1.811[bcd]	1.699[cdef]	1.19[abc]	20.34
Sorghum 3	1229[bcd]	4116	5346[ab]	884[b]	2295	3180	1.406[hij]	1.810[bcd]	1.692[def]	1.28[a]	19.95
Sorghum 4	1254[abc]	3999	5252[bc]	866b[cd]	2175	3041	1.448[defg]	1.853[bc]	1.729[bcd]	1.23[ab]	20.06
Sorghum 5	1217[cdef]	4015	5232[bc]	826[efg]	2246	3073	1.468[bcdef]	1.875[b]	1.750[b]	1.06[abcde]	20.22
Sorghum 6	1182[defg]	3961	5143[bcd]	788[gh]	2184	2972	1.500[ab]	1.815[bcd]	1.730[bcd]	1.10[abcd]	20.11
Sorghum 7	1180[defg]	4148	5328[ab]	837[def]	2317	3154	1.410[hi]	1.806[bcd]	1.697[cdef]	1.09[abcd]	19.40
Sorghum 8	1230[bcd]	4013	5243[bc]	878[bc]	2292	3171	1.403[ij]	1.784[cde]	1.668[ef]	1.19[abc]	19.56
Sorghum 9	1190[defg]	4119	5309[ab]	839[def]	2290	3129	1.437[fgh]	1.821[bcd]	1.710[bcdef]	1.13[abcd]	19.84
Sorghum 10	1011[h]	3908	4919[d]	689[i]	2282	2971	1.467[cdef]	1.731[e]	1.665[f]	1.12[abcd]	19.63
Sorghum 11	1173[efg]	3878	5050[cd]	779[h]	2162	2941	1.508[a]	1.809[bcd]	1.725[bcd]	0.97[cde]	20.05
Sorghum 12	1234[abcd]	4082	5316[ab]	839[def]	2246	3086	1.471[bcde]	1.853[bc]	1.745[bc]	1.06[abcde]	20.03
Sorghum 13	1252[abc]	3995	5247[bc]	857[bcde]	2258	3115	1.489[abc]	1.834[bcd]	1.731[bcd]	1.04[bcde]	20.72
Sorghum 14	1162[fg]	4040	5243[bc]	805[fgh]	2273	3079	1.443[efg]	1.776[de]	1.688[def]	1.14[abcd]	19.98
Sorghum 15	1290[a]	4231	5521[a]	875[bcd]	2162	3038	1.478[abcd]	1.966[a]	1.813[a]	0.86[e]	20.71
Sorghum 16	1224[bcde]	4018	5243[bc]	840[cdef]	2192	3032	1.463[cdef]	1.832[bcd]	1.724[bcd]	0.98[cde]	20.11
Sorghum 17	1135[g]	4131	5266[bc]	786[h]	2303	3090	1.455[def]	1.811[bcd]	1.713[bcdef]	0.99[cde]	19.65
Wheat control	1270[ab]	4021	5291[b]	921[a]	2210	3132	1.379[j]	1.862[b]	1.710[bcde]	0.98[de]	21.02
LSD (P=0.05)[a]	48	190	217	33	120	133	0.028	0.060	0.051	0.191	1.194
LSD (P=0.05)[b]	56	223	255	39	141	156	0.033	0.071	0.043	0.222	1.389

2 = Pacific Buster (Moree, Boomi/ Goondiwindi); 3= Pacific MR 43 (Yellarbon/East Texas); 4= Pacific Buster (Yellarbon/East Texas); 5= Hylan Liberty (Kingaroy/Jandowae); 6= Hylan Dominator (Kingaroy/Jandowae); 7= Pioneer Bonus (Dalby/Warra); 8= Pioneer 85G83 (Dalby/Warra); 9= Pacific MR 43 (Clifton); 10= Pacific Buster (Pittsworth); 11= Pacific Buster (Gunnedah); 12= Pacific MR 43 (Gunnedah); 13= Hylan Liberty (Dolby/Bowenville); 14= Pacifc MR 43 (Dalby); 15= Pacific MR Buster (Emerald); 16= Pacific MR 43 (Emerald); 17= Pacific MR Buster (Dalby); a= LSD for comparing sorghum diet means with the wheat control; b= LSD for comparing within sorghum diets. Means within a column with different superscript are significantly different (P<0.05)

Relationships between grain AME intake, live weight gain and feed conversion ratio

For the starter period 0-21 d, it was found that there was a poor relationship (r = 0.477) between bird FI and sorghum AME value, but between Sorghum AME intake and LWG there was a stronger relationship (r= 0.887) (see Figure 3a). The graph shows a substantial variation in bird performance within sorghum cultivars (P<0.05), even when the determined AME values within those sorghums cultivars were similar (mean 15.8 MJ/Kg DM, SD 0.18). There is an indication of a region effect for the variety performance. For example, the Pacifc Buster variety grown at both Pisttsworth on the Central Downs in Qld and at Gunnedah in NSW, were the poorest performing in terms of bird LWG (689 and 779 g/b). But when birds were fed the same sorghum variety harvested from Yellarbon, Moree and Emerald, they grew well (866, 874, 875 g/b).

The poor relationship observed between grain AME intake and FCR seen in the Figure 3b shows that the determined AME on these sorghums using birds aged 22-28 d old, did not fit well with the efficiency of feed utilisation (FCR). During the starter phase, calculations indicate that birds consumed about the same energy from either wheat or combined value sorghum (0.54 vs. 0.55 MJ/d). However, birds ingesting energy from wheat gained 921 g (43.9 g/d) which was about 11% higher than in birds ingesting energy from sorghum (mean 829; g 39.5g/d). In terms of feed efficiency, 5.4% less feed was required for each unit of LWG for birds fed the wheat diet when compared with bird fed sorghum diets (FCR 1.379 vs. 1.454). Black *et al.*, (2005) also found similar response when comparing AME and broiler performance between sorghum and wheat based diets.

It is worth noting that in the present study, that the control waxy wheat from Narrabri, NSW contained and AME of 14.39 MJ/kg DM, to which was added:

- A commercial xylanase enzyme to the diet, as is current commercial practice in Australia, and

- Oil was added to the wheat-based diets due to its lower AME and when compared with the main oil content of the sorghum-based diets this was 86% increased (Table 13).

These two factors (both the addition of enzyme + extra oil) may have contributed to improving the quality of the wheat based diet and thus its improved efficiency as shown by the superior birds FCR (Figure 3b).
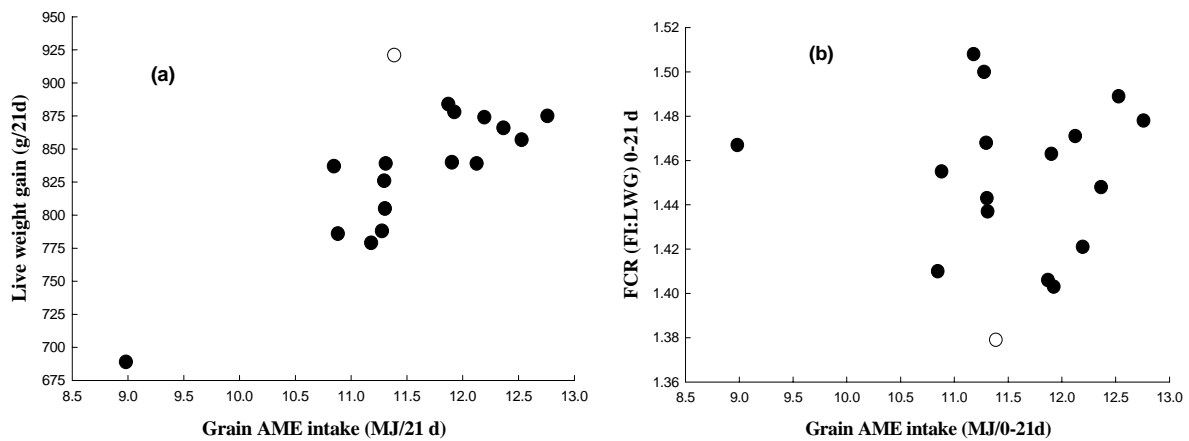
Figure 3 Relationship between grain AME intake and live weight gain (figure a) and between AME intake and feed conversion ratio (figure b) of broiler during the starter period (0-21 d) when fed either sorghum (●) or wheat (○) based diets. Each data point represents the mean value of five cages for each sorghum and 11 cages for wheat, with 8 birds/cage.

For the grower/finisher period 22-42 d, birds fed most of the sorghum cultivars consumed about 43MJ (1.9Mj/d) and displayed a consistent LWG, except those fed sorghums Pacific Buster 10, 11 and 15 (see Figure 4a and 4b). This low variability in energy intake with sorghum resulted in similar (P>0.05) LWG and FCR. During this grower/finisher phase, birds fed sorghum diets used 23 MJ AME/kg of body gain, which was slightly better than 24.2 MJ used by wheat diet fed birds. Even the diet based on sorghum 10, with the lowest LWG during the starter phase, was more efficiently used than wheat during the 22-42 d period. Similarly sorghum diet birds consumed 42.6 MJ (2.03 MJ/d) and gained 106.9 g/d, which was significantly (P<0.05) more than wheat diet birds which consumed about 40.1 MJ (1.9 MJ/d) and gained 105.6 g/d.
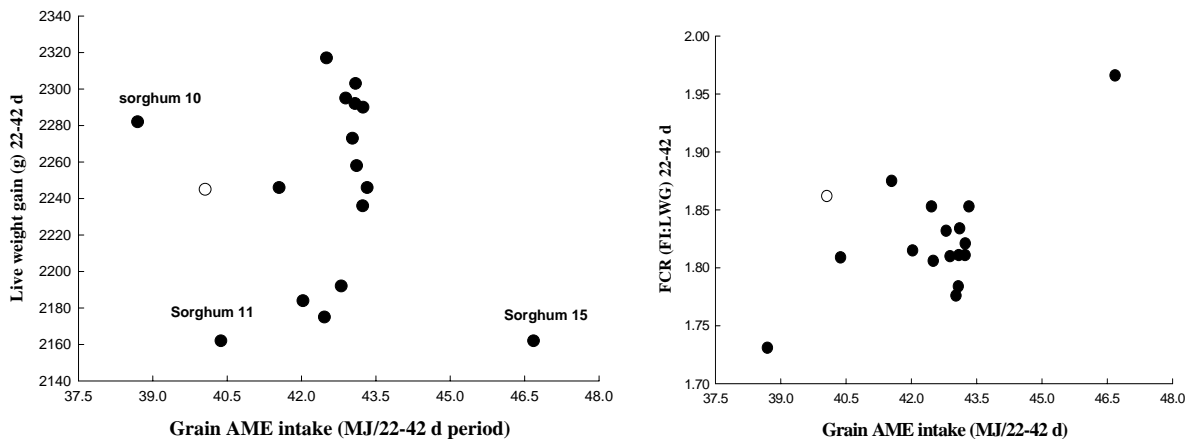
Figure 4 Relationship between grain AME intake and live weight gain (figure a) and between AME intake and feed conversion ratio (figure b) of broilers during the grower/finisher period (22-42 d) when fed either sorghum (●) or wheat (○) based diets. Each data point represents the mean value of five cages for each sorghum point and 11 cages for wheat, with 8 birds/cage.

When all data is combined (Table 16), it is clear that during the starter period (0-21 d) birds consuming sorghum diets had a significantly (P<0.05) reduced FI, LWG and poorer FCR compared to the wheat diet birds. However during the grower/finisher period, birds fed the sorghum diets had similar FI and LWG but with a superior (P<0.05) FCR. The carcass evaluations showed a similar fat pad and a 5% lower breast-meat yield than birds fed the wheat diets and so overcoming the initially lower growth and FCR observed during the starter phase. More research work is needed to explain this difference in response to sorghum in the two growth periods.

It would appear that there is a potential for improving the use of sorghum particularly during the starter phase and further studies will need to focus on feed strategies to improve nutrient availability during the 0-21 d period.

Table 14 Overall comparison of mean feed intake (FI), liveweight gain (LWG), feed conversion ratio (FCR) for birds fed diets with either sorghum or wheat over periods 0-21, 22-42 and 0-42 d of age and with final fat pad and breast-meat yield (% of body weight).

Treatment	AME	Feed intake (g/bird)			Live weight gain (g/bird)			FCR (g/g)			Fat pad	Breast yield
		Age in days			Age in days			Age in days				
		0-21	22-42	0-42	0-21	22-42	0-42	0-21	22-42	0-42	(% body wt)	(% body wt)
Wheat	13.90	1270[a]	4021	5291[a]	921[a]	2210	3132	1.379[a]	1.862[a]	1.710	0.982	21.0[a]
Sorghum	15.81	1200[b]	4044	5246[b]	829[b]	2245	3074	1.454[b]	1.824[b]	1.717	1.09	20.0[b]
LSD (P=0.05)		28.6	113	129	19.7	71.5	79.3	0.017	0.036	0.030	0.115	0.72

Means within a column with different superscript are significantly different (P<0.05)

4.2 Experiment 2 – Pilot trial evaluating different sorghums from Qld and NSW regions collected during 2005 harvest in chicken meat diets

4.2.1 Introduction

In 2005, 14 sorghum samples were collected and evaluated (Chapter 2 and 3) indicating that the crude protein content and amino acid digestibility particularly cystine and tryptophan is generally lower in Sorghum than in wheat. It was also determined that the sorghum apparent metabolisable energy (AME MJ/Kg DM) was higher and less variable than wheat. The AME content of these sorghums using younger birds (14-24 d) in the bioassay, was about 0.8MJ lower than the AME values of previous sorghums evaluations (2004 harvest), determined in older birds (22-28 d). It was concluded that AME determination is dependent on the actual bioassay used, with bird age and not method of feed preparation as the main factor affecting AME values (Chapter 3, section 3.2.2). Results in section 4.1 which evaluated broiler performance in metabolism cages indicated that the sorghum dietss despite being formulated to the same nutrient specifications as the wheat diet, produced birds with significantly lower (P<0.05) FI, LWG and FCR during the starter phase but which had similar FI, LWG and superior FCR during the grower/finisher period (22-42 d). Birds thus ended with similar LWG and FCR at 42 day but with carcass containing a higher amount of fat pad and significantly less breast-meat yield with 5% variability. The poorer LWG and FCR at 21 days and the high carcass variability was linked to anti-nutritional factors (ANF) such as condensed tannins (CT), other polyphenolic compounds, dietary phytate and the sorghum prolamins proteins (Perez-Maldonado et al., 2006), which limited the availability and digestibility of essential nutrients.

The production performance of 14 sorghum-based diets from the 2005 harvest was carried out to evaluate:

1. bird performance against wheat-based diets,

2. bird performance of the sorghum-based diets when prepared using AME values obtained in young birds (14-21 d), and

3. bird performance of sorghum-based diets when a commercial xylanase enzyme was added to selected treatments.

4.2.2 Materials and Methods

Poultry house, measurements, animals and diets

This experiment was conducted with birds kept in an insulated air-conditioned building in cages designed to house birds from 0-42 days. Birds were reared in cages for 42 days to monitor feed intake and live-weight gain. The poultry house used, bird's genetics, temperature, general management and performance measurements were as same as described in section 4.1.2.

The present study evaluated broiler performance parameters and carcass quality in two age periods, 0-21 d (starter phase) and 22-42 d (finisher phase). Birds were offered crumbled starter and pelleted grower/finisher diets prepared and formulated to achieve maximum performance.

All diets were formulated using the 2005 sorghum samples which had been previously analysed for DM, N, P, available P, Ca, AA, AME, and CT. The chemical composition of each sorghum grain including the wheat grain used in this experiment is presented in Table 5 (see chapter 1). In addition, the protein meals used for the formulation of the diets were also analysed for DM, N, P, and fat, with other components estimated from the PRDC and ARI nutrient database.

The control starter-finisher diet was formulated using wheat (637-698 g/kg), soybean meal (188-153 g/kg), meat and bone meal (55-39 g/kg), canola meal (50-30 g/kg), and sunflower meal (30-20 g/kg);

with a commercial xylanase enzyme also added according to current industry practice. The remaining sorghum treatments from 14 different Australian locations replaced wheat. Ingredients within sorghum diets slightly varied depending on the chemical composition of the sorghum to be evaluated. All diets were supplemented with vitamins, minerals and amino acids. Birds were offered the dietary treatments as crumbled starter (supplying 12.5 MJ AME and 127 g total lysine/kg) and pelleted finisher diets (supplying 13.0 MJ AME and 110 g total lysine/kg) formulated to achieve maximum production. All experimental diets were designed to contain similar levels of calcium, available P, AME with similar total crude protein content to meet the minimum total AA requirements estimated for maximum growth. Nutrient requirements used were obtained and adjusted from Baker et al., (2002).

The ingredient composition and calculated chemical analysis of the starter and finisher diets for the wheat and all sorghum diets are presented in Tables 17 and 18 respectively

Experimental design

14 sorghum (2005 harvest) diets and one wheat based-diet (control) were evaluated. All diets were offered to Arbor Acres (n= 608) male broilers housed in 76 cages with five replicates per sorghum diet and six replicates for the control wheat-based diet. The experimental unit was a cage of eight birds in a completely randomised lay out of the 76 cages. Data were analysed using ANOVA and significant (P<0.05) differences between treatment means were determined using the Least Significant Difference test.

Additional treatments

An additional sorghum samples (which performed poorly in the previous cage trial of 2004 sorghum samples) was also re-evaluated in this experiment. This additional repeated dietary treatment was evaluated with and without the additional of a commercial phytase enzyme supplement.

An additional wheat grain which exhibited a low AME was also included with commercial xylanase added. These two grains treatment were only included for observations purpose here and are not considered in the experimental design.

Table 15   Starter diet composition (g/kg as is basis) and calculated analysis using sorghum samples collected during 2005 harvest

Ingredients/Diet	P	Q	0	R	A	B	C	D	E	F	G	H	I	J	K	L	M	N
	Low	wheat	Sorg 1	Sorg 1 +	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg
Starter	AME wheat	Control	Repeat	Phytase	1 A	2 B	3 C	4 D	5 E	6 F	7 G	8 H	9 I	10 J	11 K	12 L	13 M	14 N
Wheat	653.8	637.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sorghum	0.0	0.0	602.7	602.7	588.5	628.6	625.7	593.2	601.7	611.7	608.3	605.2	604.6	570.2	575.2	583.5	621.6	613.0
Soybean meal	168.9	188.4	246.7	246.7	256.3	230.2	243.2	277.9	268.7	246.5	261.7	249.3	265.5	281.4	295.7	267.2	230.6	230.1
Canola meal	40.0	50.0	30.0	30.0	40.0	40.0	30.0	30.0	30.0	40.0	30.0	40.0	30.0	40.0	30.0	40.0	40.0	40.0
Meat/bone meal	55.0	55.0	54.6	54.6	55.0	55.0	52.8	53.8	53.1	55.0	54.7	55.0	53.3	55.0	52.3	54.9	55.0	55.0
Sunflower meal	30.0	30.0	50.0	50.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Soybean oil	36.4	24.4	0.0	0.0	16.3	0.8	0.0	0.0	0.0	2.1	0.0	5.7	0.0	9.7	0.0	10.2	7.2	16.3
Kynofos	1.7	0.1	0.3	0.3	0.1	0.5	2.6	1.1	1.9	0.3	0.6	0.2	1.7	0.0	2.1	0.0	0.6	0.6
Salt	0.3	0.8	1.2	1.2	0.3	0.2	1.1	1.5	1.4	0.2	1.3	0.2	1.3	0.3	1.6	0.3	0.2	0.3
Sodium bicarb.	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Cocidiostat	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Vit/Min premix	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Lysine HCl	4.64	3.39	3.01	3.01	2.98	3.84	3.65	2.46	2.83	3.36	2.82	3.23	2.87	2.39	2.05	2.68	3.84	3.79
DL Methionine	1.87	2.55	3.85	3.85	3.01	3.23	3.48	2.59	3.02	3.37	3.07	3.51	3.17	3.55	3.51	3.72	3.49	3.44
Xylanase enzyme	0.3	0.3	0	0.15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calculated analysis																		
Crude protein	26.2	25.9	25.6	25.6	24.4	24.5	24.4	25.6	25.5	24.4	25.6	24.4	25.1	24.1	24.6	24.3	24.3	24.1
Lysine	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27
sulphur AA	0.930	0.930	0.930	0.930	0.930	0.930	0.930	0.930	0.93	0.93	0.930	0.930	0.930	0.930	0.930	0.930	0.930	0.930
Methionine	0.494	0.538	0.629	0.629	0.583	0.596	0.611	0.565	0.59	0.602	0.590	0.606	0.593	0.608	0.607	0.617	0.609	0.611
Cystine	0.436	0.392	0.301	0.301	0.347	0.334	0.319	0.365	0.344	0.328	0.340	0.324	0.337	0.322	0.323	0.313	0.321	0.319
Met%SAA	53.1	57.8	67.6	67.6	62.7	64.1	65.7	60.8	63.0	64.7	63.5	65.2	63.7	65.4	65.3	66.4	65.5	65.7
Cyst%SAA	46.9	42.2	32.4	32.4	37.3	35.9	34.3	39.2	37.0	35.3	36.5	34.8	36.3	34.6	34.7	33.6	34.5	34.3
Threonine	0.743	0.762	0.773	0.773	0.761	0.752	0.758	0.802	0.80	0.7618	0.793	0.767	0.720	0.765	0.783	0.761	0.748	0.745
Isoleucine	0.825	0.849	0.898	0.898	0.847	0.840	0.857	0.897	0.90	0.8441	0.886	0.842	0.874	0.838	0.869	0.847	0.846	0.842
Tryptophan	0.291	0.290	0.324	0.324	0.310	0.300	0.303	0.326	0.31	0.3006	0.320	0.303	0.316	0.308	0.321	0.307	0.295	0.296
Arginine	1.399	1.416	1.461	1.461	1.407	1.359	1.352	1.479	1.45	1.3904	1.439	1.399	0.316	1.430	1.460	1.416	1.330	1.330
Calcium	0.840	0.840	0.840	0.840	0.840	0.840	0.840	0.840	0.84	0.84	0.840	0.840	0.840	0.845	0.840	0.840	0.840	0.840
Av P.	0.421	0.440	0.440	0.440	0.411	0.422	0.440	0.440	0.44	0.4152	0.440	0.413	0.440	0.410	0.440	0.421	0.422	0.421
Ca/avP	2.00	1.91	1.91	1.91	2.04	1.91	1.91	1.91	1.91	2.02	1.91	2.03	1.91	2.06	1.91	2.00	2.00	2.00
AME Mj/kg	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

A= Pac. MR 43, S Downs; B= Pacific Buster, Lowood, Lockyer; C= Pioneer 86G87, W Downs; D= Pacific Buster C Downs; E= Pacific Buster, Lowood, Lockyer; F= Pacific MR 43, C Downs; G= Pacific Buster, Dalby; H= Pioneer Bonus W Downs; I= Pioneer Bounty, Dalby; J= Pioneer Bounty, S Downs; K= Hylan Liberty, N Downs; L= Pacific MR 43, Liverpool Plains; M= Pacific MR 43, Liverpool Plains; N= Pacific MR Buster, Liverpool Plains

Table 16   Grower/finisher diet composition (g/kg as is basis) and calculated analysis (%) using sorghums collected during 2005 harvest grain

Ingredients/Diet	P	Q	O	R	A	B	C	D	E	F	G	H	I	J	K	L	M	N
	Wheat	Wheat	Sorg 1	Diet O +	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg	Sorg
Grower/finisher	Low AME	control	repeat	phytase	1A	2B	3C	4 D	5 E	6 F	7 G	8 H	9 I	10 J	11 K	12 L	13 M	14 N
Wheat	642.3	698.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sorghum	0	0	664.5	664.5	627.8	642.6	646	651.3	648.1	640.3	654.5	637.6	649.5	616.6	635.5	632.7	635.6	628.5
Soybean meal	196.9	153.9	222.4	222.4	233.4	233.2	232.6	232.3	233.8	235.1	227.4	234.1	232	252.2	247.7	235.3	233.5	231.1
Canola meal	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Meat/bone meal	40	39	39.6	39.6	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Sunflower meal	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Soybean oil	55.6	41.1	6.9	6.9	32.6	18.5	15.1	11.3	12.5	18.5	12.8	22	12.6	24.8	10.5	25.1	24.9	34.1
Limestone	0.87	1.91	1.55	1.55	0.9	1	0.75	1.18	0.95	0.93	1.35	0.91	1	0.75	0.79	1.13	1.02	1
Salt	1.39	2.1	1.34	1.34	1.38	1.36	1.35	1.35	1.35	1.36	1.35	1.36	1.35	1.37	1.35	1.37	1.37	1.38
Kynofos	1.88	0	0	0	1.11	0.83	1.44	0.41	0.93	0.97	0.07	1.05	0.85	1.13	1.08	0.51	0.82	0.92
Sodium bicarb	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Cocidiostat	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Vit/Min premix	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Lysine HCl	2.26	3.16	2.26	2.26	2.29	2.28	2.28	2.28	2.28	2.29	2.27	2.29	2.28	1.93	1.93	2.29	2.29	2.29
DL Methionine	1.29	2.22	3.43	3.43	2.57	2.6	2.84	2.18	2.56	2.86	2.62	3.04	2.71	3.23	3.21	3.42	2.86	2.83
Threonine	0	0.64	0.44	0.44	0.45	0.16	0.15	0.2	0.04	0.27	0.14	0.27	0.21	0.52	0.46	0.59	0.2	0.26
Xylanase enzyme	0.3	0.3	0	0.15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	100.03	100.03	100	100.02	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Calculated analysis																		
Crude protein	25.8	23.3	23.1	23.1	22.2	23.2	23	23	23.3	22.6	23.3	22.5	22.9	21.6	21.8	21.7	23	22.8
Lysine	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
sulphur AA	0.86	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Threonine	0.74	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
Isoleucine	0.83	0.76	0.81	0.81	0.77	0.81	0.82	0.801	0.82	0.79	0.81	0.78	0.8	0.75	0.76	0.76	0.82	0.81
Tryptophan	0.29	0.25	0.29	0.29	0.28	0.29	0.29	0.29	0.29	0.28	0.29	0.28	0.29	0.28	0.28	0.27	0.28	0.28
Arginine	1.39	1.22	1.27	1.27	1.25	1.28	1.26	1.28	1.28	1.27	1.27	1.27	1.27	1.25	1.25	1.23	1.25	1.25
Calcium	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Av P.	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Ca/avP	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
AME Mj/kg	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13

1= Pacific MR 43 (Moree, Boomi/ Goondiwindi A= Pac. MR 43, S Downs; B= Pacific Buster, Lowood, Lockyer; C= Pioneer 86G87, W Downs; D= Pacific Buster C Downs; E= Pacific Buster, Lowood, Lockyer; F= Pacific MR 43, C Downs; G= Pacific Buster, Dalby; H= Pioneer Bonus W Downs; I= Pioneer Bounty, Dalby; J= Pioneer Bounty, S Downs; K= Hylan Liberty, N Downs; L= Pacific MR 43, Liverpool Plains; M= Pacific MR 43, Liverpool Plains; N= Pacific MR Buster, Liverpool Plains

4.2.3 Results and Discussions

The responses of broilers to individual sorghum starter (0-21 d old) and finisher (22-42 d old) diets were compared with the control wheat diet for performance, and carcass evaluation in Table 19.

Bird performance

During the starter period (0-21 d), birds offered sorghum diets B, C, D, E, F, G, I, K and M (64% of sorghum evaluated) exhibited similar (P>0.05) FI to birds offered the wheat diet. However, birds given the control diet had higher (P<0.05) LWG (944 g/bird) than those given the sorghum treatments (836-902 g/bird) except for sorghum diet K (931 g/bird). FCR was also better (P<0.05) for birds on the control diet (1.263) than for those given the sorghum diets (range: 1.296-1.355).

During the grower/finisher period (22-42 d), there was no difference in LWG between the birds given the wheat or sorghum-based diets, and FCR on sorghum-based diets A, C, H, L, M and N (1.645-1.697) was similar (P<0.05) to birds on the wheat-based diet (1.655).

The carcass evaluation at 43 d revealed that all sorghum samples produced birds with similar (P>0.05) fat pad value (% of BW) and breast-meat yield (% of BW) to those on the wheat-based diet except for those given sorghum diet A where breast-meat yield was 1.6% lower (P<0.05). CT analysis of all sorghum samples revealed that sorghum variety K, had the lowest CT value at 0.73 g/kg DM.

In this experiment, reduced broiler performance was observed in birds given the sorghum-based diets only during the starter phase but not during the finisher phase. This is in agreement with previous studies using similar sorghum varieties from the 2004 harvest (Perez-Maldonado et al., 2006, Robertson et al., 2006), which have also shown better performance of broilers on wheat than on sorghum diets in the starter phase. Similarly, Cadogan et al., (2005), in a study on the effect of feed enzymes in sorghum diets, showed a positive effect on LWG and FI in the starter phase. These studies suggest that any differences between sorghum and wheat disappear during the finisher phase. However, because FCR in the finisher period was inferior (P<0.05) in more than half of the sorghum-based diets compared to the wheat diet in the present study, there still appears to be an opportunity for improving sorghum nutrient digestibility and availability, to levels similar to those achieved with wheat in the 0-21 d phase, which may also improve the FCR in the finisher phase.

Despite diets being formulated iso-energetic for the starter and finisher periods (12.5 and 13.0 MJ/kg) respectively; the efficiency of energy utilization per kg of body weight gain (EEU) during the starter phase was superior (0.83 MJ) in birds given the wheat-based diets. However, during the finisher period, performance of birds consuming sorghum diets improved, and so reduced the EEU gap between sorghum and wheat to 0.73 MJ indicating an improvement in sorghum energy utilization. Similarly, in another study (Black et al., 2005), it has been reported that despite a similar intake of AME, broilers offered wheat-based diets grew 20% faster and used 13% less feed than those offered sorghum-based diets, suggesting that the energy from sorghum is used less efficiently by broilers chickens than the energy from wheat.

Table 17 Mean feed intake (FI), live weight gain (LWG), feed conversion ratio (FCR) in birds fed diets with either sorghum (samples A-N with various CT content expressed as g/kg DM grain) or wheat over periods 0-21, 22-42 and 0-42 d of age and final fat pad and breast-meat yield (% body weight).

Treatment	Grain CT	FI (g/bird)			LWG (g/bird)			FCR (g:g)			Fat pad	Breast-meat yield
		Age in Days			Age in Days			Age in days				
Age in Days		0-21	22-42	0-42	0-21	22-42	0-42	0-21	22-42	0-42	(% BW)	(% BW)
Sorghum A	4.63	1117de	3610	4727cd	845fg	2127	2972d	1.329abcd	1.697de	1.590de	0.83	20.50d
Sorghum B	5.14	1187ab	3693	4880abc	877cdef	2121	2997cd	1.355a	1.742bc	1.628ab	0.83	22.00bc
Sorghum C	4.02	1174abc	3723	4897abc	902bc	2203	3105abc	1.302de	1.690de	1.577ef	0.90	22.10bc
Sorghum D	3.14	1160abcd	3622	4781abcd	880cdef	2134	3014bcd	1.319cde	1.712bcd	1.595cde	0.73	22.00bc
Sorghum E	4.80	1189ab	3714	4903abc	899bc	2076	2975d	1.332abcd	1.790a	1.650a	0.75	22.60ab
Sorghum F	4.15	1164abcd	3652	4816abcd	861defg	2157	3018bcd	1.352ab	1.703cd	1.602bcde	0.78	22.40abc
Sorghum G	4.36	1200a	3754	4954a	896bcd	2154	3050bcd	1.340abc	1.743bc	1.624abc	0.74	21.70bcd
Sorghum H	4.40	1130cde	3674	4804abcd	856efg	2170	3025bcd	1.322bcde	1.693de	1.588de	0.89	22.30abc
Sorghum I	3.81	1161abcd	3644	4805abcd	883cde	2134	3016bcd	1.315cde	1.750ab	1.616bcd	0.84	21.70bcd
Sorghum J	4.98	1111e	3701	4812abcd	836g	2185	3021bcd	1.328abcd	1.705cd	1.598bcde	0.88	21.80bcd
Sorghum K	0.73	1205a	3712	4916ab	931ab	2157	3088bc	1.296e	1.746abc	1.607bcde	0.83	22.70ab
Sorghum L	4.59	1129cde	3640	4770bcd	853efg	2188	3041bcd	1.324abcde	1.676def	1.576ef	0.83	22.00bc
Sorghum M	6.00	1148bcde	3724	4873abc	849efg	2200	3049bcd	1.352ab	1.693de	1.598bcde	0.80	21.60bcd
Sorghum N	6.07	1138cde	3525	4663d	848efg	2155	3003cd	1.342abc	1.645f	1.557fg	0.84	21.00cd
Wheat-control	0.24	1189ab	3696	4890abc	944a	2258	3205a	1.263f	1.655ef	1.537g	1.00	22.10bc
LSD (P=0.05)1		47	157	177	35	98	112	0.031	0.045	0.031	0.17	1.4
LSD (P=0.05)2		45	151	170	34	94	107	0.030	0.043	0.030	0.16	1.3

Different superscripts in columns indicate significantly (P<0.05) different means. [1] LSD comparing wheat *vs.* sorghum. [2] LSD comparing between sorghums; A= Pac. MR 43, S Downs; B= Pacific Buster, Lowood, Lockyer; C= Pioneer 86G87, W Downs; D= Pacific Buster C Downs; E= Pacific Buster, Lowood, Lockyer; F= Pacific MR 43, C Downs; G= Pacific Buster, Dalby; H= Pioneer Bonus W Downs; I= Pioneer Bounty, Dalby; J= Pioneer Bounty, S Downs; K= Hylan Liberty, N Downs; L= Pacific MR 43, Liverpool Plains; M= Pacific MR 43, Liverpool Plains; N= Pacific MR Buster, Liverpool Plains

In terms of grain AME intake by birds during the starter period, the mean AME intake for wheat and sorghum samples was similar at 0.5 MJ/d. But birds ingesting wheat grew 8.2% faster than birds on sorghum. This indicates the need for more research to understand the poor energy utilization on Sorghum particularly during the starter period.
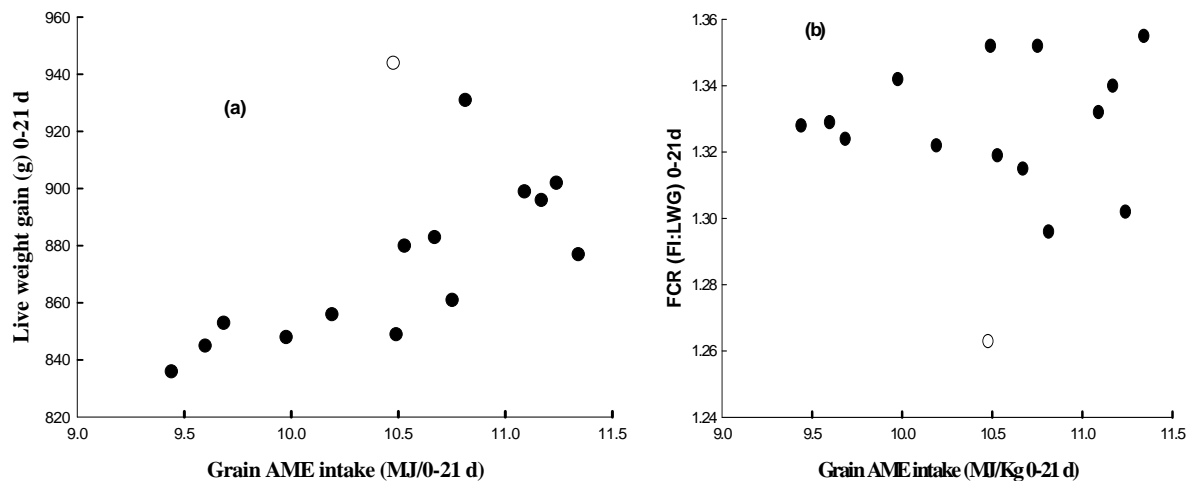
Each data point represents the mean value of five cages for each sorghum and 6 cages for wheat , with 8 birds/cage.

Figure 5   Relationship between grain AME intake and live weight gain (Figure a) and between AME intake and feed conversion ratio (figure b) of broilers during the starter period (0-21 d) when fed either sorghum (●) or wheat (○) based diets.

In the present experiment, during the starter period, a strong relationship between grain AME intake and LWG (r = 0.762) was observed, which is in agreement with our previous experiment with sorghum from 2004 (described in section 4.1.4). Although 64% of sorghum cultivars examined had a similar bird FI as that seen on the control wheat diet (Table 19), the obtained LWG values varied greatly within sorghums cultivars and this was reflected in the poorer sorghum FCR, as seen in figure 5b. This poor FCR at 21 d would appear to be strongly linked (r = 0.704) with the total intake of CT from sorghum grains during same period (Figure 6).
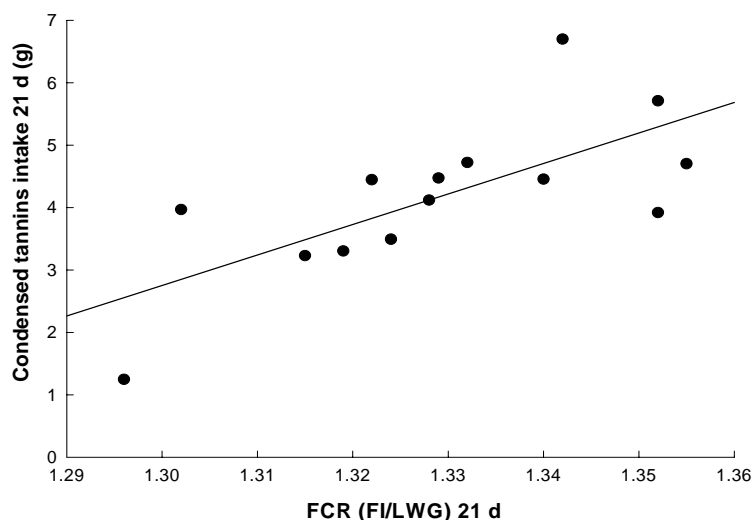
Each data point represents the mean value of five cages with eight birds/cage.

Figure 6   Relationship between feed conversion ratio (FCR) and condensed tannin intake of broiler during the starter period (0-21 d) when given sorghum-based diets.

It appears therefore, that the inferior FCR observed with sorghum diets, especially in the starter phase, appears to be due to ANF such as CT which restricted nutrient availability. In this study, during the starter period, the performance achieved by birds offered sorghum diet K, which had the lowest sorghum CT content (see Table 17), was similar to those given the wheat-based diet. This suggests the importance of CT as an ANF present in Australian sorghum grain, since CT are known to bind to digestive enzymes and reduce the digestion and availability of dietary compounds including amino acids in poultry (Nyachoti et al., 1997; Perez-Maldonado, 1994).

Our studies on sorghum AME determination (Section 3.2.4) have also revealed a strong negative relationship (r = -0.753) between sorghum CT content and AME value. Other studies (Perez-Maldonado et al., 2007) have also shown a reduction of sorghum AME values when bird age is reduced (Section 3.2.5) suggesting that the negative effect of CT is pronounced in young birds.
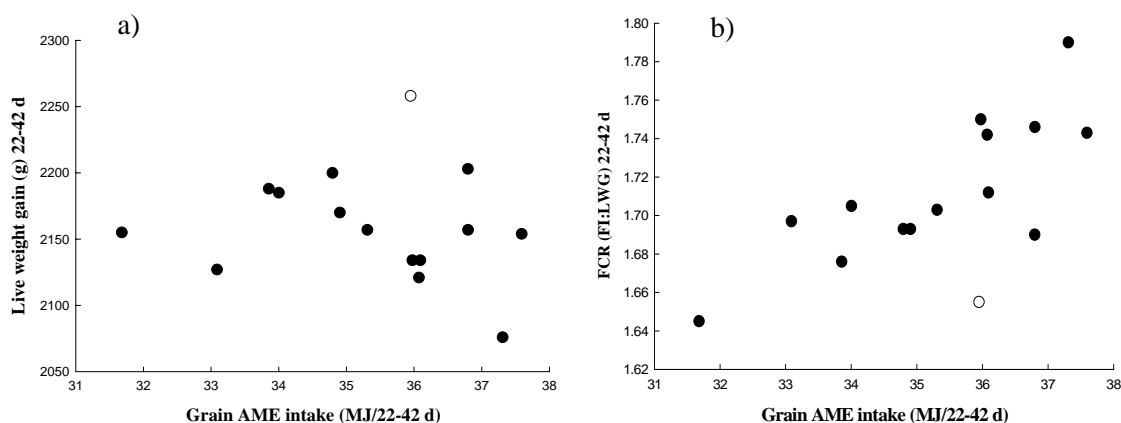
Each data point represents the mean value of five cages for each sorghum point and six cages for each wheat, with 8 birds/cage.

Figure 7   Relationship between grain AME intake and live weight gain (Figure a) and between AME intake and feed conversion ratio (Figure b) of broiler during the grower/finisher period (22-42 d) when fed either sorghum (●) or wheat (○) based diets.

Over the 22-42 d period, birds on sorghum diets had overall AME intake of 35.3 MJ, which was 1.82% less than birds consuming wheat (with AME intake of 35.95MJ). But birds on sorghum improved which can be seen with reduction of the LWG gap to only 4.8% which was not significantly different (P>0.05) when compared with LWG of birds on wheat AME intake. This improvement during the grower/finisher period (22-42 d), helped improve the FCR on sorghum diets A, C, H, L, M and N (1.645-1.697) which were similar (P<0.05) to birds on the wheat-based diet (1.655). However 50% of Sorghum cultivars were still performing poorly and this needs further investigation.

Broiler performance comparison of pilot studies conducted on sorghum grains from the 2004 and 2005 harvest

All pilot studies for the 2004 and 2005 sorghum samples which evaluated bird growth performance were conducted with diets containing similar ingredients, AA requirements, iso-energetic, and had similar protein content. All birds were of similar strain and housed under the same ambient conditions. Overall broiler performance comparison between pilot studies for the 2004 and 2005 sorghum samples show that in each growth period birds LWG mean value (Figure 8b) were similar. However broiler birds consuming 2005 sorghum diets exhibited the same LWG target with less FI (Figure 8a) and showed a better FCR (Figure 8c).

The carcass comparison analysis has revealed that birds fed the 2005 sorghums exhibited less fad pad and a superior breast-meat yield than birds fed the 2004 sorghums. The major difference between experiments was the AME values of the sorghum grains used. Diets formulated for the pilot growth study using the 2004 sorghum, utilized AME for the grain determined with birds age 22-28 d, whilst diets for the growth study using 2005 sorghums used AME for the sorghum grain which had been determined with younger birds (14-21 d old).

When an evaluation is made between the method of feed preparation and the age of birds in an AME evaluation on the sorghum AME value, it is seen that the AME determined with the older birds (22-29 days) gives a higher values close to 0.9 MJ/Kg DM more when compared with the determined AME using younger birds (14-21 days). This energy difference probably explains the observed differences in FI, FCR and carcass quality (fig. 8d and 8e) observed in the pilots growth experiments conducted in 2004 and 2005. Birds on sorghums diets with adjusted energy exhibited similar LWG with substantially lower FI, superior FCR and better breast-meat yield and with a lower fad pad value. This energy/protein ratio improvement may be responsible for the better bird performance observed with the 2005 sorghum diets.
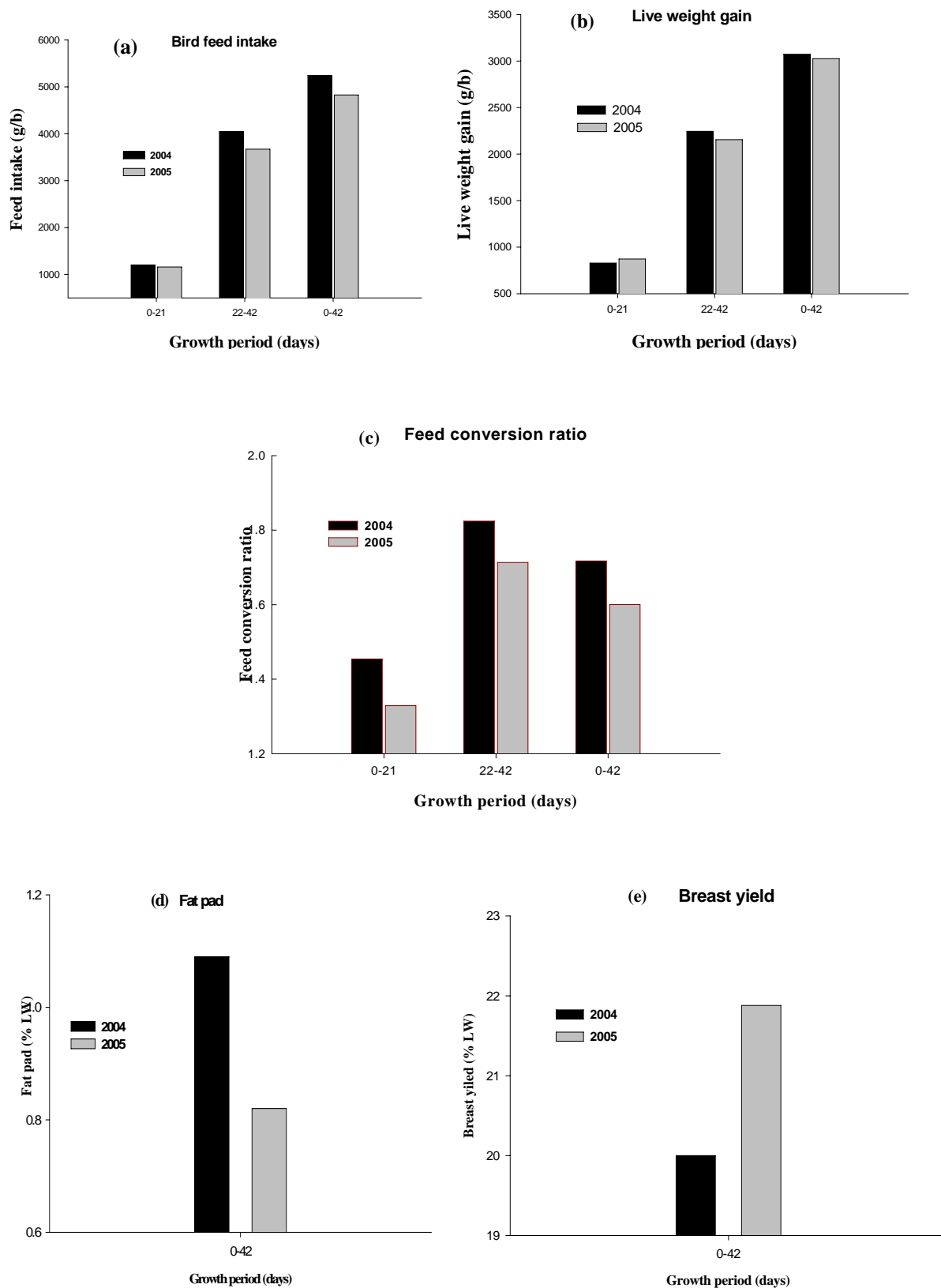
Figure 8   Comparison of (a) broiler feed intake, (b) live weight gain, (c) feed conversion ratio, (d) fat pad, and (e) breast-meat yield when fed 2004 or 2005 sorghum samples.

Phytase pilot study – phytase addition

Due to the high level of phytate phosphorous (P) found in all sorghum grains and as it represents 76% of the total P in the grain, in the present experiment an additional sorghum treatment group was included which had the addition of phytase in order to examine the effect of this enzyme on broiler performance when birds were offered sorghum diets. The starter and finisher diet formulation for this enzyme study are given in Tables 17 and 18 respectively. The response of adding phytase to sorghum-based diets is presented in Table 20. During the starter period, birds on the phytase treatment slightly increased their FI by only 0.6% with a significant ($P<0.05$) increased LWG without affecting FCR. This superior LWG at 21 d was comparable to that observed in birds consuming the wheat-based diets (Table 20). The superior LWG obtained during the starter period may be associated with an increase in nutrient digestibility due to the phytase enzyme releasing available nutrients that were attached to the P-phytate molecule.

During the grower/finisher period birds given the phytase treatment exhibited a significantly ($P<0.05$) higher FI and LWG without any effect on FCR. As a result of this birds with phytase supplementation had a superior FI, LWG with no FCR difference over the full growth period (0-42 d) when compared with birds given no supplement. The carcass evaluation indicated an 8% increase, but not significant ($P>0.05$), in fat pad for the heavier birds with similar breast-meat yield (22.5 v 22.6 % of live weight).

There is a need to further investigate reasons for the improved broiler performance when phytase is added to sorghum based diets.

Table 18   **Mean results of feed intake (FI), live weight gain (LWG), feed conversion ratio (FCR), of broilers (0-21, 22-42 and 0-42 days old) fed a sorghum-based diets (Sorghum sample O, 2004 collection) with and without adding a commercial phytase enzyme**

	FI (g/d)			**LWG (g/b)**			**FCR (g:g)**		
Treatment	0-21	22-42	0-42	0-21	22-42	0-42	0-21	22-42	0-42
Sorghum O	1209	3726[a]	4935[a]	876[a]	2120[a]	2996[a]	1.381	1.776	1.659
Sorghum O + phytase	1217	3981[b]	5198[b]	904[b]	2228[b]	3132[b]	1.344	1.811	1.669

Values with different superscript within column differ significantly ($P<0.05$)

Arabinoxylan, is another ANF which is found in sorghum, and which may also impede bird performance and which may be overcome by adding enzymes to poultry diets. Cadogan et al., (2005) reported a positive effect on LWG and FI with the addition of phytase and or a multi-enzyme product containing xylanase, protease and amylase to sorghum diets. Unfortunately, xylanases were not included in the present experiment and this may need to be examined in the future.

4.3 Experiment 3 – Pilot trial examining the effect of adding phytase, xylanase and cystine on broiler performance when offered selected sorghum grains

4.3.1 Introduction

Previous pilot trials in this report indicated that birds offered sorghum-based diets performed 5-6% lower when compared with birds offered wheat-based diets, especially in the starter phase (0-21 d). There is indication that the low cystine digestibility (35-50%), high phytate-P and total condensed tannins found in sorghum are probably responsible for the lower performances observed and that these need further investigation.

Observations during the previous growth pilot studies reported above, indicated that in some cages birds presented with unusual feather growth with a characteristic "spoon-like" appearance. Literature reports indicate that curling of feathers may be related to sulphur amino acid (SAA) deficiencies and if bird growth is adequate, then overestimation of digestibility/availability of cystine and not methionine

are likely to be responsible for feathering problems (Lesson and Summers, 2001). Similarly, Lumpkins et al., (2007) reported the importance of SAA for growth methylation reactions, and feather synthesis as important precursors for synthesis of glutathione, taurine, coenzyme A, selenoenzymes, and polyamines These resaerchers estimated bird requirements of total SAA during the first 3 weeks post-hatching to be 0.9%. Kalinowski et al., (2003) calculated that for slow and fast-feathering birds a total SAA 0.89 and 0.94% respectively was adequate, with methionine approximating 0.50% regardless of feather rate, and cystine requirement to be 0.39 and 0.44 for slow and fast-feathering respectively.

In the present study, all starter diets were formulated to meet a SAA requirement of 0.93% and 0.47% for methionine and cystine as suggested in the literature above. Previous pilot trials in this report indicated that the combination of ingredients used in the wheat-based diets provided methionine and cystine at 53.2% and 46.8% respectively. This combination of SAA in the wheat-based diets agreed with the requirements suggested in the literature. However the amount of methionine and cystine in sorghum-based diets which were 65.4% and 34.6% respectively, could be lead to an imbalance and this may have affected broiler performance.

In the results obtained in earlier experiments which were part of the present study it was apparent that during the starter period broilers offered wheat diets have been shown superior performance to birds on sorghum diets. Similarly it was found that the cystine digestibility of sorghum grains was low (35-50%). It is well known that a significant proportion of dietary methionine can be used for the biosynthesis of cystine via the trans-sulphuration pathway with sorghum-based diets having sufficient methionine for to correct cystine deficiency. However, the poorer broiler performance and the abnormal feathering observed in some birds on sorghum-based diets suggested the need to investigate the response to feeding synthetic cystine further.

Similarly, the experiment will examine reduction of phytate-P by use of a commercial phytase enzyme alone or in combination with the synthetic cystine treatments to evaluate growth performance of broiler chickens fed sorghum diets. Additional sorghum treatments were included to evaluate the effect of xylanase enzyme addition on broiler performance 0-21 days. The performance data from the sorghum diets will also be compared to a current industry standard wheat diet. Further evaluation using floor pen facilities may need to be conducted to simulate poultry industry production.

4.3.2 Materials and Methods

Dietary treatments are described in Table 21. The ingredient and chemical composition of the starter diets for the wheat control diet and all sorghums dietary treatments are presented in Table 22.

Table 19   Description of diets consisting of wheat control and 18 sorghum diets (3 sorghum varieties, each with 6 treatments)

Starter	
Diet 1	Wheat (control)
Diet 2	Sorghum A
Diet 3	Sorghum A + phytase
Diet 4	Sorghum A + cystine
Diet 5	Sorghum A + phytase + cystine
Diet 6	Sorghum A + methionine : cystine 1:1 ratio
Diet 7	Sorghum A + phytase + xylanase enzyme
Diet 8	Sorghum C
Diet 9	Sorghum C + phytase
Diet 10	Sorghum C + cystine
Diet 11	Sorghum C + phytase + cystine
Diet 12	Sorghum C + methionine : cystine 1:1 ratio
Diet 13	Sorghum C + phytase + xylanase enzyme
Diet 14	Sorghum L
Diet 15	Sorghum L + phytase
Diet 16	Sorghum L + cystine
Diet 17	Sorghum L + phytase + cystine
Diet 18	Sorghum L + methionine : cystine 1:1 ratio
Diet 19	Sorghum L + phytase + xylanase enzyme

Table 20 Ingredient composition (g/kg as is basis) of starter diets including the control wheat based diets and three selected sorghums (A, C, and L, 2005 sorghums with low cystine digestibility) with 6 levels of treatments

Ingredients/diet	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Wheat	Sorg A	Sorg A	Sorg A	Sorg A	Sorg A	Sorg A	Sorg C	Sorg C	Sorg C	Sorg C	Sorg C	Sorg C	Sorg L	Sorg L	Sorg L	Sorg L	Sorg L	Sorg L
	X	nil	PH	C	PH+ C	C	PH + X	nil	PH	C	PH +C	C	PH + X	nil	PH	C	PH +C	C	PH + X
Wheat	651.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sorghum	0.0	586	589	586	589	586	589	641	643	641	643	641	643	581	584	581	584	581	584
Soybean meal	169.6	257	261	257	261	256.9	261.4	245	260	245	260	245	260	268	272	268	272	268	272
Canola meal	40.0	40.0	40.0	40.0	40.0	40.0	40.0	11.1	0.0	11.1	0.0	11.1	0.0	40.0	40.0	40	40	40	40
Meat/bone meal	55.0	55.0	50.0	55.0	50.0	55.0	50.0	55.0	50.6	55.0	50.6	55.0	50.6	55.0	49.8	55.0	49.8	55.0	49.8
Sunflower meal	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Soybean oil	36.9	17.2	16.1	17.2	16.1	17.2	16.1	0.0	0.0	0.0	0.0	0.0	0.0	11.1	10.1	11.1	10.1	11.1	10.1
Kynofos	1.6	0.3	0.0	0.3	0.0	0.3	0.0	0.4	0.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salt	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.6	1.0	0.6	1.0	0.6	1.0	0.3	0.3	0.3	0.3	0.3	0.3
Sodium bicarb	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Dical Ph	1.2	1.4	0.0	1.4	0.0	1.4	0.0	2.1	0.6	2.1	0.6	2.1	0.6	1.5	0.0	1.5	0.0	1.5	0.0
Cocidiostat	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Minerals	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Vitamins	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Vit supp	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Lysine HCl	4.6	3.0	2.9	3.0	2.9	3.0	2.9	4.0	3.8	4.0	3.8	4.0	3.8	2.7	2.6	2.7	2.6	2.7	2.6
DL Methionine	1.9	3.0	3.0	3.0	3.0	1.9	3.0	3.6	3.6	3.7	3.6	2.1	3.6	3.7	3.7	3.7	3.7	2.2	3.7
Phytase enzyme	**0.0**	**0.0**	**0.2**	**0.0**	**0.2**	**0.0**	**0.2**	**0.0**	**0.2**	**0.0**	**0.2**	**0.0**	**0.2**	**0.0**	**0.2**	**0.0**	**0.2**	**0.0**	**0.2**
Cystine	**0.0**	**0.0**	**0.0**	**0.6**	**0.6**	**2.3**	**0.0**	**0.0**	**0.0**	**0.6**	**0.6**	**2.6**	**0.0**	**0.0**	**0.0**	**0.4**	**0.4**	**2.3**	**0.0**
Xylanase enzyme	**0.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.3**

X = Xylanase; PH = Phytase; C = Cystine

Dietary treatments with added phytase and cystine

Following industry practice, the available phosphorous was reduced from 0.44% to 0.381% in all dietary treatments were phytase was added, similarly, calcium levels were reduced from 0.85% to 0.75%. Synthetic pure cystine (Ajinomoto L-cystine) was added to treatments 4, 5, 10, 11, 16 and 17, at a level equivalent to the undigested cystine fraction of the sorghum grain calculated from the AA digestibility studies. Synthetic cystine is costly and normally formulation programs (Feedmania, Saltbush Agricultural software) will preferentially use methionine in place of the calculated required cystine to balance total sulphur AA requirements. Therefore, to dietary treatments 6, 12 and 18 synthetic cystine was added at a level equivalent to that of methionine that was calculated by the formulation program. To dietary treatments, 7, 13, and 19 a combination of phytase and xylanase enzymes were added to evaluate any possible synergistic enzyme effect

In this experiment, the wheat used in previous work and three sorghum grains (A, C and L, from the 2005 harvest) with low cystine digestibility were selected. The experimental design included one wheat-based diet (control) and 18 sorghum-based treatment diets, which included three sorghum varieties, each with six levels of treatments. Treatments were offered to 760 Arbor Acres male broilers housed in 95 cages (8 birds per cage), with 5 replicates per treatment. The experimental unit was a cage of 8 birds in a completely randomised design.

The trial evaluated the growth performance during the starter phase (0-21 days of age). Birds were offered crumbled starter diets (12.5 MJ AME and 12.7 g total lysine/kg) formulated to achieve maximum production. All diets were also supplemented with vitamins, minerals and synthetic AA before applying each respective treatment protocol. Birds were provided with feed and water ad libitum with lighting and temperature maintained in an environmentally controlled poultry house according to industry practice. Feed intake (FI g/bird) was recorded for each treatment cage by recording the weight of each feeder plus feed on days 0 (start of trial) and 21 (end of starter period). On day 21, birds from each cage were group weighed. Performance variables measured were FI, live weight gain (LWG) and feed conversion ratio (FCR).

Data was statistically analysed using ANOVA and significant (P<0.05) differences between treatment means were determined using the Least Significant Difference (LSD) test.

4.3.3 Results and Discussions

The broiler performance responses to individual starter (0-21 d old) sorghum diets compared with the control wheat diet are presented in Table 23.

Bird performance

This experiment conducted during December 2006 indicated that adding enzymes and cystine combinations in three sorghum based diets was not 100% conclusive. The results showed that synthetic cystine tended to improve LWG in two of the three sorghum-based diets (C and L). Adding phytase on reduced available P and Ca sorghum diets also improved LWG.

During the starter period, birds on the wheat-based diets had a better FCR than any other treatments evaluated in this study and is in agreement with previous pilot experiments.

There were some trends and inconsistencies evident within sorghum treatments. For example, when the available P (Av. P) and Ca levels were reduced with phytase addition to sorghum diets A2, C2, and L2, only birds fed sorghum A2 showed the increased FI with a similar LWG as the wheat control diet and the lowest FCR among all sorghums treatments. It is difficult to explain why this phytase positive response was not observed with the other sorghums diets C and L.

When only synthetic cystine was added to diets A3, C3, and L3 to compensate for the sorghum's low cystine digestibility, birds on sorghums C3 and L3 had LWG similar (P>0.05) to birds consuming

wheat diets. Similarly, when combined phytase and xylanase enzymes were added to treatments A6, C6 and L6, the birds' LWG on diets C6 and L6 were not statistically different (P>0.05) from the control wheat diets and presented the lowest FCR within cultivars. Our results agree with Lu et al., (2007), in which xylanase added in combination with phytase in low P diets resulted in a tendency for FCR to be improved.

The overall general FCR of the sorghum diets in this study was poor (above 1.40) when compared with the FCR results obtained in similar sorghums conducted during earlier cage experiment (FCR about 1.300). A limitation of the current study was that only a single enzyme level was examined and perhaps bird responses vary with either higher or lower levels of enzyme added into the diets. The level of Av. P and Ca reduction used in the present study similarly, needs to be compared with negative and a positive control to be sure responses observed were true enzyme effects and not due to Av. P and Ca reduction in the diet.

Table 21   Overall FI, LWG and FCR for birds fed Sorghum samples treated with phytase, cystine and xylanase

Diet	FI 21 overall	LWG 21 overall	FCR 21 overall	Dietary treatment
Wheat control	1181 [ae]	930.4 [f]	1.275 [e]	
Sorghums				
A1	1142 [a]	823.4 [a]	1.418 [abc]	Control
A2	1224 [bcde]	886.8 [bcdef]	1.380 [ad]	Control reduced P and Ca + Phytase
A3	1185 [abd]	858.7 [abc]	1.395 [abcd]	Control + cystine
A4	1224 [bcde]	874.0 [bceg]	1.407 [abc]	Control reduced P&Ca + Phytase + cystine
A5	1184 [ab]	851.3 [ab]	1.399 [abcd]	Control + Me:Cyst
A6	1193 [abd]	870.9 [bceg]	1.395 [abcd]	Control reduced P & Ca + Phytase + Xylanase
C1	1275 [c]	902.3 [cdef]	1.413 [abc]	control
C2	1240 [cdf]	881.4 [bcdeg]	1.413 [abc]	Control reduced P and Ca + Phytase
C3	1271 [c]	920.0 [df]	1.389 [abd]	Control + cystine
C4	1214 [befg]	863.7 [abc]	1.409 [abc]	Control reduced P&Ca + Phytase + cystine
C5	1214 [befgh]	883.1 [bcdeg]	1.392 [abcd]	Control + Me:Cyst
C6	1241 [cdf]	916.7 [ef]	1.356 [d]	Control reduced P & Ca + Phytase + Xylanase
L1	1222 [bcde]	864.2 [abc]	1.427 [abc]	control
L2	1201 [bef]	839.4 [ag]	1.436 [bc]	Control reduced P and Ca + Phytase
L3	1270 [ch]	887.9 [bcdef]	1.442 [c]	Control + cystine
L4	1213 [befg]	849.6 [ab]	1.428 [abc]	Control reduced P&Ca + Phytase + cystine
L5	1237 [bcd]	876.3 [bcdeg]	1.412 [abc]	Control + Me:Cyst
L6	1262 [cg]	898.0 [cdef]	1.410 [abc]	Control reduced P & Ca + Phytase + Xylanase
LSD (P=0.05)	55.97	45.93	0.04935	

Values within sorghums, with different superscript, within column differ significantly (P<0.05); Sorghum A= Pacific MR 43 Southern Downs, Qld); Sorghum C= Pioneer 86G87 (Western Downs Qld); Sorghum L= Pacific MR 43 (Liverpool plains, NSW)

5. Broiler floor pens, semi-commercial growth experiments

5.1　Experiment 1 – Semi-commercial evaluation of broiler performance using sorghum grains from the 2004 harvest in Qld and NSW (conducted September – October 2005)

5.1.1　Introduction

This study is an extension of a previous work examining 21 sorghum cultivars in a pilot metabolism cage study (see chapter 4, section 4.1). The cage experiment results indicated that bird performance (feed intake, efficiency and growth rate) with sorghum grain was initially poorer during the starter phase (0-21 d) but during the grower/finisher phase (22-42 d), birds on sorghum treatments performed as well as birds consuming wheat-based diets.

In a normal market situation where the price/tonne of sorghum is generally lower than the price of wheat, then it is to be expected that substantial financial savings could be made with using sorghum as the main grain ingredient in diets for chicken meat production.

The current study will examine bird performance on sorghum diets formulated on total amino acid levels, using floor pen facilities to simulate poultry industry standards. The previous pilot study results were used to select the sorghum grains to be used in the floor pen study. As a result during October-November 2005 five different sorghums were compared against wheat grain. There were a total of six dietary treatments with six reps each and 30 birds per pen.

5.1.2　Materials and Methods

Poultry house and measurements

This experiment was conducted with birds kept in a shed with floor pens from 0-42 days. The shed contained 72 pens, full insulation, ventilated fans and double shutters along each side which are adjustable according to the prevailing conditions using a computer program. Each pen measured 1.6m x 2.7m in area and was covered with new wood shavings to a depth of approximately 7cm. Heating in each pen was provided by an electric bar heater with feed and water available ad libitum from two tube feeders (ea. 134 cm circumference) and five nipple waterers, respectively.

Each pen housed 30 chickens until 42 days of age (at a density of 18.8 kg/m2 or 7.1 birds/m2) and thus complied in all respects with SCARM welfare codes. The Model Code of Practice for the Welfare of Animals – Domestic Poultry (4th Edition) stipulates an allowable maximum stocking density of 40kg/m2. The stocking density per pen in this study reached a maximum of approximately 19 kg/m2, which is 50% under the recommended maximum density. During the experiment temperature was gradually reduced from day 1 to day 42 according to breeder recommendations. There was a 23 h/d lighting period from 1-42 d. Any chickens that died, or were culled during the first 72 h, were replaced by healthy birds. Any birds dying thereafter were not replaced.

Day old chicks (1080: 540 males and 540 females) were received from a commercial hatchery; weighed in groups of 30 and randomly allocated to pens. Within pens, birds were offered water and allocated a starter experimental diet ad libitum until day 21. Electric heaters were used to provide adequate warmth (28-31oC). At day 21, the pen feed residues and chick groups were weighed. At this point grower/finisher diets were offered *ad libitum* to the birds while maintaining treatment allocations. On day 42 of age, pen feed residue and birds from each pen were weighed. On day 43 the birds were sent to a commercial abattoir for processing.

During the course of the experiment the birds' health was closely monitored at least twice daily and any abnormality was recorded and if necessary acted upon. Birds that died or were culled and not replaced were individually weighed at the time of removal from the pen and feed residues recorded in those affected pens. During the experimental period, the temperature inside the shed was gradually reduced from the initial temperature of 31-33 °C in accordance to industry practice for maximum bird comfort to 26-24 °C by the time they reach 21 days and then from 24 to 22-21 °C (when possible) by the time they reach 42 days. Dietary treatments allocated to pens were offered to birds from day one till day 42 of age. Drinker operation and feed availability were checked each day and the daily temperature recorded.

Feed intake (FI) was measured for each pen for the starter (0-21 d) and finisher (22-42 d) by initially weighing each feeder at the start and then at the end of each growth period weighing the feeder plus contents together with all feed issued during that growth period. Any feed which remained in the feeder at the end of each period was discarded after weighing. Performance variables were: FI, live weight gain (LWG) and FCR.

Animals and diets

The present study evaluated broiler production performance parameters in two age groupings 0-21 d (starter phase) and 22-42 d (finisher phase). Birds were offered crumbled starter and as steam pelleted grower/finisher diets, both of which were prepared and formulated to achieve maximum performance.

There were four sorghum samples selected from the 2004 collection harvest period. These were: sorghum 4 (Pacific buster, Yelarbon), sorghum 7 (Pioneer bonus, Dalby), sorghum 8 (Pioneer 85G, Dalby), and sorghum 11 (Pacific Buster, Gunnedah). A locally obtained commercial sorghum was also added to this experiment for comparison. This commercial sorghum was analyzed for N and DM with AME value calculated from the mean AME value determined for all 2004 sorghums. The control wheat diet contained wheat (Narrabri, NSW) which had been used in the previous pilot studies. All ingredients were analysed for DM, N, P, available P, Ca, AA, AME, and CT. The chemical composition of the sorghums and the wheat grain used during this experiment, are presented in Chapter 1, Table 4. The Protein meals which were used for the formulation of the diets were analysed for DM, N, P, and fat with other components estimated using the PRDC and ARI database.

The control diet (starter-finisher) was formulated using wheat (623-694 g/kg), soybean meal (203-173 g/kg), meat and bone meal (40-34 g/kg), canola meal (60-30 g/kg), sunflower meal (30-20 g/kg) with a commercial xylanase enzyme added according to industry practice. For the sorghum-based treatments, the four selected 2004 sorghums and the commercial sorghum replaced wheat in the diet. Levels of ingredients within sorghum diets varied slightly depending on the sorghum chemical composition. All dietary treatments were supplemented with vitamins, minerals and amino acids. Birds were offered the dietary treatments as crumbled starter (containing 12.5 MJ AME and 127 g total lysine/kg) and a pelleted grower/finisher diets (containing 13.0 MJ AME and 110 g total lysine/kg) both formulated to achieve maximum production. All diets were designed to contain similar calcium, available P, AME with similar total crude protein content to meet the minimum total AA requirements estimated for maximum growth. Nutrient requirements used were obtained and adjusted from Baker et al., (2002). The ingredient and calculated chemical composition of the starter and finisher diets for the wheat control diet and all sorghum diets are presented in Tables 24 and 25 respectively.

Experimental design

In this study, six sorghum-based diets and one wheat based-diet were evaluated. Five of the sorghums were sorghum grains selected from the 17 collected during the 2004 harvest plus a commercial sorghum obtained for comparison.

All diets were offered to Arbor Acres (n= 1080) male and females broilers housed in 36 pens with six replicates per dietary treatment. In the ANOVA the experimental unit was a pen of 30 birds (15 males and 15 females) in a randomised block lay out of 36 pens. Data were analysed using ANOVA and

significant (P<0.05) differences between treatment means were determined using the Least Significant Difference test.

Ethical considerations

The experiment was approved by the Animal Research Institute's Animal Ethics Review Committee. And the design complied with the "Australian Code of Practice for the Care and Use of the Animals for Science Purposes" (The Green Code 6th Ed.), section 2.2.11. All stocking density in cages followed the stipulated in the Model Code of Practice for the Welfare of Animals – Domestic Poultry (4th Edition).

5.1.3 Results and Discussions

The responses to the individual sorghum diets compared with the control wheat diet over the starter (0-21 d old) and finisher (22-42 d old) period, are presented in Table 26.

Bird performance

Results at 21 d (Table 26) showed that FI on sorghum 11 (Pacific Buster, Gunnedah, NSW) was significantly (P<0.05) depressed compared with birds on sorghum 7, sorghum 8, sorghum 4, or the commercial sorghum which had a similar (P>0.05) FI to the control wheat diet (1163 g). LWG at 21 d was also observed to be lowest in sorghum 11 (710 g) with wheat (832 g) and sorghum 7 (808 g) diets being superior followed by commercial sorghum (801 g), sorghum 8 (791 g) and sorghum 4 (781 g). FCR was better on the wheat diet (1.397).

During the 21-42 d period FI in all sorghums (including sorghum 11) were similar to the control wheat. Similarly bird LWG was also similar within sorghums, with sorghum 8 (1829 g) and commercial sorghum (1843 g) being significantly (P<0.05) superior to the control wheat (1768 g). FCR values tended to be better for all sorghum samples when compared to wheat.

It was concluded that the performance of broilers that consumed the sorghum diets under semi-commercial floor pen conditions was affected during the starter phase, but this negative effect disappeared during the grower/finisher period with birds fed sorghum diets performing the same or better than birds consuming the wheat diet.

Table 22   Ingredient composition (g/kg as is basis) of floor pen study starter diets (0-21 d) using 2004 sorghum

Ingredients	Diet A Wheat	Diet B Sorghum	Diet C Sorghum	Diet D Sorghum	Diet E Sorghum	Diet F Commercial
Starter	Control	7	8	4	11	sorghum
Wheat	623.1	0.0	0.0	0.0	0.0	0.0
Sorghum		587.5	607.0	624.8	596.5	613.8
Soybean meal	203.9	250.8	238.1	218.4	248.0	228.1
Canola meal	60.0	60.0	60.0	60.0	60.0	60.0
Meat/bone meal	40.0	48.0	46.7	46.7	46.2	46.2
Sunflower meal	30.0	30.0	30.0	30.0	30.0	30.0
Soybean oil	25.9	9.0	2.7	3.4	4.1	5.5
Salt	0.24	0	0	0	0	0
Limestone	3.2	1.1	1.7	1.9	1.8	2.0
Dicalcium phos	2.1	0.0	0.0	0.0	0.0	0.0
Sodium bicarb	2	2	2	2	2	2
Cocidiostat	0.5	0.5	0.5	0.5	0.5	0.5
Minerals	1.5	1.5	1.5	1.5	1.5	1.5
Vitamins	1.5	1.5	1.5	1.5	1.5	1.5
Vit supp	2	2	2	2	2	2
Lysine HCl	2.7	2.4	2.8	3.5	2.3	3.4
DL Methionine	1.4	3.8	3.6	3.8	3.6	3.5
Enzyme	0.3	0	0	0	0	0
Total	1000.3	1000.0	1000.0	1000.0	1000.0	1000.0
Calculated analysis						
Crude protein	24.9	23.5	23.5	23.6	23.5	23.4
Lysine	1.27	1.27	1.27	1.27	1.27	1.27
sulphur AA	0.93	0.93	0.93	0.93	0.93	0.93
Threonine	0.74	0.77	0.77	0.72	0.73	0.76
Isoleucine	0.83	0.84	0.84	0.84	0.85	0.85
Tryptophan	0.31	0.31	0.30	0.30	0.30	0.29
Arginine	1.43	1.40	1.39	1.34	1.37	1.33
Calcium	0.86	0.86	0.86	0.86	0.86	0.86
Av P.	0.43	0.43	0.43	0.43	0.43	0.43
Ca/avP	2.00	2.00	2.00	2.00	2.00	2.00
AME MJ/kg	12.5	12.5	12.5	12.5	12.5	12.5

Table 23   Ingredient composition (g/kg as is basis) of floor pen study grower/finisher diets (22-42 d) using 2004 sorghum

Ingredients	Diet A	Diet B	Diet C	Diet D	Diet E	Diet F
	Wheat	Sorghum	Sorghum	Sorghum	Sorghum	Commercial
Finisher	control	7	8	4	11	sorghum
Wheat	693.9	0.0	0.0	0.0	0.0	0.0
Sorghum		658.1	676.2	677.4	655.9	675.1
Soybean meal	172.6	223.3	212.5	208.3	231.6	206.3
Canola meal	30.0	30.0	30.0	30.0	30.0	30.0
Meat/bone meal	33.6	36.0	34.6	34.2	33.8	34.5
Sunflower meal	20.0	20.0	20.0	20.0	20.0	20.0
Soybean oil	34.0	16.1	9.5	12.1	11.9	17.0
Limestone	2.9	1.4	2.1	2.3	2.2	2.2
Salt	1.4	1.3	1.3	1.3	1.3	1.3
Sodium biocarb	2.0	2.0	2.0	2.0	2.0	2.0
Cocidiostat	0.5	0.5	0.5	0.5	0.5	0.5
Minerals	1.5	1.5	1.5	1.5	1.5	1.5
Vitamins	1.5	1.5	1.5	1.5	1.5	1.5
Vit supp	2	2	2	2	2	2
Lysine HCl	2.29	2.14	2.47	2.71	1.68	2.29
DL Methionine	1.04	3.55	3.32	3.39	3.33	2.93
Threonine	0.79	0.58	0.50	0.84	0.83	0.83
Enzyme	0.3	0	0	0	0	0
Total	1000.30	1000.00	1000.00	1000.00	1000.00	1000.00
Calculated analysis						
Crude protein	22.8	20.8	21.0	21.6	21.2	20.5
Lysine	1.10	1.10	1.10	1.10	1.10	1.10
sulphur AA	0.86	0.84	0.84	0.84	0.84	0.84
Threonine	0.73	0.73	0.73	0.73	0.73	0.73
Isoleucine	0.75	0.76	0.76	0.78	0.78	0.77
Tryptophan	0.28	0.27	0.27	0.28	0.28	0.27
Arginine	1.26	1.21	1.20	1.20	1.20	1.20
Calcium	0.68	0.68	0.68	0.68	0.68	0.68
Av P.	0.34	0.34	0.34	0.34	0.34	0.34
Ca/avP	2.00	2.00	2.00	2.00	2.00	2.00
AME MJ/kg	13.0	13.0	13.0	13.0	13.0	13.0

Table 24   Summarised results of sorghum semi-commercial floor pen broiler trial, PRDC September-November 2005

Period		1-21 period	21-41 period	1-42 period
Treatment	Grain	BFI	BFI	BFI
A	Control wheat	1163 [a]	3629	4792
B	Sorghum 8	1160 [a]	3589	4749
C	Sorghum 7	1125 [a]	3507	4632
D	Sorghum 4	1117 [a]	3561	4678
E	Sorghum 11	1049 [b]	3529	4577
F	Commercial sorghum	1123 [a]	3634	4757
LSD(P=0.05)		51	153	168
		LWG	LWG	LWG
A	Control wheat	832 [a]	1768 [b]	2600 [ab]
B	Sorghum 8	808 [ab]	1829 [a]	2637 [a]
C	Sorghum 7	791 [bc]	1761 [b]	2552 [b]
D	Sorghum 4	781 [c]	1758 [b]	2540 [bc]
E	Sorghum 11	710 [d]	1766 [b]	2476 [c]
F	Commercial sorghum	801 [bc]	1843 [a]	2643 [a]
LSD(P=0.05)		27	61	70
		FCR	FCR	FCR
A	Control wheat	1.397	2.054	1.843
B	Sorghum 8	1.435	1.962	1.801
C	Sorghum 7	1.423	1.991	1.815
D	Sorghum 4	1.430	2.027	1.842
	Sorghum 11	1.476	1.998	1.849
	Commercial sorghum	1.403	1.972	1.800
LSD(P=0.05)		0.052	0.067	0.042

Values within sorghums, with different superscript, within column differ significantly (P<0.05); Sorghum 4 = Pacific buster, Yelarbon; Sorghum 7= Pioneer bonus, Dalby; Sorghum 8 = Pioneer 85G, Dalby; Sorghum 11 Pacific Buster, Gunnedah; Commercial sorghum= purchased in Brisbane.

Under the semi-commercial floor pen conditions during the starter period (0-21 d), birds consuming wheat and sorghum grains had mean AME intakes of 8.9 and 9.5 MJ/d respectively (Figure 9a). As birds consumed more energy from sorghum, their LWG improved, but it was observed that birds on wheat diet exhibited a significantly (P<0.05) higher LWG (7%) equivalent to 53.8 g. Similarly, birds offered the wheat diet consumed 2.3% less feed per unit of body weight gain when compared with the mean FCR of birds on sorghum diets (FCR 1.397 vs. 1.433). This FCR difference among grains however was not significant (P>0.05) which was contrary to the earlier results during the starter phase in metabolism cage (see chapter 4). This apparent better performance of broiler under semi-commercial environment when compared with metabolism cage environment needs further examination.
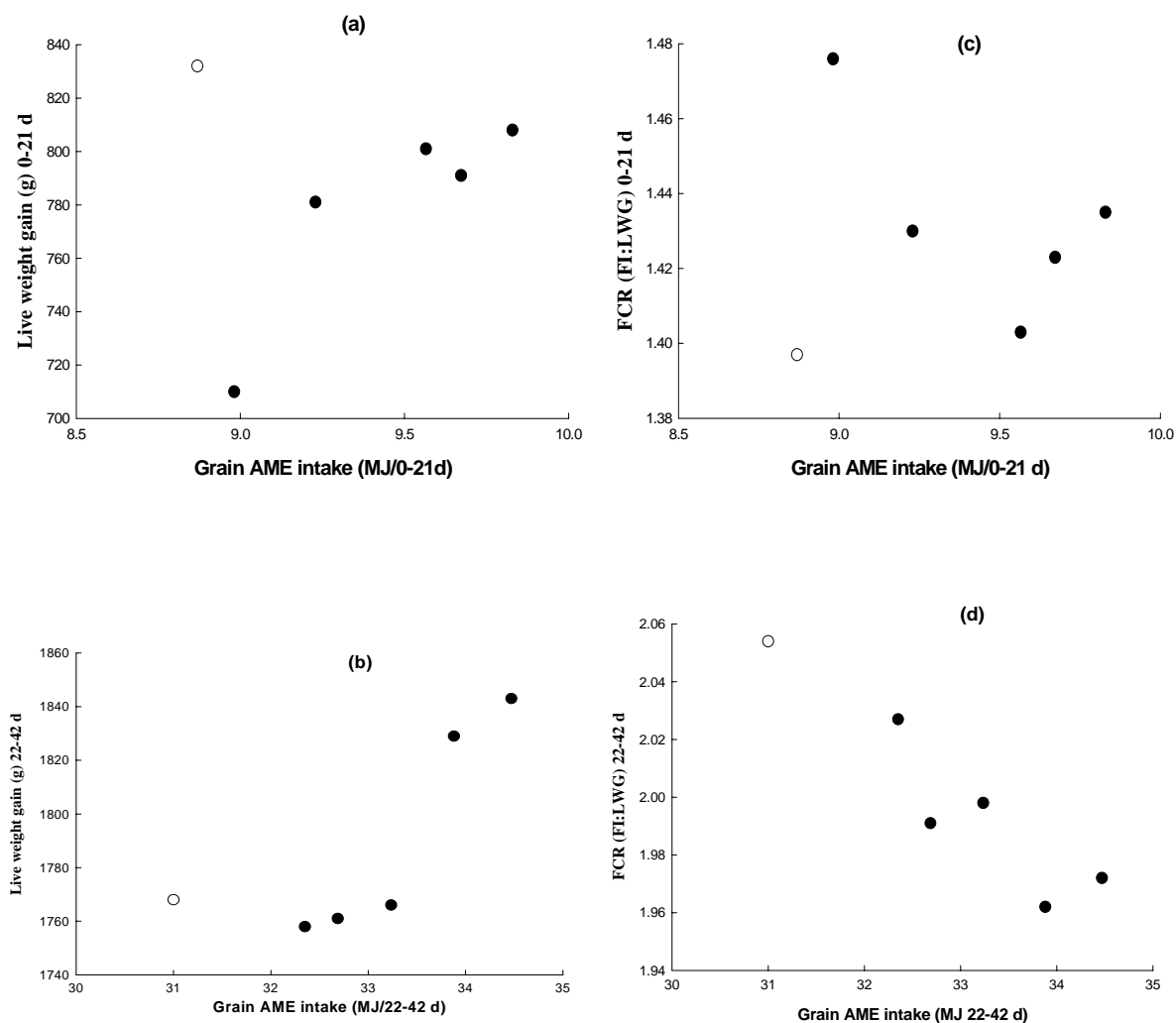
Each data point represents the mean value of six pens (30 birds/pen).

Figure 9 **Relationship between grain AME intake and live weight gain; and AME intake and feed conversion ratio (FCR) of broilers when given sorghum (●) or wheat (○) based diets during the starter (a and b) and finisher period (c and d).**

During the grower/finisher period (22-42 d), birds on sorghum diets consumed an average 7.5% more AME and gained weight at the similar rates than birds on the wheat diet. Both, sorghum 8 and commercial Sorghum exhibited a superior (P<0.05) LWG with the best FCR. This superior bird performance on sorghum diets during the grower/finisher period, agrees with the results obtained in earlier broiler metabolism cage studies.

The results of both the previous metabolism cage and the current floor pen studies conducted during this project make it apparent that the main limit to birds fed sorghum only occurs during the starter period (0-21 d) when birds somehow were not able to efficiently utilize sorghum energy.

Additionally it appears from previous work here that factors influencing this poor energy utilization may be related to bird age. Based on AME determinations conducted on 2004 and 2005 sorghums, it was apparent that the sorghum AME mean value was reduced by about 0.9 MJ/kg DM, when the age of birds used in AME determination was reduced from 22-29 d to 14-21 d.

It has also been seen that ANF, most probably the CT fraction, were strongly related to the effects seen on the utilization of energy in sorghum. This observed negative effect was more pronounced in younger birds. Therefore it is speculated that this ANF would further affect AME value of sorghum if

60

consumed by even younger birds of 0-7 and 7-14 d of age. Further work is needed to confirm this effect and to develop alternative feeding strategies that will enhance the use of energy in sorghum by younger birds.

5.2 Experiment 2 – Semi-commercial evaluation of broiler performance using sorghum grains from the 2005 harvest in Qld and NSW (Conducted in March-May 2007)

5.2.1 Introduction

This study is a continuation of earlier metabolisable cage evaluation of 14 cultivars of 2005 sorghum, in which the sorghum AME and AA digestibility were determined, enabling the formulation of diets for a floor pen trial which simulate poultry industry housing standards. The previous findings indicated that ANF, most probably condensed tannins content exhibited a strong relationship to the utilization of sorghum energy, particularly in younger birds (0-21 d). It was speculated that these ANF would further affect the AME value of sorghum when consumed by even younger chicks, 0-7 and 7-14 d old. But further work was needed to confirm this assumption including an examination of some alternative feeding strategies that may provide information on improving the use of sorghum energy in younger birds. In this experiment various feeding strategies were examined in order to improve sorghum utilisation in comparison to current industry standard wheat-based diets. Another objective of this experiment was to improve the nutritional value of sorghum grain with emphasis on the starter phase period (0-21 d).

5.2.2 Materials and Methods

Poultry house and measurements

This semi-commercial experiment was conducted with birds kept in floor pens from 0-42 days. The building housing the birds was not environmentally controlled but did have artificial lighting, heating (electric bar heater, brooders) and cooling (fans and sprinklers) devices installed. The 64 pen shed is also fitted with ventilating fans and a computer/controller that automatically manipulate shutters, fans and sprinklers.

Each pen measured 1.5m x 5m (7.5m2 in area) and was covered with new wood shavings to a depth of approximately 7cm. Feed and water were available ad libitum in each pen from two tube feeders (ea. 134 cm circumference) and six nipple waterers per pen.

The pens could house 30 chickens until 42 days of age, assuming a final body weight of 2.1 kg at 42 days, thus the stocking density would be 10.8 kg/m2 or 4 birds/m2). Thus the pens complied in all respects with SCARM welfare codes. The Model Code of Practice for the Welfare of Animals – Domestic Poultry (4th Edition) stipulates a maximum stocking density of 36kg/sqm in summer, this trial was well bellow the recommended maximum density.

During the experimental period, the temperature inside the shed was gradually reduced from the initial temperature of 29-32 °C in accordance to industry practice for maximum bird comfort to 26-24 °C by the time they reached 21 days and to 22-21 °C (when possible) by the time they reach 42 days. There was a 23 h/d lighting period from 1-42 days of age.

Day old (1800: 900 males and 900 females) Arbor Acres chicks were received from a commercial hatchery; weighed in groups of 30 birds each and randomly allocated to pens and provided with water, adequate warmth (29-32 °C) and offered the corresponding experimental starter diets *ad libitum*. At day 21, pen feed residues and chick groups from each pen were weighed, with starter diet replaced with their corresponding grower/finisher dietary treatments which was offered *ad libitum* until day 42,

then again feed residue and birds from each pen were weighed. At day 43 the birds were sent to a commercial abattoir for processing.

During the course of the experiment the birds' health were closely monitored at least twice daily and any abnormality was recorded and if necessary acted upon. Chickens that died or were culled during the first 72 h, were replaced by healthy birds. Any bird dying thereafter was not replaced. Birds that died or were culled and not replaced were individually weighed at the time of removal from the pen and the pen feed residues recorded in affected pens.

Dietary treatments allocated to pens were offered from day one till day 42. On each day during the experimental period, drinkers and feed were checked and temperature recorded.

Feed intake (FI) was measured for each pen for the starter (0-21 d) and grower/finisher (22-42 d) periods by initially weighing each feeder at the start and then at the end of each growth period; weighing the feeder plus its contents, together with all feed issued during that growth period. Any feed which remained in the feeder at the end of each period was discarded after weighing.

Animals and diets

The present study evaluated production performance parameters in two age groups, 0-21 d (starter phase) and 22-42 d (finisher phase). Birds were offered crumbled starter and steam pelleted grower/finisher diets which were prepared and formulated to achieve maximum performance.

Details of dietary feeding strategies used

Broiler performance was evaluated under floor pen conditions (semi-commercial environment) with growth rate, feed consumption and feed efficiency measured in birds fed the sorghum or the wheat-based diets. There were 10 dietary treatments described in Table 27.

Table 25   Description of dietary treatments and combinations used during the starter and finisher phase

Diet No	Starter (0-21 d)	Finisher (22-42 d)
1	Wheat (control) + xylanase	Wheat (control) + xylanase
2	Sorghum H	Sorghum H
3	Sorghum M AME reduced by 0.8 MJ	Sorghum M normal AME used
4	Sorghum B	Sorghum B
5	Sorghum E AME reduced by 0.8 MJ	Sorghum E normal AME used
6	Commercial Sorghum	Commercial Sorghum
7	Sorghum K	Commercial Sorghum
8	Wheat	Commercial Sorghum
9	Commercial Sorg. + phytase	Commercial Sorg. + phytase
10	Commercial Sorg. + phytase with reduced AvP & Ca	Commercial Sorg. + phytase with reduced AvP & Ca

1= Control wheat-based diet; 2= Sorghum H Pioneer Bonus, western downs Qld; 3= Sorghum M Pacific MR Buster (Liverpool plains, NSW), with reduced SG AME by 0.8MJ in starter phase only to switch to sorghum M during finisher period using normal sorghum AME value; 4= Sorghum B (Pacific Buster, Lowood, Qld); 5= Sorghum E Pacific Buster (Lockyer, Qld) sorghum AME reduced by 0.8MJ starter phase only; 6= Commercial sorghum, purchased in Brisbane; 7= Sorghum K Hylan Lyberty (Northern Downs, Qld) and the commercial sorghum finisher phase (insufficient sorghum K); 8= Control wheat-based diet during starter period and switch to commercial sorghum during finisher period; 9= Commercial sorghum + phytase added on top; 10= Commercial sorghum with phytase added after reducing available phosphorous from 0.44% to 0.38% starter period and from 0.34% to 0.30% finisher period, Ca was reduced from 0.85% to 0.75% starter period and from 0.68% to 0.60% finisher period.

To evaluate broiler performance when offered sorghum-based diets supplemented with dietary phytase enzymes, a commercial sorghum which had been purchased locally, was added to evaluate this

enzyme. Phytase enzyme was added to a commercial control sorghum either on top of the diet or after reducing the formulated diet levels of available phosphorous (Av. P from 0.44% to 0.38 % and from 0.34% to 0.30% in the starter and the finisher period respectively) and Ca levels (reduced from 0.85% to 0.75% and from 0.68% to 0.60% in the starter and finisher period respectively).

An additional treatment tested evaluated broiler performance when offered white sorghum during the starter phase and red sorghum during the finisher phase.

An additional strategy was included to examine whether broiler performance can be improved during the starter phase (0-21 d) by changing ingredient specifications. Two sorghum based diets (sorghum M and sorghum E) were formulated on an estimated lower (-0.8 MJ/Kg) sorghum AME during the starter phase and the actual measured AME value during the finisher phase. The responses to these formulations were then compared with the response to diets with the same sorghums but formulated on the actual measured sorghum AME value (Sorghum H and Sorghum B).

As the price of wheat can be about $50 to $80/tonne higher than sorghum and in order to improve overall feed costs, an additional strategy investigated the use of wheat during the starter phase with sorghum used only during the finisher phase.

Sorghum samples used from the 2005 harvest were: Sorghum H (Pioneer Bonus, western downs Qld), Sorghum M (Pacific MR Buster, Liverpool plains, NSW), Sorghum B (Pacific Buster, Lowood, Qld), Sorghum E (Pacific Buster, Lockyer, Qld) and Sorghum K (Hylan Lyberty Northern Downs, Qld). A commercial soft wheat grain was purchased, from Grain Corporation, and used in the control wheat-based diet after N and DM analysis. All other ingredients were analysed for DM, N, P, available P, Ca, AA, AME, and CT. The chemical composition of the sorghums used is given in Chapter 1, Table 5. All protein meals used for the dietary formulation were analysed for DM, N, P, and fat with other components estimated from PRDC and ARI database values.

Birds were offered the dietary treatments in diets as crumbled starter (containing 12.5 MJ AME and 127 g total lysine/kg) and a pelleted grower/finisher diets (containing 13.0 MJ AME and 110 g total lysine/kg) formulated to achieve maximum production. All dietary treatments were supplemented with vitamins, minerals and amino acids. All experimental diets were designed to contain similar calcium, available P, AME (unless indicated) with similar total crude protein content to meet the minimum total AA requirements estimated for maximum growth. Nutrient requirements used were those adjusted from the values of Baker et al. (2002).

Experimental design

In this study, 10 dietary treatments were evaluated during two growth periods (0-21 d and 22-42 d of age), and were offered to 1800 (900 male and 900 females) Arbor Acres broilers housed in 60 pens with six replicates per dietary treatment. In the ANOVA the experimental unit was a pen of 30 birds (15 males and 15 females) in a randomised block lay out of 60 pens. The primary parameters under investigation were growth rate (LWG) and feed intake (FI) to measure feed efficiency (FCR). Data were firstly analysed with the diet as a factor with 10 levels, secondly the variation due to diet was broken up to isolate the effect of grain (ie wheat versus wheat in the starter period and sorghum commercial versus sorghum in the finisher period) and within sorghum, (commercial versus others). Data was statistically analysed using ANOVA and significant (P<0.05) differences between treatment means were determined using the Least Significant Difference (LSD) test in Genstat™.

The ingredient and calculated chemical composition of the starter and finisher diets for the floor pen 2007 growth trial are presented in Tables 28 and 29 respectively.

Table 26   Starter diets composition (g/kg as is basis) and calculated analysis (%) for floor pen 2007 growth trial

Starter Phase Ingredients	Wheat control	Sorg H	Sorg M (-) AME	Sorg B	Sorg E (-) AME	Sorg comm	Sorg K	Wheat Starter	Sorg comm +Phy ontop	Sorg comm+Phy adj AvP
Wheat	647.68	0.00	0.00	0.00	0.00	0.00	0.00	647.68	0.00	0.00
Sorghum	0.00	618.23	595.00	630.00	600.00	630.87	595.84	0.00	630.87	641.60
Soybean meal	177.03	225.78	234.79	223.74	233.20	217.90	268.54	177.03	217.90	223.48
Canola meal	50.00	50.00	40.85	43.89	50.00	50.00	40.00	50.00	50.00	40.00
Meat/bone meal	50.00	50.00	50.00	50.00	50.00	50.00	40.00	50.00	50.00	49.33
Sunflower meal	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Soybean oil	25.74	5.92	29.32	2.42	17.49	1.83	0.00	25.74	1.83	0.00
Kynofos	1.85	3.25	3.11	3.11	3.14	3.05	5.79	1.85	3.05	0.41
Salt	0.88	0.20	0.34	0.27	0.22	0.19	1.45	0.88	0.19	0.31
Sodium bicarb	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Limestone	2.05	1.51	1.68	1.67	1.53	1.64	4.07	2.05	1.64	0.31
Cocidiostat	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vitamins/Minerals	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Lysine HCl	4.21	3.95	3.86	4.11	3.73	3.70	3.07	4.21	3.70	3.71
DL Methionine	3.07	3.66	3.56	3.30	3.21	3.32	3.75	3.07	3.32	3.35
Enzyme Phytase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.15
Enzyme Xylanase	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00
Total	1000.3	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.30	1000.15	1000.15
Calculated analysis										
Crude protein	24.90	23.38	23.76	23.91	24.20	24.32	23.00	24.90	24.32	24.30
Lysine	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27
calccompSAA	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
Meth comp	0.55	0.61	0.61	0.60	0.59	0.60	0.62	0.55	0.60	0.60
cystine comp	0.38	0.32	0.32	0.33	0.34	0.33	0.31	0.38	0.33	0.33
Me%SAA	59.31	65.87	65.76	64.31	63.81	64.37	66.41	59.31	64.37	64.67
Cystine%SAA	40.69	34.13	34.24	35.69	36.19	35.63	33.59	40.69	35.63	35.33
Threonine	0.72	0.74	0.74	0.74	0.76	0.78	0.74	0.72	0.78	0.78
Isoleucine	0.81	0.81	0.84	0.83	0.85	0.88	0.82	0.81	0.88	0.88
Tryptophan	0.27	0.29	0.29	0.30	0.30	0.30	0.30	0.27	0.30	0.30
Arginine	1.33	1.33	1.32	1.33	1.36	1.33	1.36	1.33	1.33	1.33
Calcium	0.85	0.85	0.85	0.85	0.85	0.85	0.86	0.85	0.85	0.75
Av P.	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.38
Ca/avP	1.93	1.93	1.93	1.93	1.93	1.93	1.95	1.93	1.93	1.98
AME MJ/kg	12.50	12.50	12.50	12.50	12.50	12.50	12.50	12.50	12.50	12.50

Table 27   Grower/finisher diets composition (g/kg as is basis) and calculated analysis (%) for floor pen 2007 growth trial

Grower Phase Ingredients	Wheat control	Sorg H	Sorg M	Sorg B	Sorg E	Sorg comm	Sorg comm	Sorg comm	Sorg comm +Phy ontop	Sorg comm + Phy
Wheat	657.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sorghum	0.00	634.04	632.07	639.10	644.52	654.78	654.78	654.78	654.78	657.87
Soybean meal	171.31	215.17	214.58	214.28	214.95	199.91	199.91	199.91	199.91	202.94
Canola meal	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Meat/bone meal	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	36.94
Sunflower meal	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Soybean oil	44.15	23.50	26.43	20.01	14.04	18.70	18.70	18.70	18.70	17.53
Limestone	1.71	1.25	1.35	1.34	1.29	1.40	1.40	1.40	1.40	0.67
Salt	1.94	1.25	1.26	1.25	1.24	1.24	1.24	1.24	1.24	1.28
Sodium bicarb	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Kynofos	0.00	1.30	1.07	1.08	1.18	1.14	1.14	1.14	1.14	0.00
Cocidiostat	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vitamins/Minerals	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Lysine HCl	2.69	2.62	2.62	2.62	2.61	2.60	2.60	2.60	2.60	2.56
DL Methionine	2.38	3.03	2.85	2.59	2.55	2.73	2.73	2.73	2.73	2.71
Threonine	0.51	0.34	0.28	0.24	0.12	0.00	0.00	0.00	0.00	0.00
Enzyme xylanase	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enzyme phytase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.15
Total	1000.30	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.15	1000.15
Calculated analysis										
Crude protein	22.2	22.0	22.5	22.7	22.8	22.7	22.7	22.7	22.7	22.7
Lysine	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
sulphur AA	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Threonine	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.74
Isoleucine	0.75	0.77	0.80	0.80	0.81	0.83	0.83	0.83	0.83	0.83
Tryptophan	0.26	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Arginine	1.26	1.25	1.23	1.26	1.26	1.23	1.23	1.23	1.23	1.23
Calcium	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.60
Av P.	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.30
Ca/avP	1.98	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
AME MJ/kg	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0

5.2.3 Results and Discussions

The performance responses to the various sorghum feeding strategies and that of the control wheat diet during the starter (0-21 d old) and grower/finisher periods (22-42 d old), are presented in Table 30. The relationship between grain AME intake, live weight gain and FCR during the starter, grower/finisher and overall growth period are presented in Figures 10 and 11 respectively.

Bird performance in a semi-commercial floor pen experiment

During the starter period (0-21 d) birds given dietary treatments 2, 6, and 7 representing diets based on sorghums H, commercial and K, had a similar FI to birds consuming the wheat control diet 1 (Table 30). However, those sorghum diets produced significantly (P<0.05) poorer LWG and FCR. Sorghum K which had previously performed as good as the wheat diets in starter period in the metabolism cage experiments did not perform well in the present experiment. Sorghum K had been hammered milled and stored for about eight months prior to this examination and it may have affected its nutritional value. Further work evaluating this promising cultivar, which did show high potential, may be necessary in future.

 Birds on sorghum dietary treatments 3, 4, 5, 9 and 10 representing sorghums diets B, M, E and commercial sorghum with added phytase either on top or after reduced available P and calcium, exhibited a significantly higher (P<0.05) FI with a similar LWG when compared with the control birds, but a poorer FCR. It is noteworthy that birds consuming the sorghum grains M (diet 3) and E (diet 5) with the reduced -0.8MJ in grain AME applied during the starter phase diet formulation, exhibited a superior (P<0.05) FCR among sorghums (1.398 and 1.391 respectively) and were only worse by 3.2% and 2.7 % respectively than the FCR observed in the control wheat diets (FCR 1.354).

During grower/finisher period (22-42 d), except for the birds on diets 2 (sorghum H) and 4 (sorghum B), all birds on the sorghum-based diets had a similar (P>0.05) FI to birds fed the control wheat based diet. However birds on all sorghum based diets had a significantly (P<0.05) superior LWG and FCR than the control birds. As a result of this excellent bird performance during this grower/finisher period, birds on the sorghum based diets displayed a superior overall LWG and FCR at 42 days. Birds consuming sorghum grains M (diet 3) and E (diet 5) in which a reduction of -0.8MJ in grain AME was applied during the starter phase, exhibited the largest LWG (1980 and 1923 g, respectively) than any other treatment and ended up with a similar FCR among sorghum cultivars at 42 d of age.

Table 28 **Mean feed intake (FI), live weight gain (LWG), feed conversion ratio (FCR) of broilers in semi-commercial floor pens for starter (0-21 d) grower/finisher (22-42 d) and overall (0-42 d) periods when fed sorghum-based diets (2005 sorghum harvest) with various strategies applied or a wheat-based (control) diet**

Treatment	FI (g/bird)			LWG (g/bird)			FCR (g : g)		
Age in Days	0-21 d	22-42 d	0-42 d	0-21 d	22-42 d	0-42 d	0-21 d	22-42 d	0-42 d
1 Wheat control (both starter and grower)	1077[b]	3567[bc]	4637[abc]	796[c]	1803[d]	2595[d]	1.354[d]	1.986[e]	1.788[d]
2 Sorg H (both starter & grower)	1085[abd]	3464[a]	4549[ab]	760[bd]	1920[a]	2681[ab]	1.430[a]	1.810[bd]	1.702[b]
3 Sorg M (reduced AME for -P1 normal AME- P2)	1114[cd]	3607[b]	4721[c]	796[c]	1980[c]	2777[c]	1.398[bc]	1.855[ac]	1.719[ab]
4 Sorg B (both starter & grower)	1116[cd]	3466[a]	4582[ab]	784[ac]	1894[ab]	2679[ab]	1.423[ab]	1.847[abc]	1.721[ab]
5 Sorg E (reduced AME for P1 normal AME-P2)	1110[ac]	3605[b]	4715[c]	797[c]	1923a	2720[ac]	1.391[c]	1.880[a]	1.735[ac]
6 Sorg Comm (both starter & grower)	1079[ab]	3535[ab]	4614[abc]	767[ab]	1908[ab]	2675[ab]	1.418[ab]	1.854[abc]	1.728[abc]
7 Sorg K (for starter) & Sorg Comm (grower)	1053[b]	3473[ac]	4526[b]	743[d]	1907[ab]	2651[bd]	1.432[a]	1.831[cd]	1.718[ab]
8 Wheat (for starter) & Sorg Comm (grower)		3489[ac]	4573[ab]		1857[bd]	2657[bd]		1.882[a]	1.722[ab]
9 Sorg Comm + Phyt (both starter & grower)	1117[cd]	3532[ab]	4649[ac]	776[abc]	1898[ab]	2674[ab]	1.443[a]	1.863[ac]	1.739[ac]
10 Sorg Comm + Phyt adj AvP (both starter & grower)	1128[c]	3517[ab]	4645[ac]	781[abc]	1884[ab]	2666[ab]	1.443[a]	1.878[a]	1.749[c]
LSD (P=0.05)	33.6	94.8	117.4	22.5	56.52	62.2	0.0253	0.0409	0.02608

Different superscripts in columns indicate significantly (P<0.05) different means; comparing wheat *vs.* sorghum.

1= Control wheat-based diet; 2= Sorghum H Pioneer Bonus (Western Downs, Qld); 3= Sorghum M Pacific MR Buster (Liverpool plains, NSW) with reduced AME by 0.8MJ in starter phase only to switch to sorghum M during finisher period using normal sorghum AME value; 4= Sorghum B Pacific Buster (Lowood, Qld); 5= Sorghum E Pacific Buster (Lockyer, Qld) AME reduced by 0.8MJ starter phase only; 6= Commercial sorghum, purchased in Brisbane; 7= Sorghum K Hylan Lyberty (Northern Downs, Qld); 8= Control wheat-based diet during starter period and switch to commercial sorghum during finisher period; 9= Commercial sorghum + phytase added on top; 10= Commercial sorghum with phytase added after reducing available phosphorous from 0.44% to 0.38% starter period and from 0.34% to 0.30% finisher period. Calcium was reduced from 0.85% to 0.75% starter period and from 0.68% to 0.60% finisher period.
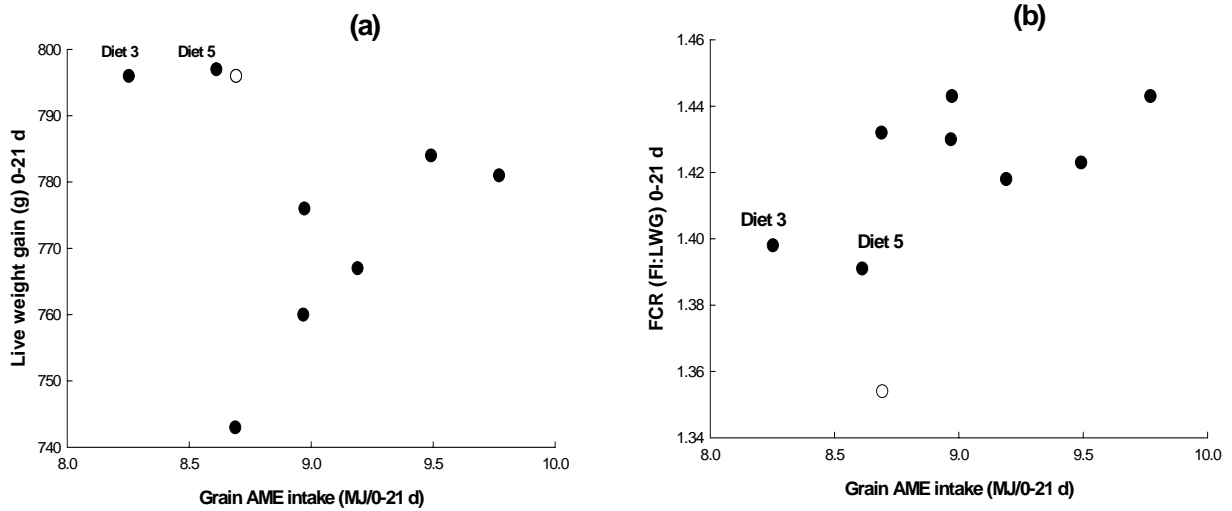
Figure 10   Relationship between AME intake and live weight gain (a) and AME intake and feed conversion ratio (FCR) (b) of broiler during the starter period when given sorghum (●) or wheat (○) based diets. Each data point represents the mean value of six floor pens (30 birds/pen).
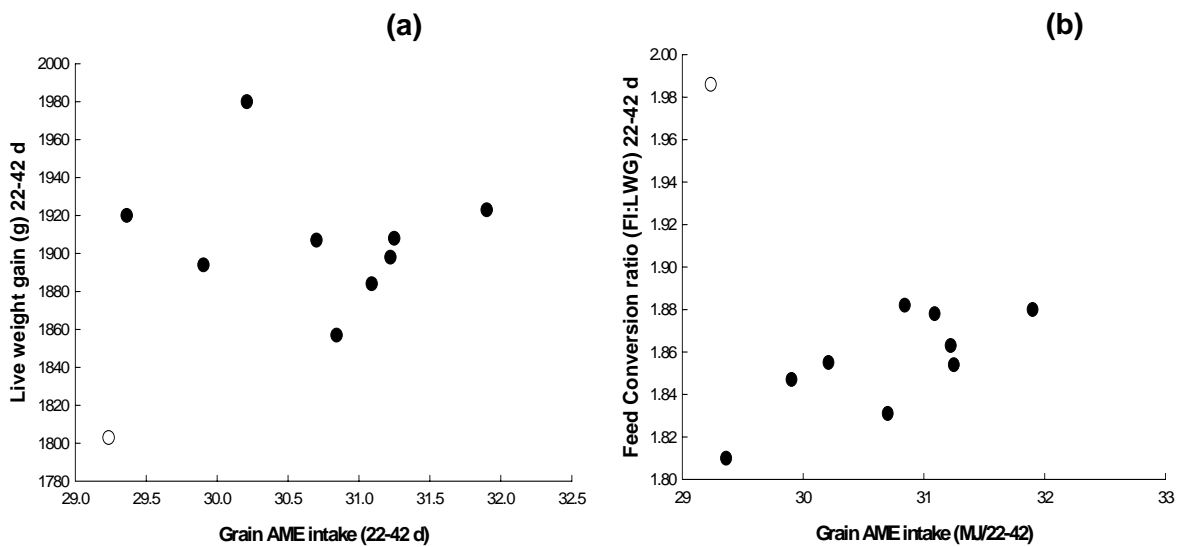
Figure 11   Relationship between grain AME intake and live weight gain (a) and feed conversion ratio (b) of broiler during the grower/finisher period (22-42 d) when given sorghum (●) or wheat (○) based diets. Each data point represents the mean value of six floor pens (30 birds/pen).

Feeding strategies to improve sorghum grain energy utilisation

Results obtained during the course of this project, indicate that birds consuming sorghum-based diets during the starter phase (0-21 d) did not match the performance of birds on wheat-based diets. It is believed that ANF (condensed tannins, phytate-P or reduced AA digestibility or combination of all these) in sorghum affected its potential energy value and use in younger birds. In this experiment to investigate this problem, during the starter phase, the AME value of sorghums M and E (diets 3 and 5, Table 30) was reduced by 0.8 MJ and additional soy oil was added to the formulated diet to be iso-energetic (12.5 MJ/kg diet) as with the other studied treatments. The results show (Figure 10a) that birds consuming sorghum M (diet 3) and E (diet 5) had a similar grain energy intake, producing similar LWG as birds consuming the wheat diets. Similarly the FCR of birds fed on the sorghums M and E tended to improve when compared with birds offered other sorghum diets (Figure 10b). It would appear that the addition of oil on these sorghum based starter diets (Table 28) was required, to compensate for the lower energy utilisation of the sorghum grain by young birds. Our results agree with Douglas *et al.,* (1990) who highlighted that additional animal fat seems to be needed (1-2.5% in the starter phase and 5-5.5% in the finisher phase) to compensate for the lower MEn of low and high-tannin sorghum grains respectively, especially when sorghum grain was used as a replacement for yellow corn in a typical broiler diet. Douglas *et al.* (1990) suggested that the low energy utilisation with high tannin sorghum grains is caused, in part, by the poor utilisation of starch due to cross-link between protein in sorghum grain, which decreases the digestibility of the protein and of the starch embedded in it. Another loss of energy utilisation is due to undigested tannin-protein complexes. In the present experiment, as a nutritional strategy, the oil content of the sorghum diets M and E were raised from 0% and 0.7% respectively (as formulated in a previous cage experiment, see Table 17) to 2.9% and 1.8% respectively (see Table 28) to compensate for the 0.8 MJ AME value reduced in each sorghum grain during the diet formulation of the starter period. As noticed in Table 29, during the grower/finisher period, no extra oil was needed in these sorghums M and E diets which were formulated with the actually derived normal sorghum grain AME value. The results showed that during the grower/finisher period the M and E diets and all other sorghum diets produced excellent bird performance (Figure 11). This supports the decision that during the grower/finisher period there was no need to add extra oil to compensate for any restriction of energy utilisation which appears to be confined to the starter period only.

Influence of sorghum condensed tannins and phenolics on chicken gut microflora development

The work by Torok et al., (2007), showed that significant differences are observed in the overall gut microbial populations of birds aged 1, 2, 3-5, and 6 weeks, with no significant differences detected in microbial composition at 3-5 weeks. This demonstrated that under normal conditions, microbial populations in birds gut are well established during first 21 d of age.

In the present study it has been observed that sorghum ANF appeared to only affect bird performances during the first 21 d corresponding to the starter growth period. Since gut microflora development is necessary for normal bird growth, it may be possible that its development can be affected by the intake of CT and phenolics which are found in sorghum grain and thus influencing the normal uptake and utilisation of energy and other nutrients, and on the response of poultry to ANF. During the bird grower/finisher stage (22-42 d) when gut microflora usually are established, it was found that the negative effect of sorghum ANF was reduced resulting in a normal bird development and performance. Adding 2.3% of oil in sorghums M and E (see section above) starter diets, improved bird performance. It may be possible that the extra energy from oil counteracted any sorghum CT and phenolic negative effects on microbial development which is necessary for efficient energy utilisation during the first 21 d of bird development.

In the present experiment gut microflora samples from birds fed on sorghum or wheat based diets were collected to evaluate the interaction between grain, bird performance and microflora profile. However at the conclusion of this report, the results were not available and no further conclusions can be proposed.

Effect of adding phytase to sorghum-based diets

In the present study, it has been seen that 76% of the total P in sorghum grain is in phytate-P. Pilot studies described in section 4.2.5, investigated the effect of adding phytase on top of sorghum-based diets, with a significant ($P<0.05$) improvement bird production performance. In a subsequent experiment described in section 4.3, adding phytase to a diet formulated with lower available phosphorous (AvP) and calcium (Ca) in selected sorghum-based diets tended to improve bird LWG, but the results were not consistent with the results obtained when phytase was added on top of diets.

In the present semi-commercial experiment (Table 30), two dietary treatments were examined with a commercial phytase enzyme added to a commercial sorghum control diet, either on top of the diet (diet 9), or after reducing the Av. P and Ca formulated levels of the diet (diet 10). The results showed a numerical ($P>0.05$) trend for the birds fed the phytase on top of the diet, to increase the overall LWG and FCR when compared to birds fed phytase diets with the reduced Av. P and Ca levels. But the overall performance of birds on both phytase treatments were not different ($P>0.05$) from the performance of birds on the commercial sorghum control diet (diet 6). These results may indicate an economical and environmental advantage to adding phytase to sorghum diets formulated with reduced Av. P and Ca levels. More work is needed to confirm this enzyme effect, since a negative control (sorghum diet with reduced Av. P and Ca without enzyme) was not used in the experimental design and hence this enzyme response may be due to the Av. P and Ca reduction only.

6. Conclusions and Implications

The consistent wide range of sorghum crude protein (CP) values determined for the 2004 and 2005 harvest (overall 8.7-13.5) indicated the need to continue N analysis prior to dietary formulation. National groups who are developing NIR calibrations for Australian grains, will need to update their database to incorporate sorghum grain N results from this project so that can be accessible to nutritionists for the formulation of animals diets. In the present study, with the exception of lysine (in 2004), amino acid (AA) levels in the grain were highly and positively correlated (~0.90) to the CP content of the grain. Therefore, it is expected that grains with higher CP content will display larger AA values and hence saving diet formulation costs from protein meals as they would be less needed for the supply of AA in the diet. As sorghum contains nearly half the AA values (excepting leucine) of wheat, there would be a need to formulate and prepare poultry diets using well balanced single protein sources (soybean meal) or by a combination of meals such as soybean, meat and bone, sunflower, canola meal together and aided with supplements of synthetic commercially available AA (ie lysine, methionine, and trytophan).

The total bound P as phytate-P represents 62% (40-74% range) and 78% (58-83% range) for 2004 and 2005 sorghums respectively and hence it may negatively influence AA, N, DM, minerals and energy utilisation in poultry. In this study there was a positive correlation (r= 0.70) between grain available P and sorghum AME. By adding phytase on top of a sorghum-based diet during the second metabolism cage pilot study, there was an overall improved FI, LWG with no difference in FCR and no effect on carcass quality. This superior performance was related to an increase in nutrient digestibility in the phytase treatment. Whereas in the semi-commercial floor experiments, adding phytase on top or after formulating a diet with reduced Av. P and Ca, the results showed a numerical (P>0.05) trend for the birds on the treatment with phytase on top to increase the overall LWG and FCR but it was no better than the sorghum control diet, which had no added phytase. These results although different to that obtained in cages may still indicate an economical and environmental advantage of using phytase to sorghum-based diets with reduced av. P and Ca levels. More works is needed to investigate if the response of phytase with reduced Av. P and Ca was a true enzyme effect and not due to nutrient reduction. There is also a need to investigate different enzyme levels and combinations and level of enzymes (xylanases, proteases, pectinases, etc).

With regards to N and AA digestibility it has been found that Sorghum protein digestibility was consistently lower at about 13 % than that determined in wheat grain. This low protein digestibility value was associated with the low cystine (52.5%), threonine (63%), tryptophan (71%) and histidine (69%) digestibility. Sorghum proteins are less digestible than those from other grains due to the presence of α-kafirins which are proteins rich in sulphur AA containing many disulphide bonds that are more resistant to protease enzymes during digestion. With cystine a major sulphur AA component in the CP of sorghum, and with a determined digestibility value of about 52.5%, our studies tend to agree with literature reports suggesting the α-kafirins (which are rich in cysteine) are one of the main factors responsible for the sorghum lower protein digestibility in sorghum. Other reports have indicated that protein inadequacy and arginine as the first limiting AA, may be responsible for the differences in the efficiency of use of available energy from sorghum relative to wheat-based diets, even when the daily intake of AME was similar.

In the present study, we found that cystine and tryptophan were the first and second limiting AA and were available at only 0.86 and 1.0 g/kg sorghum DM respectively. The literature suggested that the low CP digestibility of sorghum may also influence its starch variability and its digestibility. However, in our study the lower protein digestibility was not highly correlated with sorghum starch digestibility. Although we found that sorghum starch digestibility value does vary considerably among cultivars (2004= 85.3% range 71.3-92.9 and 2005= 92.0% range 84.6-97.9), hence the opportunity for improving its digestibility, in cultivars which exhibit lower to middle digestibility range. Starch digestibility improvement can be achieved by using external enzymes additives, which have been shown to improve starch digestibility in other grains. But there is also a need to understand the characteristics of sorghum starch and its interaction with protein molecules within the grain and other

possible ANF interactions such as phytate-P and CT in order to better develop strategies to improve starch digestibility.

In a pilot study examining the addition of synthetic cystine to three selected sorghum diets, it was observed that LWG on two of the sorghums was increased to levels similar to birds consuming wheat diets, but the FCR was not improved. This inconsistency in the results during the starter phase may prompt the need to further investigate responses in the grower/finisher period.

Australian sorghums have been shown to exhibit relatively high levels and variation of CT within years and locations which indicates that soil and environment of the sorghum growing conditions have a significant effect on the CT levels found. With CT having been found in Australian sorghums, this raised concerns on their impacts on digestibility of the starch and actual grain AME values and how they impact on bird growth. It was suggested that CT, which are found in nearly all sorghum grains, may be involved in the sorghum low protein digestibility (due to cystine, tryptophan and threonine low AA digestibility found). In this study was found a strong negative relationship between sorghum CT content and tryptophan ($r = -0.673$) which, in the current study, was calculated to be the second limiting AA due to its low level and medium digestibility value in sorghum. Other literature reports have suggested that protein, protein-carbohydrate, protein-poyphenol and carbohydrate-polyphenol interactions may be the main factors which affect protein digestibility. In our studies the grain AME in younger birds was highly and negatively correlated with free ($r= -0.725$) and bound CT ($r= -0.773$) fractions (see figure 1). This suggests that CT may be responsible for the lower AME value found, when determined with younger birds (14-21 d). When all the AME data obtained during this study (both the 2004 and 2005 sorghums) was plotted (Figure 2), the regression line indicated a trend for a reduction of energy utilisation as birds were younger. We demonstrated that the sorghum AME value was reduced when bird age was reduced by one week and that there was no influence of method of feed preparation. It was calculated that for a one week bird age reduction, sorghum AME was reduced by about 0.9-1.0 MJ. Therefore, both due to age of bird and the negative CT effect seen, it is necessary for this AME adjustment value to be applied in the formulation of broiler diets in order to improve sorghum utilisation particularly during the early starter period. It may be possible that use of this adjusted grain energy value may also improve carcass composition as the energy/protein ratio in the diets will be more balanced. However more research is needed to investigate the potential effect of CT on AME determined in much younger birds (0-7 d old and 7-14 d old) and when fed these sorghum-based diets.

A comparison between pilot growth cages studies for 2004 and 2005 sorghums showed that the overall birds LWG mean value for each sorghum year were similar. But, birds on sorghum-based diets, from 2005 sorghums, consumed less feed, had a superior FCR and carcass composition than birds fed the 2004 sorghums. The only major difference between cage experiments was in the AME values of the sorghum grains used. When diets were formulated for pilot growth study 1 (2004 sorghum), the AME of the grain used were determined with birds aged 22-28 d, whilst diets for the pilot growth study 2, (2005 sorghums) the AME of the sorghum grains were determined with younger birds (14-21 d old). It was calculated that the sorghum AME determined with the older birds (22-28 days) was higher by about 1.0 MJ/Kg DM when compared to the AME determined with younger birds (14-21 days). This energy difference may explain the differences in FI, FCR and carcass quality observed between the pilot growth experiments in 2004 and 2005. The resultant energy/protein ratio improvement may have been responsible for the superior bird performance observed with the 2005 sorghum diets. This AME difference may have significant implications when formulating broiler diets for the starter phase (0-21 days old) which traditionally used grain AME values obtained from older birds (22-29 d).Thus it was suggested that for formulations of starter diets which are offered to birds 0-21 d old, grain AME determinations need to be performed using birds of the same age group (ie 14-21 d old).

The 2005 sorghum results have showed that during the starter period, there was a strong relationship between grain AME intake (AMEI) and LWG ($r = 0.762$) which was in agreement with our previous experiment with 2004 sorghum. Although 64% of sorghum cultivars examined had a similar bird FI as the birds in the control wheat diet, the obtained LWG values varied greatly within sorghums cultivars and this was reflected with the poor sorghum FCR, (figure 5b). This poor FCR at 21 d was

strongly linked (r = 0.704) with the amount of total CT intake from sorghum grain during same period (Figure 6). Therefore, the inferior FCR observed with sorghum diets, especially in the starter phase, would seem to appear to be due to ANF such as CT which probably restricts nutrient availability. In this study, during the starter period, the performance of birds offered sorghum diet K, which had the lowest sorghum CT content (see Table 17), was similar to those given the wheat-based diet, further supporting the importance of CT as ANF in Australian sorghums, particularly as CT are known to bind to digestive enzymes and reduce the digestion and availability of dietary compounds including AA in poultry. In the present study it was observed that younger birds were 55% less capable for degrading/absorbing the free-CT fraction. This may explain the overall superior sorghum response on older birds.

The overall observations from the broiler growth experiments clearly indicate that during the grower/finisher period, birds were able to utilise the sorghum energy more efficiently; with an initially poorer growth and FCR found during the starter phase but this greatly improved during the grower/finisher phase. Thus more research work needs to be undertaken to explain why this sorghum issue occurs during the early growth period of birds. There would appear to be a potential for improving performance of birds fed sorghum particularly during the starter phase and further studies need to focus on the best feeding strategies to improve nutrient availability during the critical period of 0-21 d of age.

It was observed for 2004 sorghum and for 2005 sorghum, that 80.5% and 44 % repectively of the free-CT fraction disappeared from the small intestine, with older birds being 55% more efficient at degrading/digesting CT. It is possible that during intestinal transit, the majority of free-CT may have also interacted with either proteins or fibre in sorghum to form bound-CT fractions or simply may have undergone absorption/degradation. Since CT evaluation in excreta was not performed in our studies, the fate of the free-CT fractions can not be fully defined. Thus more work is needed to fully understand CT metabolism in broilers, particularly the possible free-CT degradation that may have occurred in the ceacum compartment (due to the action of the lower gut microflora) or whether it was voided in the excreta. This possible free CT-microflora interaction may also have some effect on microflora population and its development and the resultant bird performance but this still needs to be investigated. Consistently, it was seen in both years, that about 50% of bound-CT fraction disappeared in the small intestine. This indicates that a substantial proportion of compounds which can be bound to this CT fraction such as proteins, enzymes, AA, fibre, or minerals, were possibly not digested/absorbed in the small intestine for utilisation by the bird. More studies are needed to clarify the CT effect on nutrient utilisation by broilers in different growth periods.

Under semi-commercial conditions, during the starter period birds on sorghum-based diets tended to perform better than when compared with birds on metabolism cage environment studies and this needs further examination.

It was consistently observed during the course of this research that sorghum ANF appeared to only affect performance of birds during the starter period. It can be speculated that the CT and phenolics found in sorghum may be affecting/restricting normal development of bird gut microflora which may impact on nutrient uptake and utilisation of energy and on the performance response of poultry to ANF. As birds matured then with the full establishment of the microbial population of the gut meant that the observed negative effect of sorghum ANF was reduced with better bird performance observed. This may need some further research to confirm microbial differences during both starter and finisher phase when fed sorghum and wheat based diets.

Due to the expected negative effect of CT in younger birds (0-7 and 7-14 d) and based on the results obtained on this research, it was proposed the sorghum AME values need to be reduced by 0.8-1.0 MJ. Therefore feeding strategies to improve sorghum grain energy utilisation was investigated in a semi-commercial experiment in which the AME value of selected sorghums was reduced by 0.8MJ and the diets based on these sorghums had soy oil added to the diet so as to be iso-energetic with the other studied treatments during the starter period (0-21 d). The results obtained (Figure 9a) showed that birds consuming the reduced sorghum grain AME had a similar performance to birds consuming

wheat-based diets. Therefore, the addition of oil to these reduced AME sorghum starter diets seems to compensate for the poorer sorghum AME value seen in younger birds. During the grower/finisher period all sorghum diet formulated used the normal AME value with no extra oil added. The results showed that all the sorghum-based diets resulted in excellent bird performance. This further supported the decision that during the grower/finisher period there was no need to add extra oil to compensate for a lower energy value for sorghum which appears to be confined to the starter period only.

References

Ahn, J.H. (1990). Quality assessment of tropical browse legumes: Tannin content and nitrogen degradability. PhD Thesis. University of Queensland, Department of Agriculture. Australia.

A.O.A.C. (1984) Association of Official Analytical Chemists, Official methods of Analysis, 14th Edn (Washington DC, Section 7.099(a).

A.O.A.C. (1980)*,* Association of Official Analytical Chemists, Official methods of Analysis, 13th Edition (Washington DC Sections 3.098-3.100).

A.O.A.C. (1975)*,* Association of Official Analytical Chemists, Official methods of Analysis, 13th Edition (Washington DC).

Anon (1989). Nutrition Guide. Feed Formulation with Digestible Amino Acids. 34 p. (Rhone-Poulenc Animal Nutrition, Antony, France).

Baker, D.H.; Batal, A.B.; Parr, T.M.; Augspurger, N.R. and parson, C.M. (2002). Ideal ration (relative to lysine) of tryptophan, threonine, isoleucine, and valine for chicks during second and third weeks posthatch. Poult. Sci. 81: 485-494.

Barry, T.N and Forss, D.A. (1983). The condensed tannin content of vegetable Lotus Pedunculatus, its regulation by fertility application, and effect upon protein solubility. *Journal of the science of food and Agriculture* 34: 1047-56

Beta, T.; Corke, H.; Rooney, L.W. and Taylor, J.R.N (2000). Starch properties as affected by sorghum grain chemistry. *Journal of the Science Food and Agriculture* 81: 245-251.

Black, J.L. (2005). Quality feed grains – research highlights and opportunities, www.regional.org.au

Black, J.L.; Highes, R.J.; Nielsen, S.G.; Tredea, A.M.; MaAlpine, R. and Van Barneveld, R.J. (2005). The energy value of cereal grains, particularly wheat and sorghum, for poultry. *Aust. Poult. Sci. Symp*. 17: 21-29.

Blaney BJ, Maryam R, Murray SA and Ryley MJ (2003). Alkaloids of the sorghum ergot pathogen (Claviceps Africana) : assay method for grain and feed and variation between sclerotia/sphacelia. *Australian Journal of Agricultural Research* 54: 1-9

Bob Hanzel, (2004). Bob Henzel sorghum breeder at Hermitage Research Station, personal communication, telephone No 07-46603621

Boren, B. & Waniska, R.D. (1992). Sorghum seed colour as an indicator of tannin content. *Journal of Applied Poultry Research* 1:117-121.

Cadogen, D.J., Selle, P.H., Creswell, D. and Partridge, G. (2005). Phytate limits broiler performance and nutrient digestibility in sorghum-based diets. *Proceedings Australian Poultry Science Symposium.* **17:** 39-41.

Choct, M and Hughes, B. (2000). The new season grain phenomenon: The role of endogenous glycanases in the nutritive value of cereal grains in broiler chickens. RIRDC publications No 00/143.

Connor, J.K., Neill, A.R., and Barram, K.M (1976). The metabolisable energy content for the chicken of maize and sorghum grain hybrids grown at several geographical regions. *Australian Journal of Experimental Agriculture and Animal Husbandry* 16: 699-703

Connor, J.K., Hurwood, I.S., Burlin, H.W. and Fuelling, D.E. (1969). Some nutritional aspects of feeding sorghum grain of high tannin to growing chickens. *Australian Journal of Experimental Agriculture and Animal Husbandry*, 9: 497-501.

Cowieson, A.J. Acamovic, T. and Bedford, M.R. (2006). Phytic acid and phytase: Implications for protein utilization by poultry. *Poultry Science* 85:878-885.

Dalzell, S.A. and Kerven, G.L. (1998) A rapid method for the measurement of Leucaena spp proanthocyanidins by the Proanthocyanidin (Butanol/HCl) assay. *Journal of the Science, Food and Agriculture* 78: 405-416.

Dicko, M.H.; Gruppen, H.; Traore, A.S.; Voragen, A.G.J. and van Berkel, W.J. H. (2006). Sorghum grain as human food in Africa: relevance of content of starch and amylase activities. *African Journal of Biotechnology* 5: 384-395.

Douglas, J.H.; Sullivan, T.W.; Bond, P.L.; and Struwe, F.J. (1990). Nutreient composition and metabolisable energy values of selected grain sorghum varieties and yellow corn. *Poultry Science*, 69: 1147-1155

Finlayson, A.J. (1964) Amino acid recoveries in the analysis of some feed samples. *Canadian Journal of Plant Science*, 45: 184-188.

Hafi, A. and Connell, P. (2003). Feed grains: future supply and demand in Australia, ABARE *e*Report 03.21 Prepared for the Grains Research and Development Corporation, Canberra, November

DPI&F Queensland, (2002). www.dpi.gov.au/fieldcrops/8728.html

FAO Statistics, (2004). www.fao.com

Farrell, D.J. (1999). *In vivo* and *in vitro* techniques for the assessment of the energy content of feed grains for poultry: a review. *Australian Journal of Agricultural Research*, 50: 881-888

Farrell, D.J. and Perez-Maldonado, R.A. (1999). Tannins in feedstuffs used in the diets of pigs and poultry in Australia. In Tannins in Livestock and Human Nutrition. ACIAR Proceedings No 92, pp 24-29.

Goodchild, A.V. (1989). Use of leguminous browse foliage to supplement low quality roughages for ruminants. PhD. Thesis University of Queensland, Australia.

Groenewoud, G. and Hunt, H.K.L. (1986). The microbial metabolism of condensed (+)-catechins by rat caecal microflora. *Xenobiotica,* 16: 99-107.

Gualtieri, M and Rapaccini, S. (1990). Sorghum grain in poultry feeding. *World's poultry Science Journal*, 46:246-254.

Hackett, A.M. (1986). The metabolism of flavanoids compounds in mammals. In: Plant flavanoids in biology medicine: Biomedical pharmacological and structure-activity relationship (pp 177-194). Eds. Cobly, V., Elliot, M.; Harborne, J.B. and Alan, R.L.

Hagerman, A.E. and Butler, L.G. (1989). Choosing appropriate methods and standards for assaying tannin. Journal of Chemical Ecology, 15: 1795-1810.

Hagerman, A.E. (1991). Tannin Analysis. In: Tannin analysis internal publication. Miami University. Oxford, Ohio. 45056.

Kent-Jones, D.W. and Amos, A.J. (1957). *Modern Cereal Chemistry*, 5th Edition, Northern Publishing Co. Ltd., 564.

Kleiner, K.W. (1991). Stability of phenolic and protein measures in exised oak foliage. *Journal of Chemical Ecology,* 17: 1243-1251.

Kalinoswski, A.; Moran, E.T.; and Wyatt, C. (2003. Methionine and cystine requirements of slow- and fast-feathering male broiler from zero to three weeks of age. *Poultry Science*, 82: 1423-1427

Kumar, V. Elangovan, A.V.; Mandal, A.B.; Tyagy, P.K.; Bhanja, S.K. and Dash, B.B. (2007). Effects of feeding raw or reconstituted hugh tannin red sorghum on nutrient utilisation and certain welfare parameters of broiler chickens. *British poultry Science*, 48: (2) 198-204.

Leeson, S. and Summers, J.D. (2001). Nutrition of the Chicken. 4th Edition, University Books, Guelph, Ontario, Canada.

Lu, M.B; Li, D.F.; Gong, L.M. and RU, Y.J. (2007) Effects of phytase and xylanas addition to corn and wheat-based diets on broiler performance. *Proc. Aust. Poult. Sci. Sym.* 19: 63.

Lumpkins, B.S.; Batal, A.B. and Baker, D.H. (2007). Variation in the digestible sulphur amino acid requirement of broiler chickens due to sex, growth criteria, rearing environment, and processing yield characteristics. *Poultry Science,* 86: 325-330.

Mannion, P.F and Blaney, B.J. (1998). Impared performance of chickens fed sorghum infected with ergot (*claviceps Africana*). *Proc. Aust. Poult. Sci. Sym.* 10: 211.

McClymont, G. and Duncan, D.C. (1952). Studies on the nutrition of poultry. 3 Toxicity of grain sorghum for chickens. *Australian Veterinary Journal*, 28: 229-233.

Mole, S. and Waterman, P.G. (1987). A critical analysis of techniques for measuring tannins in ecological studies. I. Techniques for chemically defining tannins. *Oecologia* (Berlin), 72: 137-147.

Mole, S. and Waterman, P.G. (1988). Light-induced variation in phenolic levels in foliage of rain-forest plants. II. Potential significance to hervibores. *Journal of Chemical Ecology,* 14 (1): 23-24.

Muller-Harvey, I., Mc Allan, A.B., Theodorou, M.K. and Beever, D.E. (1988). Phenolics in fibrous crop residues and plants and their effects on the digestion and utilisation of carbohydrates and proteins in ruminants. Plant breeding and nutritive value of crop residues Addis Ababa, Ethiopia: ILCA.

Nyachoti, C.M., Atkinson, J.L. and Leeson, S. (1997). Sorghum tannins: a review. *World's Poultry Science Journal,* 53:5-21.

O'Brien, L. (1999). Genotype and environment effects on feed grain quality. *Australian Journal of Agricultural Research,* 50: 703-719.

Oduguwa, O.O.; Pirgozliev, V.; Acamovic, T. (2007). Energy metabolisability and digestibility of amino acids by broilers fed on malted sorghum sprouts supplemented with polyethylene glycol, charcoal, phytase and xylanase. *British Poultry Science*, 48: (1), 55-63

Perez-Maldonado, R.A.; Robertson, S. and Barram, K. and Rodrigues, H.D. (2007) Effect of bird age and diet preparation on the apparent metabolizable energy of sorghum grain - implication on broiler performance. *Proc. Aust. Poult. Sci. Sym.* 19: 97

Perez-Maldonado, R.A. (2003). Canola meal and cottonseed meal in broiler and layer diets. AECL publication No 03/10

Perez-Maldonado, R.A. (1994). The Chemical Nature and Biological Activity of tannins in Forage Legumes Fed to Sheep and Goats. PhD Thesis. The University of Queensland, St Lucia.

Perez-Maldonado, R.A. and Norton, B.W. 1996. Digestion of C-labelled condensed tannins from *Desmodium intortum* in sheep and goats. British Journal of Nutrition. 76:501-513

Porter, L.J., Horstich, L.N. and Ghan, B.G. (1986). The conversion of procyanidins and prodelphinidins to cyaniding and delphinidin. *Phytochemistry* 23: 223-230

Porter, L.J. (1989) Tannins In: Methods in Plant Biochemistry (389-419) Vol. 1. Eds Dey, P.M. and Harborne, J.B. Academic Press.

Ravindran, V., Hew, L.I. and Byrden, W.L. (1998). Digestible amino acids in poultry feedstuffs. *RIRDC Publication* No. 98/9.

Ravindran, V., Hew, L.I. and Byrden, W.L. (1999). *British Poultry Science*, 40: 266-274

Rhône-Poulenc Animal Nutrition (1993). *Rhodimet™ Nutrition Guide*; Feed ingredients formulation in digestible amino acids. Rhône-Poulenc

Rogler, J.C. & Sell, D.R. (1984) Effect of stage, maturity and tannin content on nutritional quality of low and high tannin sorghum. *Nutrition Report International*, 6:1281-1287.

Rooney, L.W. & Pflugfelder, R.L. (1986). Factors affecting starch digestibility with special emphasis on sorghum and corn. *Journal of animal Science*, 63: 1607-1623

Shaw, I. C. and Griffiths, L.A. (1980). Identification of the major biliary metabolites of (+)-cathechin in the rat. Xenobiotica 10:905-911.

Selle, P.H., Walker, A.R., and Bryden, W.L. (2003). Total and phytate-phosphorus contents and phytase activity of Australian-sourced feed ingredients for pigs and poultry. *Australian Journal of Experimental Agriculture*, 43: 475-479.

Spackman, D.H., Stein, W.H. & Moore, S. (1958) Automatic recording apparatus for use in the chromatography of amino acids. *Analytical chemistry*, 30: 28-35.

Sweeney R.A (1989) Generic Combustion Method for Determination of Crude Protein in *Feeds. J. Assoc. Off. Anal. Chem.* 72: 770-774.

Taylor, J.R.N (2005). Non-starch polysaccharides, protein and starch: Form function and feed-highlight on sorghum. *Aust. Poult. Sci. Symp.* 17: 9-16

Thomas, D.V. and Ravindran, V. (2006). Influence of age in the apparent metabolisable energy of diets containing maize or wheat for broilers. Aust. Poult. Sci. Symp. 18: 47

Walker, T. (1999). Sorghum for poultry and swine. *ASA Technical Bulletin* Vol. AN20-1999

Waniska, R.D.; Hugo, L.F.; and Rooney, L.W. (1992). Practical methods to determine the presence of tannins in sorghum. *Journal of Applied poultry research,* 1: 122-128

Torok, V.A., Ophel-Keller, K., Hughes, R.J., Forder, R. Ali, M., and MacAlpine, R. (2007). Environment and age: Impact on poultry gut microflora. *Australian Poultry Science Symposium*, 19: 149-152.

Nutritional Characteristics of Sorghums from Queensland and New South Wales for Chicken Meat Production

ByDr Rider A Perez-Maldonado and Dr Hugh D Rodrigues

This report provides technical information from the research project on the evaluation of Australian sorghum grains for chicken meat production.

In Australia sorghum is the most promising grain of the low rainfall and poor soil condition regions of north-eastern Queensland and northern New South Wales in which 720,000 ha are devoted to sorghum producing 2 million MT/year. About 1/2 million MT of sorghum is utilised by the chicken meat industry due to its availability and lower price. Sorghum represents $7-9 and $18-20 million in savings by replacing wheat or maize in poultry diets respectively. Sorghum grain generates about $150 million/year to the Queensland and Australian economy.

However it has been observed that Sorghum can have a lower feed conversion ratio than wheat costing the chicken meat industry $2-3m/year. This project investigated this reduction in performance of broilers on Sorghum diets.

The Rural Industries Research and Development Corporation (RIRDC) is a partnership between government and industry to invest in R&D for more productive and sustainable rural industries. We invest in new and emerging rural industries, a suite of established rural industries and national rural issues.

RIRDC books can be purchased by phoning 1300 634 313 or online at: www.rirdc.gov.au.

Most RIRDC books can be freely downloaded or purchased from www.rirdc.gov.au or by phoning 1300 634 313 (local call charge applies).

www.rirdc.gov.au