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Evaluation of new millet varieties as a poultry feed ingredient

A report for the Rural Industries Research and Development Corporation

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Foreword

The increase in feed prices and the real prospect of declining availability of grains for livestock has stimulated research into finding alternative feed sources.

Pearl millet has been identified as a potential new livestock feed grain. It is also identified as a suitable alternative crop to sorghum in low rainfall and sandy regions in Queensland. New dwarf-grain pearl millet hybrids now being evaluated will complement sorghum in dryland farming areas of Queensland and Northern New South Wales and deliver considerable benefits to the summer cereal value chain.

This publication details a series of studies that examined the chemical characteristics and energy and protein digestibility of new pearl millet hybrids when fed to broiler chickens.

This project was funded from industry revenue that is matched by funds provided by the Australian Government. Significant funds were also provided by the Department of Primary Industries and Fisheries (DPI&F), Queensland.

This report, an addition to RIRDC's diverse range of over 1,000 research publications, forms part of our Chicken Meat R&D program, which aims to support increased sustainability and profitability in chicken meat industry by focussing research and development on those areas that will enable the industry to become more efficient and globally competitive and that will assist in the development of good industry and product images.

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Simon Hearn
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Contents

List of Tables

Executive Summary

The demand for cereals as protein and energy sources for stock feed and human consumption is forecast to increase dramatically with consequent increases in their prices expected. It is therefore essential that research be undertaken to find alternative feed sources for the chicken meat industry in order to reduce the cost of feed and maintain an internationally competitive chicken meat industry. The use of non-conventional feed ingredients will decrease the dependence of the poultry industry on cereal grains such as wheat and sorghum.

Pearl millet has been identified as a suitable alternative crop to sorghum in low rainfall and sandy areas in Queensland. In the United States of America, pearl millet is identified as being the new feed grain. The potential benefits from the application of existing knowledge and from further research on pearl millet are substantial for this feed grain crop in warm-temperate agriculture. New pearl millet hybrids now being developed in Australia have never been evaluated as a grain for poultry.

The main objective of this project was to examine the potential of three elite pearl millet hybrids (PM31, PM3 and PM4) as poultry feed ingredients. The pearl millet hybrids were grown at Biloela Research Station, Biloela, Queensland, and clean grain was then transported to DPI&F's Poultry Research and Development Centre, Alexandra Hills, for evaluation. Chemical analyses were performed on these three grains to measure their protein, fat, fibre, starch, phosphorus, calcium and amino acid contents. Feeding experiments were conducted on broiler chickens to measure the metabolisable energy content and the digestibility of amino acids in the three pearl millet hybrids.

In comparison to sorghum, the millet hybrids had higher protein, fat and neutral-detergent fibre. Pearl millet hybrids contained nearly 2% more protein than sorghum. The fat content of the millet hybrids was more than twice that of sorghum. The fibre content of hybrid PM31 was lower than that of PM3 and PM4 but was higher than sorghum. The starch content and gross energy (GE) content of the three elite pearl millet hybrids were the same. Condensed tannin was not detected in any of the three elite pearl millet hybrids. Linolenic acid (ClS:3n-3) comprised 3% of the total fatty acid in the elite pearl millet hybrids, which is higher than other cereal grains. The ratio of n-6:n-3 fatty acid of the three elite hybrids were 13.72, 12.68 and 14.13 for PM31, PM3 and PM4 respectively, compared to sorghum's 28.43.

The total amino acid profile of the three elite pearl millet hybrids is much more suitable for poultry diets than sorghum. Pearl millet hybrids contained 50% more lysine, methionine, threonine and tryptophan than sorghum. Except for the protein content, where PM31 had slightly less protein, the three elite hybrids had very similar chemical compositions. The fat content was 6.4% and fibre 2.0%. The amino acid profile of PM31 was poorer than PM3 and PM4. The lysine content of PM31 was 2.83 g/kg compared to 3.18 g/kg and 3.09 g/kg for PM3 and PM4 respectively. The elite pearl millet hybrids had at least a 0.6 MJ/kg higher energy content than sorghum. The digestibility coefficients for most amino acids in sorghum were found to be within the range reported by Ravindran *et al.* (1998). The digestibilities of cystine, lysine and threonine in the elite pearl millets were higher than that of sorghum, whereas the digestibilities of the other amino acids in the elite pearl millet hybrids were very similar to sorghum.

The results suggest that the three pearl millet hybrids could be used as feed ingredients in broiler diets. However, further research on the upper inclusion levels of pearl millet in broiler diets, together with the effects of feeding pearl millet on carcass quality and yield, and on the interaction of enzymes on the utilisation of nutrients in the millet hybrids, is warranted.

1. Introduction

In any intensive livestock production system, feed costs amount to a considerable proportion of production cost. In Australia, 60-65% of the cost of production of the live bird is feed related. Poultry diets are generally based on cereal grains such as wheat and sorghum. A dilemma facing the poultry industries is that the demand for cereal grains as stock feed and for human consumption is steadily increasing. Finding suitable feed grain, especially for northern Australian producers, is often problematic because of the climatic and environmental conditions that prevail in this region.

With the escalation of poultry feed prices and the real prospect of declining availability of grains for livestock, it is opportune that research efforts be directed towards finding alternatives to wheat/sorghum based diets. The cost of traditional poultry feeds has maintained a sustained upward trend since the energy crisis of the early 1970's. This has stimulated research to develop alternative and cheaper sources of nutrients for poultry. Since one of the major causes of the increasing cost of feed is the man-animal competition for energy-intensive traditional food materials, alternative or non-traditional poultry feed materials must be those that are not eaten or relished by humans. As identified above, a significant proportion of total production costs is attributable to feed costs. For the poultry industries to be internationally competitive, this production cost needs to be reduced. A comparison of feed grain prices in the USA and in Australia shows that the prices in US are usually 10-20% lower than in Australia ($180 cf $265/tonne). One of the possible ways of reducing this cost is to replace the traditional feeding ingredients with cheaper, yet equally efficient, alternatives that are not consumed by humans.

The Grains Research and Development Corporation (GRDC) is currently supporting a five year research program to develop a pearl millet feed grain industry in Australia. However, this GRDC project does not address some of the basic requirements for the end user, such as poultry producers; that is, the nutritive value of the grains when fed to livestock. In order to promote pearl millet as a feed grain, better information on the nutritional quality needs to be supplied to buyers and end users.

In the USA, pearl millet is identified as being the ‘new feed grain’. It has also been identified as a suitable alternative crop to sorghum in low rainfall and sandy areas in Queensland. The potential benefits from the application of existing knowledge and from further research on pearl millet are substantial for this feed grain crop in warm-temperate agriculture (Andrews and Kumar, 1992). Pearl millet is widely grown as a food crop in subsistence agriculture in Africa and in the Indian subcontinent on a total of 26 million hectares, where grain yields average 500-600 kg/ha. In the US pearl millet was developed as a summer annual crop and now is grown on 1.5 million acres. Agronomic studies and breeding efforts supported by the US Agency for International Development have demonstrated that it is a promising grain crop for areas of the US in which drought, soil type, short season, or excessive heat diminishes the yield potential of sorghum. Also, short-season pearl millet hybrids are a promising double crop after wheat harvest. In 1994, a new grain-type pearl millet was planted on more than 15,000 acres in Georgia and Florida for livestock feed.

Current pearl millet varieties available in Australia are dual forage/grain types. Pearl millet grain hybrids and varieties are currently not available here. Plant breeding research over the past 20 years in Africa, India and the USA for pearl millet grain types, using Iniadi germplasm from Togo, has resulted in the development of early maturing, high-yielding breeding lines with good general adaptation. In 1996, three breeding programs in the USA released parental inbreds (both A and R lines) plus germplasm bulks that have been derived from Iniadi germplasm and are suitable for mechanised farming.

Results from poultry feeding experiments in the USA using pearl millet with maize or sorghum indicate that pearl millet is at least equivalent to maize and generally superior to sorghum in protein content and quality, protein efficiency ratio (PER) values, and metabolisable energy (ME) levels (Hoseney *et al*., 1987; Rooney and McDonough, 1987; Sullivan *et al*., 1990; Bramel-Cox *et al*., 1986). Pearl millet does not contain any condensed polyphenols such as the tannins in sorghum that can interfere with or slow down digestibility. Chicken feeding experiments conducted by Sullivan *et al.* (1990) and Kumar *et al.* (1991) showed that weight gains and feed/gain ratios obtained on pearl millet based diets are equal to that of maize and some sorghums. Smith *et al.* (1989) similarly reports that pearl millet can replace maize in chicken diets without affecting weight gain or feed efficiency. Both the gross energy and metabolisable energy (ME) values of pearl millet tend to be higher then those of maize and many have been previously underestimated by 20% (Fancher *et al.*,1987).

In general, feeding test results support data from biochemical analyses, which indicate that pearl millet is similar to maize and superior to sorghum as a feed grain. A number of factors are thought to be responsible. Pearl millet grain generally has a higher crude protein level by 1 to 2 percentage points relative to sorghum grown with similar cultural practices. Pearl millet is still deficient in essential amino acids, but averages 35% more lysine than sorghum (Rooney and McDonough, 1987; Singh *et al*., 2000). Pearl millet grain has 5-6% oil and a lower proportion of the less digestible cross-linked prolamines than sorghum (Jambunathan and Subramanian, 1988). These differences can be partly attributed to the different structure of the kernel. The proportion of germ in pearl millet grain (17%) is about double that of sorghum, while the endosperm accounts for 75% of pearl millet grain as against 82% of sorghum grain.

New dwarf-grain pearl millet hybrids evaluated in the GRDC project will complement sorghum in Queensland's dryland farming areas and deliver considerable benefits to the summer cereal value chain. The crop's short season will allow late season opportunity cropping and remove grain growers from exposure to economic risks such as sorghum midge and sorghum ergot. Based on its nutritional profile and on feed prices current at the time this report was prepared, pearl millet (14% protein) should be worth a 20% premium over grain sorghum to feed manufacturers. Pearl millet also contains elevated levels of the omega-3 fatty acids and will present an opportunity for Queensland's egg and meat producers to target the lucrative functional food market.

Two variety trials of eleven female and ten male lines at Biloela identified 183A4 and 59041A4 (female) and 4AmRm (male) as elite hybrid parents. These trials were conducted by Colin Douglas under the GRDC funded project. In spring, pearl millet hybrids matured in 85 days and produced grain yields of up to 3.8 tonnes/ha, comparable to the quick maturity sorghum hybrids 'Express' and 'Sonic', which produced yields of 3.88 tonnes/ha and 3.58 tonnes/ha respectively. From a February planting elite pearl millets yielded 4.8 tonnes/ha in 82 days and were 25 days quicker to mature than sorghum hybrids. Both Express (1.4 tonnes/ha) and Sonic (3.26 tonnes/ha) sorghums were subject to sorghum midge and ergot pressure. On this basis, pearl millet would have been at least as economical in the spring trial and the preferred option in the late-planted trial.

2. Objectives

The objectives of this project were:

- To determine the gross chemical composition of new varieties of millet;
- To determine the metabolisable energy content of the selected millet varieties when fed to broilers;
- To establish the digestible amino acid values of the millet varieties when fed to broilers;
- To promote the benefits of the selected pearl millet hybrids as a feed ingredient to grain growers and to the chicken meat industry.

3. Methodology

3.1 Sampling and selection

The initial agronomic evaluation of grain pearl millet hybrids was undertaken at DPI&F's Biloela Research Station (BRS) as part of GRDC project DAQ-459 ("Developing an Australian Pearl Millet Industry") between 2001 and 2003.

Twenty one grain pearl millet hybrids were grown in three replicated trials at (BRS) in central Queensland (spring 2001 and autumn 2002) and on a property near St. George in south-west Queensland (summer 2001-02). Bulked sub-samples of grain were collected and analysed for their chemical composition at the Animal Research Institute (ARI), Yeerongpilly, Queensland.

Hybrids made from female line 293A4 showed the highest levels of crude protein (see Table 1).

Table 1. Crude protein (CP%) content of twenty one pearl millet hybrids and their respective parent lines across yield trials at three sites in Queensland 2001-02.

male / female	1056/58016R4	4AmRm	4Rm	68wR4	9Rm4Rm	mean
293A4	16.88	17.5	16.88	17.94	15.25	16.89
413A4	15.31		16.63	15.63	15.25	15.70
59022A4	14.44	15.56		17.00	13.38	15.09
59043A4	14.50		16.00		14.38	14.96
59037-2wA4	14.75	15.38	15.88	15.06	15.25	15.26
Mean	15.18	16.15	16.34	16.41	14.70	15.67

In the 2002-03 season, 21 parent lines were used to make 86 hybrid combinations planted in replicated trials at BRS in spring 2002 and autumn 2003. Lines 183A4 and 59041wA4 and 293A5 were identified as elite female parents and produced hybrids with grain yields from 3.5 to 4.8 tonnes/ha. Bulked grain samples of four of these hybrids were analysed for grain quality (see Table 2). Hybrids of female parents 183A4 and 293A5 were both high yielding and had protein contents of between 12% to 14% (and hence were considered to be 'elite' hybrids), while a lower yielding white seeded hybrid had a protein content of 15.4%. White seeded pearl millet has been targeted in breeding programs in India where it is grown for human consumption and can be mixed with higher value wheat flour. Similar niche applications may be developed in Australia. Hybrids of female parent 183A4 were considered to have good commercial prospects on the basis of yield and favourable agronomic characteristics.

Table 2. Grain protein content and gross energy (GE) of elite hybrids in 2002-03 trials.

Hybrid	Female parent	Male parent	Protein (%)*	GE (MJ/kg)*	Notes
25	59041wA4	4AmRm	13.31	19.27	Elite hybrid
29	183A4	4AmrRm	12.13	19.35	Elite hybrid
33	293A5	NM7R1R5	14.00	19.65	Elite hybrid
60	68wA4	4AmRm	15.41	19.72	White seeded

* dry matter basis

On the basis of agronomic factors, yield performance in trials and chemical characteristics, three hybrids were selected for further testing. Parentage of these three elite hybrids (PM3, PM4 and PM31) is shown in Table 3. Grain from these three elite hybrids was grown at BRS. After harvesting and cleaning, the millets were transported to the Poultry Research and Development Centre (PRDC), Cleveland, for nutritional analysis and testing of their suitability as poultry feed ingredients.

Table 3. Parentage of elite pearl millet hybrids selected for further nutritional testing.

Hybrid	Female parent	Male parent
PM3	293A4	1163wA4
PM4	293A4	59026A4
PM31	183A4	1163wA4

3.2 Chemical analyses

The determination of dry matter, protein, ash, crude fibre, calcium and phosphorus content of 52 out of the 86 hybrid combinations of pearl millet and the selected three elite pearl millet hybrids were undertaken according to the methods of the AOAC (1992).

The amino acid analyses were undertaken by ion-exchange chromatography (Walter HPLC) after hydrolysis with 6 M HCL at 110 ^{o}C for 18 hours under reflux conditions.

3.3 Metabolisable energy

Apparent metabolisable energy (AME) was determined using the classical method with total collection of excreta and measurement of food intake. Ninety-six birds were purchased as day olds. All the chicks were offered starter diets for 13 days. On day 14, birds were allocated into metabolism cages in groups of six birds/cage and were fed diets containing either sorghum or the elite pearl millet hybrids (PM31, PM3 or PM4). After three days of adaptation to the diets, birds were offered measured amounts of diet and excreta were collected for the next three days.

The procedure was carried out as follows:

- 20 kg of each experimental diet was prepared in mash form. The composition of the four diets is shown in Table 4. The moisture contents of the basal diet and test ingredients (pearl millet hybrids) were determined.
- Day 14, diets were offered to the birds for an adaptation period of three days.
- Day 17, at 7.00am, all feeders from cages were removed.
- Day 17, at 1.00pm, collection trays were placed under cages and measured amounts of the experimental diets were offered.
- Days 18, 19 and 20, all excreta on each tray was collected and stored at –10°C.
- Day 21, at 7:00 am, all feed was removed and feed consumed recorded. At 1:00pm all excreta was collected (final excreta collected). Aluminium trays were left to thaw out.
- Excreta collected was oven dried for three to four days at 70 °C.

- After all excreta was oven dried, trays were removed from ovens and allowed to equilibrate with ambient temperature for three to four hours. Dried excreta was ground and gross energy of the feed and excreta samples were determined using an AC-350 LECO adiabatic bomb calorimeter.

AME values were calculated using the following formula after correcting for moisture content to an as-fed basis.

$$AME(MJ/kg) = \frac{(\text{Feed Intake}^* \ GE) - (\text{Excreta Output} * \text{GE excreta})}{\text{Feed Intake}}$$

Table 4. Diets used in metabolisable energy experiment (g/kg).

Ingredient	Sorghum Diet	Pearl Millet Diet 1	Pearl Millet Diet 2	Pearl Millet Diet 3
Sorghum	968			
Pearl millet hybrid PM31		968		
Pearl millet hybrid PM3			968	
Pearl millet hybrid PM4				968
Salt	1.0	1.0	1.0	1.0
Sodium bicarbonate	0.5	0.5	0.5	0.5
Limestone	14.0	14.0	14.0	14.0
Di-calcium phosphate	6.0	6.0	6.0	6.0
Vitamins	1.5	1.5	1.5	1.5
Vitamin supp	2.0	2.0	2.0	2.0
Minerals	1.5	1.5	1.5	1.5
Choline chloride	1.0	1.0	1.0	1.0
Lysine	2.0	2.0	2.0	2.0
DL methionine	1.5	1.5	1.5	1.5
Threonine	1.0	1.0	1.0	1.0
Total	1000	1000	1000	1000

3.4 Amino acid digestibility

Sixteen groups (one sorghum + three elite pearl millet hybrids x four replicates) of eight birds (35 days old) of similar weight were selected and placed in metabolism cages.

The three millet hybrids were ground to pass through a 2 mm screen. Each pearl millet hybrid and sorghum was incorporated as the sole source of dietary protein in the assay. Test diets contained 969.5 g/kg of the pearl millet and an appropriate mix of mineral and vitamin supplements and chromic oxide as an indigestible marker (see Table 5). A marker is an indigestible substance that passes along the digestive tract and can be fully recovered in the ileal digesta. By measuring its concentration in both the feed and the ileal digesta the quantitative relationship between the foods consumed and the ileal digesta can be determined.

All diets were fed *ad libitum* for a total period of seven days. Water was constantly available from two nipple waterers per cage. On day 7 all birds were euthanased by cervical dislocation and immediately opened to remove digesta from the vitelline diverticulum (formerly Meckel's diverticulum) to 40-mm back from the ileo-caecal junction. Ileal digesta of birds within a pen was pooled, frozen immediately after collection and subsequently freeze-dried. Dried ileal digesta samples were ground/crushed using a mortar/pestle and stored in airtight containers at –20 °C for chemical analysis. A proportion of each sample was used for an acid insoluble ash determination. The amino acid analysis of the digesta and diet was analysed as per the method described for the analysis of the grain samples. Ileal amino acid digestibilities were calculated using chromic oxide as the marker.

$$\text{Amino acid digestibility (\%)} = \frac{(AA/CrO)diet - (AA/CrO)ileal * 100}{(AA/CrO)diet}$$

where (AA/CrO) is the ratio of amino acid to Chromic oxide in diet and in ileal digesta.

Table 5. Diets used in ileal digestibility experiment (g/kg).

Ingredient	Sorghum Diet	Pearl Millet Diet 1	Pearl Millet Diet 2	Pearl Millet Diet 3
Sorghum	969.5			
Pearl millet hybrid PM31		969.5		
Pearl millet hybrid PM3			969.5	
Pearl millet hybrid PM4				969.5
Salt	1	1	1	1
Sodium bicarbonate	0.5	0.5	0.5	0.5
Limestone	14	14	14	14
Di-calcium phosphate	6	6	6	6
Vitamins	1.5	1.5	1.5	1.5
Vitamin supp	2	2	2	2
Minerals	1.5	1.5	1.5	1.5
Choline chloride	1	1	1	1
Chromic oxide	3	3	3	3
Total	1000	1000	1000	1000

4. Results

4.1 Grain yield

Grain yield of elite hybrid PM31 was the same as elite hybrid PM4 in spring, and was higher than elite hybrid PM3 (Table 6). However, in the autumn harvest, yield of PM31 was much higher than PM3 and PM4 (4.2 compared with 3.4 and 3.0 tonnes/ha respectively).

Table 6. Yield of hybrids harvested in spring and autumn (tonnes/ha).

Harvest	Hybrid		
	PM31	PM3	PM4
Spring	2.8	2.5	2.9
Autumn	4.2	3.4	3.0
Total	7.0	5.9	5.9

These hybrids matured in 85 and 82 days respectively for spring and autumn harvests and were 25 days shorter than quick maturing sorghum hybrids (Express and Sonic). Yield of these sorghum hybrids was similar to the elite pearl millet hybrids in the spring harvest but was much lower in the autumn harvest (4.8 tonnes/ha for pearl millet hybrids and 1.4 and 3.6 tonnes/ha by Express and Sonic sorghum hybrids respectively).

4.2 Chemical analyses

Chemical analyses of the 52 pearl millet hybrids (out of the original 86 hybrid combinations) are shown in Tables 7 and 8. The protein content of pearl millet hybrids ranged between 10.5 – 17.94%, with a mean value of 14.85%, compared to sorghum (14.2%) and Katherine pearl millet (13.7%). Eighty-seven percent of pearl millet hybrid samples tested had a protein content greater than 14%. The fibre (2.6, 5.1 and 2.2%), ash (1.85, 2.3 and 1.2%) and fat (5.8, 6.5 and 2.8%) content of the pearl millet hybrids were lower than Katherine pearl millet but higher than sorghum. The pearl millet hybrids had a superior amino acid profile to sorghum viz lysine (3.45 cf 2.3 g/kg), methionine (2.52 cf 1.5 g/kg), cystine (6.02 cf 4.4 g/kg) and threonine (5.09 cf 3.5 g/kg), respectively for pearl millet and sorghum.

Results of the chemical composition of the three elite pearl millet hybrids are given in the Table 9. Measurements for sorghum are given for comparison.

Table 7. Chemical analyses of pearl millet hybrids.

Pearl millet hybrid sample ident. no.	DM %	Ash %*	N %*	CF %*	Fat %*	P %*	Ca %*	GE MJ/kg*	Protein %*
1	89.7	2.0	2.44	1.8	5.7	0.43	0.05	19.4	15.25
2	90.1	2.2	2.56	1.6	5.7	0.48	0.05	19.2	16
5	90.1	2.2	2.80	2.0	5.2	0.46	0.05	19.5	17.5
6	89.7	2.5	2.87	2.4	6.4	0.52	0.05	19.5	17.938
7	89.8	2.2	2.44	1.9	6.1	0.45	0.04	19.3	15.25
8	89.9	2.1	2.41	1.6	6.2	0.41	0.03	19.4	15.063
9	89.9	2.0	2.36	1.7	5.5	0.41	0.03	19.2	14.75
10	89.8	2.1	2.46	1.9	6.0	0.40	0.03	19.4	15.375
11	89.9	2.0	2.30	1.8	5.8	0.37	0.03	19.2	14.375
12	89.6	2.3	2.70	2.1	5.7	0.47	0.05	19.4	16.875
13	89.8	2.2	2.32	1.6	5.6	0.44	0.03	19.3	14.5
14	89.7	1.9	2.14	1.6	6.1	0.37	0.04	19.4	13.375

Pearl millet hybrid sample ident. no.	DM %	Ash %*	N %*	CF %*	Fat %*	P %*	Ca %*	GE MJ/kg*	Protein %*
15	89.9	2.0	2.31	1.7	6.0	0.40	0.03	19.4	14.438
16	90.0	2.1	2.49	1.7	6.4	0.41	0.04	19.6	15.563
17	89.8	2.4	2.72	2.1	6.0	0.49	0.04	19.5	17
18	89.5	2.1	2.44	2.8	5.8	0.42	0.03	19.4	15.25
19	89.8	2.4	2.66	3.6	5.6	0.47	0.03	19.4	16.625
20	89.8	2.2	2.45	2.8	5.2	0.44	0.03	19.3	15.313
21	89.8	2.3	2.54	2.7	5.1	0.43	0.02	19.3	15.875
22	90.0	2.3	2.70	3.2	4.8	0.42	0.03	19.3	16.875
23	89.8	2.2	2.50	3.3	6.1	0.41	0.02	19.5	15.625
24	89.6	1.9	2.75	3.2	6.4	0.27	0.03	19.7	17.188
25	89.5	1.7	2.52	3.9	7.1	0.23	0.02	19.6	15.75
26	88.7	2.0	1.44	2.2	5.2	0.35	0.02	18.8	9
27	89.1	2.1	1.68	3.9	7.0	0.37	0.02	19.2	10.5
28	88.6	2.1	2.07	3.4	5.4	0.34	0.02	19.3	12.938
29	88.8	2.0	1.78	3.3	5.7	0.37	0.02	19.2	11.125
30	89.4	1.5	2.21	3.3	5.6	0.19	0.02	19.4	13.813
31	89.7	1.4	2.43	2.8	4.7	0.20	0.02	19.5	15.188
32	89.5	1.6	2.19	2.6	5.8	0.20	0.02	19.4	13.688
33	89.3	1.6	2.33	2.9	5.7	0.21	0.02	19.5	14.563
34	88.8	1.8	1.94	2.9	5.6	0.32	0.02	19.1	12.125
35	88.2	1.9	1.53	2.5	3.7	0.33	0.02	19.0	9.5625
36	89.5	1.5	2.58	2.7	6.3	0.20	0.02	19.6	16.125
37	88.8	1.7	2.18	2.2	3.7	0.30	0.02	19.0	13.625
38	89.4	2.0	2.08	2.6	5.7	0.35	0.02	19.3	13
39	89.2	1.6	2.08	2.1	3.7	0.31	0.02	19.2	13
40	89.5	1.3	2.39	2.6	5.9	0.19	0.02	19.4	14.938
41	90.2	1.6	2.66	2.5	5.4	0.28	0.02	19.6	16.625
42	89.3	1.8	1.83	2.1	5.0	0.33	0.02	19.1	11.438
43	89.7	1.6	2.68	2.8	5.6	0.26	0.02	19.6	16.75
44	89.5	1.4	2.64	3.1	6.7	0.23	0.02	19.8	16.5
45	89.1	1.4	2.30	2.7	4.9	0.20	0.02	19.4	14.375
46	89.5	1.5	2.45	2.6	6.3	0.23	0.02	19.4	15.313
47	89.7	1.4	2.45	2.8	6.5	0.21	0.02	19.7	15.313
48	89.8	1.4	2.63	2.7	5.9	0.21	0.02	19.6	16.438
49	89.6	1.6	2.46	2.4	5.7	0.23	0.02	19.6	15.375
50	89.6	1.6	2.68	2.3	5.7	0.24	0.02	19.5	16.75
51	90.2	1.3	2.61	2.2	5.9	0.15	0.02	19.7	16.313
52	89.6	1.5	2.43	3.1	5.6	0.21	0.03	19.5	15.188
53	89.6	1.4	2.19	3.0	6.5	0.20	0.03	19.5	13.688
54	89.4	1.5	2.73	2.9	6.5	0.24	0.03	19.7	17.063

* dry matter basis

Table 8. Amino acid profile of pearl millet hybrids (g/kg dry matter).

Pearl millet hybrid sample ident. no.	Ala	Arg	Asp	Cyst	Glut	Gly	Hist	IsoLe	Leu	Lys	Meth	Phe	Pro	Ser	Thr	Tryp	Tyr	Val
1	11.89	7.91	9.73	2.27	25.27	4.47	3.22	6.04	13.73	3.42	2.51	7.03	9.18	6.83	5.25	2.65	3.86	7.57
2	12.37	8.16	9.85	2.34	26.06	4.50	3.38	6.37	14.61	3.37	2.12	7.46	9.45	7.28	5.50	2.87	4.35	7.85
5	11.78	7.80	9.66	2.09	27.42	4.48	3.53	6.96	16.22	3.22	2.07	8.68	10.40	7.62	5.73	2.02	4.80	8.33
6	11.57	9.37	10.51	2.19	26.67	5.40	3.84	6.92	15.68	3.94	2.31	8.49	10.27	7.92	6.00	3.23	4.91	8.61
7	10.72	7.29	9.67	2.21	24.59	4.42	3.17	5.97	13.58	3.49	2.33	7.04	8.97	6.67	5.02	2.25	4.09	7.47
8	10.12	6.87	9.04	2.25	23.46	4.13	3.07	5.91	13.54	3.31	2.45	7.10	8.77	6.48	4.87	2.56	4.07	7.27
9	10.65	8.46	9.04	2.84	24.11	4.57	3.09	5.97	13.88	3.56	3.04	7.35	8.82	6.61	5.07	2.14	3.97	7.47
10	10.76	8.18	8.76	2.21	24.50	4.56	3.14	6.27	14.70	3.31	2.36	7.89	9.42	6.96	5.29	2.49	4.15	7.67
11	10.69	10.20	10.02	2.12	26.25	5.93	3.98	7.16	16.31	3.73	2.18	8.62	10.09	8.22	6.02	2.40	4.86	8.92
12	13.24	10.96	9.35	2.52	26.28	5.80	4.25	8.27	18.74	3.90	2.57	10.60	11.44	8.60	6.69	3.02	5.94	9.89
13	11.14	8.81	8.95	2.29	24.46	5.05	3.70	7.07	16.18	3.79	2.19	8.59	9.94	7.38	5.71	2.19	4.97	8.72
14	10.89	8.08	8.87	2.11	23.63	5.01	3.37	6.49	14.77	3.55	2.13	7.93	9.33	7.01	5.30	1.83	4.53	8.21
15	11.14	9.17	9.21	2.02	24.88	5.73	3.83	7.24	16.54	3.82	2.12	8.95	10.24	7.92	6.05	2.27	5.13	9.06
16	10.79	9.36	9.11	2.21	24.78	5.94	4.05	7.43	17.00	4.07	2.22	9.37	9.96	8.26	6.22	2.61	5.37	9.26
17	10.94	9.35	9.66	2.50	25.10	4.87	3.36	6.53	15.05	3.69	2.46	7.91	9.19	7.31	5.39	2.95	4.38	8.21
18	10.01	7.55	8.82	2.80	24.06	3.98	2.88	5.87	13.69	3.25	3.00	6.97	8.38	6.30	4.81	2.54	3.96	7.31
19	10.60	9.20	9.54	2.57	25.05	4.64	3.31	6.46	14.83	3.65	2.50	7.88	8.87	7.00	5.25	2.80	4.26	8.05
20	11.23	8.86	10.61	2.44	26.75	4.86	3.43	6.06	14.00	4.12	2.52	7.37	8.90	6.92	5.20	2.81	4.13	7.68
21	12.08	8.71	11.08	3.14	28.06	4.89	3.33	6.55	15.05	4.14	3.58	7.84	9.76	7.49	5.59	2.68	4.31	8.17
22	12.71	8.27	12.27	3.54	31.60	4.56	3.46	6.77	15.74	3.94	4.29	7.85	10.00	7.46	5.55	3.43	4.32	8.44
23	11.87	8.34	11.67	2.76	29.00	4.62	3.30	6.24	14.42	4.13	3.24	7.53	9.14	7.08	5.18	3.01	4.12	7.85
24	12.37	8.85	11.63	3.32	29.21	5.27	3.59	6.89	15.83	4.07	3.71	8.30	10.14	7.93	5.75	3.37	4.61	8.58
25	11.80	8.98	12.46	2.82	28.82	5.12	3.25	6.11	13.97	4.45	3.08	7.17	8.85	7.22	5.35	2.89	4.12	7.90
26	6.57	5.24	6.77	1.58	15.75	3.14	1.85	3.41	7.74	2.67	1.50	4.15	5.29	4.02	3.15	1.39	2.32	4.48
27	7.19	5.38	7.27	1.56	17.28	3.19	2.00	3.73	8.53	2.70	1.63	4.64	5.73	4.30	3.31	1.89	2.62	4.80
28	9.40	6.55	8.88	2.88	22.86	3.70	2.48	4.97	11.55	3.08	3.03	6.11	7.48	5.59	4.20	2.15	3.29	6.25
29	8.06	6.40	8.42	1.80	19.71	3.71	2.31	4.16	9.41	3.20	1.68	4.94	6.24	4.96	3.67	1.85	2.93	5.43
30	10.16	7.02	9.74	2.06	24.71	3.97	2.63	5.40	12.43	3.41	2.23	6.49	7.97	5.97	4.55	2.18	3.55	6.79

Pearl millet hybrid sample ident. no.	**Ala**	**Arg**	**Asp**	**Cyst**	**Glut**	**Gly**	**Hist**	**IsoLe**	**Leu**	**Lys**	**Meth**	**Phe**	**Pro**	**Ser**	**Thr**	**Tryp**	**Tyr**	**Val**
31	11.55	7.28	11.06	3.24	28.34	4.12	2.87	6.07	14.22	3.51	3.66	7.15	9.02	6.82	5.06	3.05	3.96	7.52
32	10.33	6.73	9.83	2.23	24.38	4.49	2.83	5.59	12.73	3.65	2.24	6.75	8.20	6.32	4.78	2.32	3.73	7.02
33	10.45	6.44	9.62	2.20	24.68	4.33	2.82	5.62	13.00	3.38	2.37	6.84	8.42	6.38	4.79	2.38	3.82	7.06
34	9.25	5.90	8.64	2.09	21.82	3.81	2.54	4.84	10.91	3.20	2.10	5.91	7.52	5.46	4.20	2.20	3.32	5.85
35	6.88	4.02	6.74	1.71	17.25	2.84	1.76	3.71	8.54	2.36	1.54	4.64	5.79	4.11	3.19	1.83	2.54	4.51
36	11.33	7.15	10.46	2.54	26.48	4.48	3.03	6.16	14.23	3.61	2.67	7.49	8.94	6.86	5.16	3.08	4.07	7.61
37	10.20	5.38	9.52	1.94	25.36	3.55	2.55	5.53	12.95	2.81	2.02	6.58	8.42	6.03	4.52	2.88	3.56	6.77
38	9.41	5.93	9.58	1.93	23.76	3.75	2.50	5.02	11.57	3.20	1.92	6.01	7.61	5.59	4.18	2.26	3.36	6.38
39	10.12	5.89	9.04	1.92	24.34	3.78	2.65	5.42	12.63	3.06	2.16	6.67	8.35	5.87	4.46	2.62	3.64	6.75
40	11.11	7.71	10.01	2.31	26.07	4.36	3.09	6.09	14.11	3.39	2.40	7.37	8.93	6.73	5.05	2.86	3.98	7.50
41	12.23	7.66	10.34	2.27	28.03	4.55	3.17	6.88	15.82	3.40	2.77	8.39	10.21	7.50	5.61	3.14	4.49	8.33
42	8.72	5.80	7.89	2.01	20.98	3.40	2.26	4.68	10.85	2.76	2.09	5.74	7.37	5.07	3.92	2.36	3.23	5.92
43	12.08	8.54	10.83	3.01	27.73	5.13	3.42	6.71	15.46	3.85	3.46	8.16	10.08	7.51	5.60	2.52	4.48	8.33
44	10.62	8.83	8.72	3.37	24.05	5.41	3.56	6.57	15.25	3.19	3.87	8.50	9.80	7.57	5.61	3.17	4.69	8.06
45	10.03	7.41	8.75	2.22	23.14	4.34	2.80	5.57	12.90	3.27	2.30	6.81	8.20	6.41	4.79	2.60	3.82	7.07
46	10.56	8.41	8.67	2.27	22.85	5.33	3.36	6.16	14.21	3.31	2.41	7.82	9.13	7.23	5.38	3.00	4.46	7.74
47	10.71	8.25	9.33	2.19	23.99	5.21	3.34	6.14	14.17	3.55	2.52	7.65	9.03	7.26	5.40	2.84	4.26	7.66
48	11.56	8.64	9.64	2.33	25.92	5.04	3.36	6.51	15.22	3.29	2.52	7.93	9.67	7.48	5.55	3.11	4.41	8.11
49	10.66	7.83	8.92	2.33	23.57	4.82	3.11	5.98	13.80	3.35	2.70	7.43	8.91	6.90	5.21	3.13	4.12	7.45
50	11.46	8.91	9.72	2.57	26.16	5.12	3.40	6.61	15.43	3.34	2.67	8.04	9.95	7.55	5.58	3.19	4.63	8.17
51	11.20	8.20	9.22	2.37	25.37	5.02	3.32	6.61	15.51	3.22	2.64	8.34	9.84	7.59	5.53	2.97	4.53	8.02
52	10.47	9.16	8.94	2.23	23.63	5.02	3.17	6.01	13.78	3.56	2.33	7.50	8.92	6.95	5.34	3.12	4.22	7.50
53	9.57	7.58	8.44	2.02	21.94	4.28	2.66	5.29	12.26	3.27	2.22	6.60	8.03	6.11	4.70	2.64	3.61	6.63
54	10.80	8.75	8.77	2.26	23.63	5.22	3.35	6.47	15.04	3.14	2.66	8.33	9.49	7.36	5.57	3.12	4.58	7.96

Table 9. Chemical composition of three elite pearl millet hybrids and sorghum (dry matter basis).

Percentage:	**PM31**	**PM3**	**PM4**	**Sorghum**
DM	88.6	88.7	88.9	86.7
Ash	2.0	2.1	2.1	1.2
Protein	13.69	14.75	14.31	12.44
Ca	0.06	0.04	0.05	0.04
P	0.43	0.42	0.44	0.31
Fat	6.4	6.4	6.4	2.8
$C_{18:3n-6}$ Fatty acid	43.9	44.4	45.2	45.5
$C_{18:3n-3}$ Fatty acid	3.2	3.5	3.2	1.6
CF	1.9	2.1	2.1	2.2
NDF	8.9	10.7	10.5	6.1
Starch	69.4	68.1	66.3	
Condensed tannins	ND	ND	ND	NA
GE (MJ/kg)	19.32	19.44	19.36	18.06
Amino acids (g/kg):				
Arginine	5.56	6.77	6.31	3.8
Cystine	1.87	2.19	2.22	1.8
Glycine	3.76	4.31	3.94	3.1
Histidine	2.64	3.03	2.88	2.4
Iso Leucine	5.19	5.89	5.78	4.4
Leucine	12.63	14.38	14.07	15.1
Lysine	2.83	3.18	3.09	2.3
Methionine	1.90	3.34	2.47	1.5
Phenylalanine	6.15	6.89	6.80	5.9
Serine	5.98	6.82	6.42	4.8
Threonine	4.47	5.18	4.94	3.5
Tryptophan.	2.60	2.92	2.70	1.2
Tyrosine	3.46	3.94	3.88	4.2
Valine	6.57	7.46	7.21	5.5

Notes: ND = not detected; NA = not analysed

In comparison to sorghum, the elite millet hybrids had higher protein, fat and neutral-detergent fibre (NDF). The elite pearl millet hybrids contained nearly 2% more protein than sorghum. The fat content of the millet hybrids was more than twice that of sorghum. The NDF content of hybrid PM31 was lower than that of PM3 and PM4 but was higher than sorghum. The starch content and gross energy (GE) content of the three pearl millet hybrids were the same. Condensed tannin was not detected in any of the three hybrids. Linolenic acid ($C_{18:3n-3}$) comprised 3% of the total fatty acid in the pearl millet hybrids, which is higher than other cereal grains. The ratio of n-6:n-3 fatty acids in the three pearl millet hybrids were 13.72, 12.68 and 14.13 respectively for PM31, PM3 and PM4, compared to sorghum's 28.43.

The total amino acid profile of the three elite pearl millet hybrids is much better than sorghum. Pearl millet hybrids contained 50% more lysine, methionine, threonine and tryptophan than sorghum.

Except for the protein content, where PM31 had slightly less protein, the three millet hybrids had very similar chemical composition. The fat content was 6.4% and fibre content 2.0%. The amino acid profile of PM31 was lower than PM3 and PM4. The lysine content of PM31 was 2.83 g/kg compared to 3.18 g/kg and 3.09 g/kg for PM3 and PM4 respectively.

4.3 Apparent metabolisable energy

Results of the uncorrected, nitrogen corrected and dry matter corrected AME's are presented in Table 10. The coefficients of variation (CV%) within the replicates were very low (0.7%).

Table 10. AME of sorghum and three elite pearl millet hybrids (MJ/kg).

Treatment:	**Replicate:**	**AME uncorrected MJ/kg**	**AMEn corrected MJ/kg**	**AME DM (diet) MJ/kg**
Sorghum	1	13.19	12.88	14.68
	2	13.23	12.92	14.73
	3	13.24	12.91	14.74
	4	13.27	12.92	14.78
Mean		13.23	12.91	14.73
SEM		0.03	0.01	0.03
PM31	1	14.15	13.66	15.76
	2	13.64	13.17	15.19
	3	14.01	13.59	15.60
	4	14.06	13.60	15.65
Mean		13.96	13.50	15.55
SEM		0.20	0.20	0.22
PM3	1	13.80	13.23	15.25
	2	13.77	13.20	15.21
	3	13.93	13.45	15.40
	4	13.75	13.20	15.19
Mean		13.65	13.12	15.09
SEM		0.29	0.29	0.32
PM4	1	14.17	13.70	15.55
	2	14.04	13.57	15.41
	3	14.11	13.66	15.49
	4	13.92	13.44	15.28
Mean		14.06	13.59	15.43
SEM		0.09	0.10	0.10

The uncorrected AME, nitrogen corrected AME (AMEn) and AME corrected for diet dry matter (AME DM) of sorghum were all significantly lower ($p<0.001$) than for the three elite pearl millet hybrids (Table 11). The AMEn of sorghum was 0.8 MJ/kg lower than the elite pearl millet hybrids and its AME on a diet dry matter basis nearly 1.0 MJ/kg lower ($p<0.001$). Nitrogen corrected and diet DM corrected AME of PM31 was significantly higher than PM3 ($P<0.01$) but was similar to PM4.

Table 11. Apparent metabolisable energy of three elite pearl millet hybrids and sorghum (MJ/kg).

	PM 31	PM 3	PM 4	Sorghum
AME uncorrected	14.04 [a]	13.81[b]	14.06 [a]	13.23 [c]
LSD (p<0.05)	0.128			
AMEn	13.57 [a]	13.27 [a]	13.59 [a]	12.91[b]
LSD (p<0.05)	0.146			
AME DM	15.64 [a]	15.26 [b]	15.43 [a]	14.73[c]
LSD (p<0.05)	0.141			

[a-c] Means in a row with no common superscript differ significantly (p<0.05)

4.4 Amino acid digestibility

Results for the ileal digestibility coefficients of the three elite pearl millet hybrids and sorghum are presented in the Table 12. The digestibility coefficients for most amino acids in sorghum are within the range reported by Ravindran *et al*. (1998). The digestibilities of cystine, lysine and threonine in the millets were higher than those in sorghum, whereas the digestibilities of the other amino acids in the millet hybrids was very similar to sorghum.

Table 12. Means and SEM of ileal digestibility coefficients in three elite pearl millet hybrids and sorghum.

	PM 31		**PM 3**		**PM 4**		**Sorghum**	
	Mean	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**
Protein	0.74	0.027	0.78	0.017	0.79	0.017	0.78	0.015
Alanine	0.84	0.018	0.86	0.011	0.87	0.013	0.87	0.007
Arginine	0.74	0.059	0.84	0.014	0.82	0.028	0.80	0.032
Aspartic Acid	0.77	0.029	0.81	0.016	0.80	0.013	0.78	0.014
Cystine	**0.72**	**0.030**	**0.74**	**0.037**	**0.73**	**0.039**	**0.69**	**0.005**
Glutamic Acid	0.87	0.019	0.88	0.012	0.89	0.013	0.88	0.005
Glycine	0.62	0.030	0.71	0.023	0.67	0.023	0.67	0.038
Histidine	0.77	0.024	0.83	0.015	0.84	0.011	0.75	0.010
Iso Leucine	0.78	0.048	0.85	0.012	0.83	0.028	0.81	0.018
Leucine	0.83	0.029	0.87	0.011	0.87	0.019	0.87	0.008
Lysine	**0.72**	**0.009**	**0.76**	**0.019**	**0.75**	**0.019**	**0.69**	**0.021**
Methionine	**0.85**	**0.023**	**0.86**	**0.018**	**0.88**	**0.016**	**0.85**	**0.012**
Phenylalanine	0.80	0.038	0.87	0.009	0.86	0.023	0.85	0.013
Proline	0.77	0.052	0.84	0.015	0.82	0.022	0.81	0.015
Serine	0.69	0.063	0.78	0.019	0.76	0.024	0.73	0.042
Threonine	**0.75**	**0.019**	**0.74**	**0.022**	**0.75**	**0.041**	**0.66**	**0.026**
Tryptophan	**0.82**	**0.015**	**0.79**	**0.012**	**0.77**	**0.022**	**0.90**	**0.027**
Tyrosine	0.72	0.042	0.81	0.014	0.81	0.018	0.83	0.010
Valine	0.80	0.050	0.83	0.012	0.84	0.023	0.79	0.022

5. Discussion of Results

The yield potential of new pearl millet hybrids is superior to that of the quick maturing sorghum hybrids. These pearl millet hybrids are therefore viable alternatives to sorghum. Autumn planting pearl millets reached physiological maturity in 82 days, 25 days quicker than sorghum hybrids. Hybrid grain yields of up to 4.8 tonnes/ha were significantly higher than yields for sorghum. In spring, pearl millet hybrid grain yields (up to 3.8 tonnes/ha) were equal to early maturing sorghum hybrids. These results suggest that growing pearl millet would be at least as economical as early sorghum hybrids on a grain yield basis. Pearl millet margins would become still more favourable in later planting scenarios and when the risks of sorghum midge and sorghum ergot are significant.

The parent lines of pearl millet were very variable in their protein content (10 - 18%). However, the three elite hybrids derived from elite parents had similar protein contents (13.69 - 14.75%). Also, the new varieties' grains were twice the size of the old Katherine pearl millet (9 g/1000 seeds vs 20 g/1000 seeds (Douglas, *pers. comm.*). Compared to sorghum, pearl millet hybrids contain twice as much lysine, methionine and tryptophan and their apparent metabolisable energy (AME) is at least 0.6 MJ/kg higher. The amino acid digestibility of the hybrids was similar to sorghum, although the protein content was higher in pearl millet hybrids. The grain of pearl millet is enriched in essential amino acids and has the potential to replace some of the more expensive protein meals such as meat and bone meal and soybean meal that are used in poultry diets. Furthermore, the oil content of pearl millet grain is higher than other cereal grains (Rooney and McDonough, 1987). Since the omega-three fatty acid content of pearl millet hybrids was twice that of sorghum, it would suggest that the inclusion of these pearl millet hybrids in broiler and layer diets may result in the transfer of higher levels of omega-three fatty acids into chicken meat and eggs, with potential implications in terms of the development of new 'functional foods' from poultry products. Omega-three fatty acids have been shown to accumulate in the eggs of hens fed pearl millet based diet (Collins *et al.*, 1997). Omega-three enriched eggs are already available as a 'functional food' in European supermarkets and command a price premium.

6. Implications

There is little doubt that the demand for cereal grains for poultry feed will increase substantially, especially with the problem of ergot in sorghum crops. It is essential that a detailed knowledge of the nutritional value of any alternative feed ingredients be established to allow them to be used effectively and efficiently. The experiments conducted in this project have highlighted the nutritive value of the pearl millets, which is important when formulating least cost poultry diets.

Female lines 183A4 and 59041 A4, and male lines 4AmRm were the elite parent lines identified in yield trials (conducted under a GRDC project) and only small quantities of these parent lines (ca. 200g) are currently held in stock at the Australian Tropical Crops and Forages Genetic Resource Centre. Any subsequent evaluation of pearl millet hybrids is likely to be on a larger scale than these trials and will require several kilograms of seed. Since production of F1 hybrid seed is labour intensive and can take several cycles of regeneration it would appear prudent to begin increasing seed stocks of the three identified elite parent lines.

The results from ileal amino acid digestibility and from AME studies suggest that the three elite pearl millet hybrids studied could be used as feed ingredients in broiler diets.

7. Recommendations

One of the objectives of this research was to promote the benefits of pearl millet as a feed grain to grain growers and the poultry industry. Based on grain production results it is suggested that growing pearl millet would be at least as economical as early sorghum hybrids. However, margins for pearl millet would become still more favorable in later planting scenarios and when the risks of sorghum midge and sorghum ergot are significant. The shorter time to reach maturity and higher grain yields of pearl millet hybrids could potentially make pearl millet a more profitable crop to plant.

The chemical characteristics of pearl millet hybrids, together with their superior digestibility in terms of energy and amino acids, would make these hybrids very good feed ingredients for the poultry industries. Cheaper diets could be formulated with the inclusion of pearl millet. Pearl millet has the potential to replace sorghum, and partially replace the more expensive protein meals, to produce cheaper poultry diets. Further research is warranted to assess these hybrids in terms of broiler growth, feed efficiency and carcass quality. In particular, the conduct of small pen, inclusion level experiments designed to ascertain the maximum inclusion rates of pearl millet in broiler diets, followed by a semi-commercial feeding trial, is recommended. Research on the effects of egg quality when laying hens are fed pearl millet based diets is also recommended. These experiments will confirm the true feeding value of pearl millet hybrids for the Australian poultry industries.

Many authors (eg Andrews and Kumar, 1992; Amato and Forrester, 1995) believe that in the next decade or so, the greatest advances in agriculture in the warmer climatic regions of the world will come from the development of pearl millet as a feed grain crop. Though the good nutritional status of the grain is already established, opportunities for further improvement in its feed value are known to exist.

8. References

Amato, S.V. and Forrester, R.R. (1995). Evaluation of pearl millet as a feed ingredient for broiler rations. In *“First National Grain Pearl Millet Symposium,”* Edited by I.D. Teare pp125-128. Tlifton, Georgia, USA. January 17 & 18, 1995.

Andrews, D.J. and Kumar, K.A. (1992). *Advances in Agronomy* **48:** 89-139.

AOAC (1992). Association of Official Analytical Chemists. *Official Methods of Analysis*, 15th edn (Washington, DC, AOAC).

Bramel-Cox, P.J., Andrews, D.J. and Frey, K.J. (1986). *Crop Sci.* **26:** 687-690.

Collins, V.P., Cantor, A.H., Pescatore, A.J. and Straw, M.L. (1997). *Poult. Sci.* **76:** 326-330

Douglas, C. (2003). Developing an Australian pearl millet industry. Progress on GRDC project DAQ459.

Fancher, B.I., Jensen, L.S., Smith, R.L. and Hanna, W.W. (1987). *Poult. Sci*. **66:** 1693-1696.

Hoseney, R.C., Andrews, D.J. and Clark, H. (1987). Sorghum and pearl millet. In “*Nutritional Quality of Cereal Grains: Genetic and Agronomic Improvement,”* ASA Monograph 28 pp. 397-456.

Jambunathan, R. and Subramanian, V. (1988). Grain quality and utilization in sorghum and pearl millet. In *“Proceedings of Workshop on Biotechnology for Tropical Crop Improvement”* pp. 133-139. ICRISAT, Patancheru, India.

Kumar, A.M., Reddy, V.R., Reddy, P.R. and Reddy, R.S. (1991). *Poult. Sci*. **32:** 463-469.

Ravindran, V., Hew, L.I. and Bryden, W.L. (1998). *Digestible Amino Acids in Poultry Feedstuffs.* RIRDC Publication No 98/9, Occasional Bulletin No.4.

Rooney, L.W. and McDonough, C.M. (1987). Food quality and consumer acceptance in pearl millet. *In “Proceedings, International Pearl Millet Workshop”*, edited by J.R. Witcombe and S.R. Beckerman, pp. 43-61. ICRISAT, Patancheru, India.

Singh, D.N., Perez-Maldonado, R., Mannion, P.F. and Robinson, D. (2000). Pearl millet (*Pennistum americanum*) – an alternative feed grain for layers. *Proceedings 2000 Australian Poultry Science Symposium* pp. 133-136.

Smith, R.L., Jensen, L.S., Hoveland, C.S. and Hanna, W.W. (1989). *J. Prod. Agric.* **2:** 78-82.

Sullivan, T.W., Douglas, J.H., Andrews, D.J., Bond, P.L., Hancock, J.D., Bramel-Cox, P.J., Stegmeier, W.D. and Brethour, J.R. (1990). Nutritional value of pearl millet for food and feed. In *“Proceedings International Conference in Sorghum Nutritional Quality,”* pp.83-94. Purdue University, Lafayette, Indiana.