RURAL INDUSTRIES RESEARCH
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Alternative Protein Sources for Laying Hens

A report for the Rural Industries Research and Development Corporation

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Foreword

This project was stimulated chiefly by the need to expand the pool of vegetable protein feedstuffs available to the poultry industry.

While the population of under-developed regions of the world continues to grow, many countries in the Asian region are becoming increasingly affluent and consequently their intensive animal production industries are expanding rapidly. This is leading to increased competition for vegetable protein resources by humans and livestock.

It has been widely predicted that traditional sources of protein for poultry will become scarce and expensive in the near future. Despite the dominance of primary produce in Australia's export trade, the poultry industry has become increasingly dependent on imported feedstuffs, especially soybean meal, to supply its protein requirements.

To reverse this trend, much can be done to encourage the production and utilisation of alternative, locally grown feedstuffs. In the long run the poultry industry will benefit from the price advantages generated by the wider choice and constancy of supply of ingredients.

The catchwords of the day, however, are agricultural and economic sustainability, and every change, however small, devised to enhance any sector of agricultural production and the market which it supplies must also address these broader issues. It is hoped that the present project contributes something of value not only to the poultry industry but to Australian agriculture as a whole.

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

This report, a new addition to RIRDC's diverse range of over 600 research publications, forms part of our Egg Industry program, which aims to support improved efficiency, sustainability, product quality, education and technology transfer in the Australian egg industry.

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Peter Core
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Contents

Abbreviations

AME	Apparent metabolisable energy (adult fowl)
ANF	Antinutritional factor
PRDC	Pig Research & Development Corporation
QDPI	Queensland Department of Primary Industries
QPRDC	Queensland Poultry Research & Development Centre
TIA	Trypsin inhibitor activity

Executive Summary

Many of the traditional ingredients used in poultry diets are forecast to be in short supply within ten years. Inevitably there will be an increase in the world-wide demand for protein feed which is expected to be met largely by legumes and canola. As total feedgrain production in Australia is forecast to decline over the medium term, there is a risk of becoming more reliant on imports. Importation of soybean meal, the staple protein ingredient in poultry diets, increased dramatically between 1988 and 1998, but there are signs of a reversal in this trend, due mainly to increased production and utilisation of locally grown canola. While grain legume production in Australia is also increasing, most of this harvest is grown in the southern states. It would be highly advantageous to shift some of this production northwards, both to meet the demands of the livestock industry in this region more economically and to provide more agronomic diversity in the region. Some legume varieties are well suited to subtropical regions and show promise as competitive sources of protein for livestock. Agronomists recognise that increased cultivation of grain legumes would make a valuable contribution to sustainable agriculture. They are therefore encouraging more regular rotation of legumes with cereal crops to reduce soil degradation and break the disease cycle.

Currently most grain legumes are grown specifically for human consumption and much of the legume used for poultry comprises down-graded batches that are unsuitable for human use. However, some agronomists are of the opinion that legumes could be grown specifically for intensive livestock use at competitive prices. A disadvantage of many grain legumes, when fed in raw form to poultry, is that they contain antinutritional factors (ANFs), in particular protease inhibitors, which limit the proportion of legume that can be included in the diet. Although most of these ANFs can be reduced by appropriate means such as heat treatment or enzyme additives, this is an extra cost which might be avoidable if varieties with low ANF levels can be obtained.

The objective of this project was to broaden the base of locally available vegetable protein sources that can be profitably included in the diet of layers. To achieve this the project aimed to:

(a) Conduct a literature review of alternative protein sources, with special reference to grain legumes and suitability for conditions in northern Australia

(b) Identify and evaluate suitable recently introduced cultivars of grain legumes in laying hen trials

(c) Define nutritional profiles of these legumes by chemical analysis and metabolisable energy determinations

(d) Determine levels of common antinutritional factors in these legumes

(e) Recommend upper inclusion levels of these legumes in layer diets

(f) Exchange information with a parallel project supported by the Pig Research and Development Corporation.

Three varieties of chickpea, two of mung bean, two of cowpea and one of lablab were selected for evaluation for laying hens, and batches of Queensland-grown grain of each variety were obtained. Nutrient analyses, metabolisable energy determinations and measurements of a range of ANFs were completed for all these materials. Three successive rounds of laying hen performance trials (each of approximately four months duration) were conducted, using IsaBrown layers. In each trial, several cultivars were included in nutritionally balanced layer diets at a range of concentrations determined on the basis of the laboratory information and existing knowledge of layer (or broiler) responses to the species of legume being tested. Concentrations higher and lower than previously indicated maxima were used and compared with a zero-level control diet. All cultivars were studied in untreated form using mash diets, but the effects of steam pelleting and decortication were also investigated with selected cultivars.

Varieties of the same legume species were found to be nutritionally similar, except that total sulphur amino acid levels were much lower in Amethyst chickpea (1.55 g/kg) than in Barwon (5.50 g/kg) or Dooen (5.39 g/kg). Trypsin inhibitor activity (mg/g) was higher in chickpea (3.8-7.1) and lablab (3.8-5.5) than in mung bean (1.9-2.9), and higher in Amethyst (6.8-7.1) than in Barwon (3.8-4.5) chickpea. However, bird performance (other than bodyweight gain) appeared to be unrelated to ANF levels, which therefore did not provide a useful indicator of safe maximum concentrations of legume in the diet. Diet composition (legume type and level) did not significantly affect mortality, and reduced mean egg weight in only one case (400 g/kg lablab). In trial 1, diets containing 450 g/kg Delta or Emerald mung bean or 300 g/kg Barwon chickpea resulted in 7-9% fewer eggs, 4-5 g/d lower egg mass and 9-10% poorer feed conversion than the control diet ($P<0.05$). Bodyweight gain over the trial period was depressed by 90-150 g ($P<0.05$) in four of the six chickpea treatments. Trends in the data suggested that both Amethyst and Barwon chickpea had a depressing effect on egg mass output when included in the diet at concentrations above 100 g/kg. In trial 2, Koala lablab at 400 g/kg in mash or pelleted diets resulted in markedly lower egg number, egg mass output and feed intake and poorer feed conversion than any other treatment ($P<0.001$) but did not affect body weight gain. For 200 g/kg lablab these comparisons were not quite significant ($P<0.05$). In this trial none of the chickpea (Amethyst) or mung bean (Emerald) treatments differed significantly from the mash or pellet control treatment ($P<0.05$) in respect of egg number, feed intake or feed conversion. However, birds given 450 g/kg mung bean as mash produced less egg mass but gained more bodyweight than the control birds ($P<0.05$). Egg weight was 0.87 g higher ($P<0.05$) when birds were fed pelleted instead of mash diets. Mung bean at 450 g/kg in the pelleted diet resulted in 14% more eggs than the control pellets ($P<0.05$). Although there were no interactions between diet form and diet composition, diets containing 200 or 300 g/kg chickpea tended to depress performance when fed as mash but not when fed as pellets. In trial 3, moderate levels of Caloona or Red Caloona cowpea (125-250 g/kg) or Dooen chickpea (175 g/kg) tended to increase egg number and egg mass output, sometimes significantly, compared to the control diet or diets containing high levels (350-375 g/kg) of these legumes. Decortication of Dooen chick pea tended to adversely affect egg mass output. Body weight gain consistently declined (or body weight loss increased) with increasing dietary levels of legumes. The average yolk colour score of eggs from birds given 375 g/kg Red Caloona cowpea was substantially higher ($P<0.001$) than that of the control treatment.

The results overall suggest that safe dietary concentrations for long term feeding of untreated grain legumes in mash diets for laying hens are (g/kg): Barwon and Amethyst chickpea 100, Dooen chickpea 175, mung bean 300, lablab <100, Caloona cowpea 150, Red Caloona 100. These levels may be increased for short term feeding or if the diet is steam pelleted.

The information provided by this research will primarily benefit stockfeed manufacturers. Mung beans were considered to be of greatest value, followed by cowpeas and chickpeas. Benefits to the egg industry will flow through mainly from the lower cost diets that will ensue from the wider variety of feed ingredients and higher usage levels of these ingredients. The performance results provided some suggestion that inclusion of certain grain legumes at low to moderate concentrations in layer diets may improve production. ANF profiles did not provide a reliable guide to maximum inclusion rates. Reliable, cost effective chemical methods of quantifying ANFs need to be developed, so that diminished productive performance can be related to the presence of a specific dietary factor.

This research plays an important part in the promotion of locally grown products as substitutes for imported protein meals, in particular soybean. The grain legumes studied in this project also show potential for export growth, while at the same time they will command strong interest by the livestock feed sector. A major indirect benefit of this work, therefore, is its contribution to reduced import expenditure and increased export revenue.

Increased knowledge of the particular limitations of different species and cultivars in poultry nutrition should encourage plant breeders to apply appropriate selection pressures to further improve the varieties suited to poultry.

Lablab (cv Koala) appears to be relatively toxic in the raw form; pending further research, it cannot be recommended for high level use in poultry feed without further processing. It may therefore have a lower market value as livestock feed. Legumes are being strongly promoted for their value in crop rotation systems. Grain growers should be aware that Koala lablab appears to be less suitable for poultry feeding than the other grain legumes investigated in this project. Current varieties of mung bean appear to be of greatest value to the poultry industry, having low toxicity, high energy content and an excellent, consistent nutritional profile that complements either wheat or sorghum.

In summary, the greatest impact of this project and related work on the Australian economy is probably its influence on the reduction of imports, expansion of exports, development of local agriculture and the long-term sustainability of the grain industry. To achieve these benefits to the fullest extent it is important to do research within the poultry sector, but the direct benefits to that sector, though significant, may turn out to be comparatively small.

Introduction

Background material for this project was initially researched by Mr Danny Singh, who is the principal investigator in a related pig project funded by the Pig Research and Development Corporation. This material was supplemented by a follow-up search and review by Mr David Robinson. The entire review is reproduced in Appendix I of this report and extracts and summaries of immediate general relevance to the studies conducted in this project appear below.

General background

Traditional sources of protein for livestock are predicted to become increasingly scarce and expensive and are likely to be in short supply within approximately ten years (Farrell 1997). Factors contributing to this shortage include competition with human requirements, expanding intensive livestock industries in Asia and elsewhere and the threat of restrictions on the usage of animal protein sources for feeding livestock. Despite the recent economic downturn in South-east Asia, the developing economies and increasing affluence of most Asian countries, especially China, will create a sharply increasing demand for animal products in the region. The demand for feedstuffs will be further intensified by the increased rate of development of modern intensive systems in contrast to village production methods. The implementation of the GATT agreement and the recent support of ASEAN nations for trade liberalisation will hasten these changes, leading to an urgent need to find alternatives to traditional grains and oilseeds. The increased world-wide demand for protein feed is expected to be met largely by legumes and canola. In Australia, over the medium term, the combined effects of changes in production and rising domestic feed demand are likely to reduce Australia's ability to be a net exporter of feedgrains. Feedgrain production in Australia is forecast to decline over the medium term. Consequently there is a high probability that Australia will have to import significant quantities of feedgrains in the near future. This trend could be slowed or reversed by a concerted research effort into the use of alternative local sources of protein.

In recent years the range of high-protein plants being grown in Australia has increased substantially. This has been brought about by the development of new varieties with higher yields, improved adaptation to Australian conditions and better acceptability through improved nutritional status (such as fatty acid and ANF profiles); by the expansion of export markets; and through a keener appreciation of the benefits of crop rotation and alternative cropping systems. Yet despite the comprehensive range of crops being grown, there has been an increasing reliance on imported feedstuffs for livestock, a trend which is expected to gather pace over the next ten years. In 1988-89 Australia imported 25,600 tonnes of soybean meal but by 1994-95 this figure had increased to approximately 190,000 tonnes and was estimated to have peaked in the late 1990s at close to 300,000 tonnes (Australian Oilseeds Federation and Bowman Richards & Associates, Melbourne). Over three quarters of all imported soybean meal is used by the poultry industry, the main consumer being the chicken meat industry, where demand has been increasing since 1990 by approximately 16,000 tonnes per year. However the trend in soybean meal imports has recently shown distinct signs of reversing, locally grown canola meal being the chief substitute for soybean when prices are favourable. Australia undoubtedly has the capacity for large-scale production of feedstuffs that could replace imported protein meals, with grain legumes and canola showing the greatest potential for development. A wide variety of legume species and cultivars is available, most of which have the ability to make a valuable contribution to sustainable agricultural systems.

Grain legumes

The steep rise in the use of grain legumes in the intensive livestock industry in Australia began in the 1980s. Currently Australia’s legume production - chiefly sweet lupins, field peas, faba beans and chick peas - comes mostly from the southern states. However there is a need to shift some of this production northwards, for two reasons. First, there is a distinct asynchrony of supply and demand for grain legumes in northern Australia, due mainly to the high freight cost of delivering grain legumes from the southern states. Secondly, northern Australia does appear to have soils and climatic conditions which are suitable for growing certain grain legumes and which can sustain high yields. This can be inferred both from current research on legumes in Australia and from the successful cultivation of a wide variety of legumes in similar environments overseas. Thus there is a considerable incentive to identify suitable grain legumes for growers and poultry producers in Queensland.

The potential of specific grain legumes for use as poultry feed depends largely on their agronomic prospects and relevance to sustainable agriculture. In Queensland the introduction of pulses is considered a high priority strategy by the DPI and the Grains Research and Development Council. At present pulses are grown on only about 5% of the cultivated area. Agronomically, it is considered that chickpea, mung bean and to a lesser extent faba bean offer the best prospects, with pigeon pea, cowpea, field pea, white lupin, lentil and lablab being other possibilities (Brinsmeade, 1997). Currently in Queensland several wheat crops can be grown between each legume crop, while in Western Australia two wheat crops is the norm. Agronomists are encouraging more regular rotation of grain legumes with wheat crops to break the disease cycle.

Pengelly and Conway (1998) point out that long-term cropping has reduced soil fertility in the northern grain belt, resulting in corresponding declines in grain yield and quality. This deteriorating situation has serious implications for the economic and environmental sustainability of the grain industries in the region. Of the various options available to arrest the decline in soil fertility, increasing the legume content of pastures in crop rotations appears to be the most cost-effective way to further improve cereal crop yields and protein content. Pulses such as chickpea and mungbean can be included in rotations, or forage or ley legumes can be incorporated in the cropping system. The most commonly used tropical ley legume is lablab (*Lablab purpureus*). A joint CSIRO/Queensland DPI project is evaluating various alternative tropical species, either as self-regenerating annuals or as perennial ley pasture legumes for central and southern Queensland. So far the project has identified a number of promising species and confirmed that tropical legumes can produce considerable dry matter on the major cropping soils of the northern grain belt and persist for at least two years under the range of environments encountered.

Another important consideration for the future of pulses in Australia is the development of food products for the local market. This country has one of the lowest *per capita* levels of pulse consumption in the world, being only half that of the UK and one fifth that of India. Most of the locally grown pulse that is not exported is thus used for animal feed.

In reviewing the literature relevant to this project, a number of legumes, including mung bean (*Vigna radiata*), chickpea (*Cicer arietinum*), lablab (*Lablab purpureus*) and cowpea (*Vigna unguiculata*), were identified as providing the greatest potential for increased use in intensive livestock. New varieties are becoming available which are suitable for cultivation in a wide range of conditions, especially in the warmer northern regions. However, little is known of their nutritional value for poultry or of the extent to which anti-nutritional factors may interfere with their utilisation by poultry and other livestock. Many grain legumes have a rather low sulphur amino acid content, but since methionine can be added to diets quite economically this is no longer a major concern.

Mung beans typically contain 230-260 g/kg protein and about 0.7-1.0 g/kg fat and appear to have very low levels of antinutritional factors. The amino acid profile of mung bean is comparable to that of soybean and it is rich in vitamins A, B1, B2, C and niacin. Limited studies on mung bean as a feed source for poultry and pigs indicate that it is approximately half as valuable as solvent extracted soybean meal. Currently mung bean production in Queensland and Northern NSW is probably around 30,000 tonnes/year. Of this, 10-20% is used for stock feed at $150-200/t, 50-70% for processing at $400-450/t and the rest is sold as prime sprouting and cooking beans at $650-700/t. There has been a concerted effort by the Australian Mung bean Association to promote the growing and marketing of the crop. Genetic improvement has recently concentrated on yield and resistance to diseases such as leaf spot. Little research has been conducted on varietal differences in terms of nutritive value of the crop and yield. The literature suggests that the protein content of the seed is variable.

The area sown to chickpea in Australia is expected to double in the next five years, and new higher yielding varieties are soon to be released. Production of chickpea in Queensland is currently around 40,000 tonnes and this is expected to increase dramatically over the next five years. At least 10-20% will go to feed grade. Chickpeas occur in a very wide range of varieties most of which are relatively free from anti-nutritional factors, and their protein digestibility is generally high in comparison to other pulses. With its high fat digestibility, chickpea is becoming useful as a protein and energy source for all classes of poultry. There is some information on a few current popular varieties of chickpea but limited data on the varietal differences in terms of its nutritive value and yield. Some research on chickpea in both layers and meat chickens has been done at the QPRDC with promising results. When included in a layer diet at 250 g/kg chick pea (cv Amethyst) supported similar performance to the control diet.

Lablab (dolichos or hyacinth bean), an annual robust twiner native to India, is cultivated mainly for its edible seeds. The pods and seeds contain small quantities of a cyanogenic glycoside, as well as haemagglutinins (Leopoldo *et al* 1994) but have been fed to animals as concentrates without any obvious deleterious effects. It is widely grown in northern Australia as a ley crop for feeding cattle. Recently a new grain variety, Koala, has been released. The production of lablab is likely to increase because it is both a forage and grain legume crop and it fits well in the cropping cycle.

The crude protein value of these three legumes ranges from 200 to 290 g/kg (dry matter basis). There is good knowledge of the agronomic practices required to grow them. While less is known about the value of cowpea, it grows very well in the warmer parts of Australia, has a good nutritional profile and has been used successfully in poultry feeds. Some other grain legumes have excellent nutritional qualities but there are difficulties with cultivating and harvesting them. For these species, a better agronomic foundation needs to be developed before they can be considered for general use in the poultry industry (see Appendix I).

Least cost feed formulation runs indicate that the opportunity cost of the legumes studied in this project, relative to Australian soybean meal with a protein content of 450 g/kg, varies from 37% to 62% of the cost of soyabean, when a wide variety of other ingredients are also available. Of all the common legumes, mung bean and chickpea are best able to act as direct substitutes for soybean meal, easily replacing 80-90 g/kg soybean (plus part of the cereal component) with 200 g/kg legume, with no change in diet cost when the price of the legume is approximately 50-60% of the soybean price. This suggests that there is considerable potential to use these legumes in poultry diets. Most of them are currently grown for human consumption, for which purpose they attract a considerably higher price. However, downgraded material for livestock use is sometimes sold at well under $200/t, making it a worthwhile substitute for soybean and oilseed meals. It is likely that this situation will change, with increasing areas of legumes being cultivated primarily for livestock use, and that the cost to the poultry and stockfeed industry will become highly competitive with other protein sources.

The use of grain legumes for poultry is restrained by uncertainty about the amount and effect of antinutritional factors (ANF) which they may contain (Wiryawan and Dingle, 1999). Legume seeds may contain appreciable amounts of protease inhibitors, principally trypsin and chymotrypsin, and phytohaemagglutinins (D'Mello 1995; Wiseman 1995). Protease inhibitors interfere with the digestion of proteins, causing depressed growth and production. There are differences in ANF content between varieties and cultivars of grain legumes. For example Batterham *et al* (1993) showed that two cultivars of chick pea gave good growth in pigs at 75% dietary inclusion but a cultivar of pigeon pea (Hunt) gave a reduction in growth at 25% of the diet. ANFs can be reduced and nutritional quality improved by plant breeding, dehulling, heat treatment or supplementation of diets with enzymes. Early harvesting also results in seeds with lower ANF content. Although total yield is lower, green legume seeds of some species have their uses in the human food industry, their nutritional properties are usually superior to mature pulses, and it may be possible to select varieties which are better suited to early harvesting. (Pigeon pea provides an example, described in Appendix I). Problems with chemical evaluation of ANFs in feedstuffs include differences in methodology and interpretation of results. The effects of common ANFs, such as TIA and tannins, on layer performance are unclear (Huisman 1991).

This project was run during the timeframe of another, larger project on the use of grain legumes for pigs in northern Australia. This research project entitled “Alternative protein sources from legumes for pigs” was supported by the PRDC and included the following objectives:

1. To identify the single, most common cultivar of each of the target grain legumes that has the potential to be included in pig diets.
2. To chemically characterise the selected cultivars in respect of protein, fat, gross energy, amino acids, crude fibre, ash, dry matter and other components
3. To use digestibility studies to further characterise energy and amino acid *in vitro* values.
4. To screen the legumes for anti-nutritional factors (such as trypsin and chymotrypsin inhibitors), quantifying the amounts present and determining the endogenous protein loss when diets containing these legumes are fed to pigs.
5. To determine upper inclusion levels of the legumes for pigs

The poultry project utilised some of the same batches of legumes and some of the laboratory data obtained in the pig project.

Objectives

The aim of this project was to broaden the base of locally available vegetable protein sources that can be profitably included in the diet of layers. In addition to their nutritional potential for poultry, the criteria employed for selection of materials for laying hen studies included potential for development or cultivation in the subtropical and tropical regions of Australia, contribution to sustainable agriculture and the existence of export markets. The objective was achieved by identifying and evaluating suitable recently introduced cultivars of grain legumes in laying hen trials, complemented by metabolisable energy determinations and chemical analyses to ascertain nutrient and anti-nutritional factor profiles. The trial work aimed to establish maximum feasible concentrations of these legumes (varieties of mungbean, chickpea, lablab and cowpea) in layer diets when included in the raw form, or with only minimal treatment (such as decortication). A further aim was to attempt to relate laying performance to the levels of antinutritional factors present in the materials. It was originally intended to evaluate legumes of the same cultivars grown at different sites. However laboratory analyses indicated that there was little effect of site on chemical composition, and after discussion with RIRDC it was decided to progress the studies with chickpeas and cowpeas rather than conduct performance studies on cultivars grown at different sites.

This project was conducted in parallel with a similar project on pigs, supported by the Pig Research and Development Corporation.

Methodology

Background research and selection of experimental materials

Comprehensive background research, consultation with agronomists and a thorough literature review were conducted with the aim of identifying, first, a general class of vegetable protein sources meriting investigation and, secondly, particular species and cultivars within that class able to meet a number of selection criteria. These criteria included availability, yield, adaptability, suitability for Queensland conditions, cultivation requirements, use in other countries and export potential, genetic progress and expectations, economics and contribution to sustainable agriculture. A limited amount of nutritional data was also necessary to facilitate selection; in particular it was considered an advantage if there was information on chemical composition or livestock performance indicating suitability for inclusion in layer diets, preferably without any need for costly further processing (e.g. to eliminate toxic components).

As a result of this search, legumes were identified as the class of vegetable proteins having the greatest potential for development. Within this class a number of species were initially selected for possible investigation, including mungbean, chickpea, lablab, cowpea, pigeon pea and adzuki bean. As it was an aim of this project to study and promote the use of grain legumes in the raw form, pigeon pea was subsequently eliminated because considerable research on the composition of Australian varieties had already been conducted which indicated the presence of high levels of trypsin inhibitors. In addition harvesting of pigeon pea is more difficult than with some other legumes. Similarly, adzuki beans were also eliminated because of their rather high ANF content and because they are relatively difficult to grow.

Recently released cultivars were then selected mainly on the basis of their agronomic characteristics (see Appendix I). Table 1 lists the experimental materials and the types of dietary presentation used in the performance trials. It had been intended also to compare the performance of birds using identical legumes grown at different sites, but chemical analyses (reported below) indicated that differences in nutrient and ANF composition due to site were small, suggesting that performance would be little affected by site. This aspect was therefore not pursued.

Table 1. Grain legumes studied, and presentation methods used in the performance trials

Species/type	Cultivar	Presentation methods
Chickpea (Desi type) *Cicer arietinum*	Amethyst	Mash and steam pelleted diets
	Barwon	Mash diets
	Dooen	Intact and decorticated
Mung bean *Vigna radiata*	Emerald	Mash and steam pelleted diets
	Delta	Mash diets
Lablab (dolichos) *Lablab purpureus*	Koala	Mash diets
Cowpea *Vigna unguiculata*	Caloona	Mash diets
	Red Caloona	Mash diets

Description of cultivars

Chickpea cv Amethyst.
A tall, short season, early to medium maturing Desi type variety, more tolerant to water logging than Tyson chickpea. Best suited to the 400-450 mm rainfall zone.

Chickpea cv Barwon.
A late flowering Desi variety with a larger seed than Amethyst, moderately tolerant of dry conditions and water logging. Resistant to *Phytophthora* root and stem rot, a disease of chickpeas especially common in northern New South Wales.

Chickpea cv Dooen.
A tall, long season, early to medium maturing Desi variety, less tolerant to drought than Tyson. Best suited to higher rainfall zones (over 400 mm). Grows very well on the Darling Downs.

Mung bean cv Delta.
A tall, erect, early maturing variety, with a good synchrony of maturity, bright green, rather soft seeds suitable for sprouting, and moderate resistance to powdery mildew. Extensive trials in Queensland and northern New South Wales in 1995-97 indicate better average yields than Berken or Emerald.

Mung bean cv Emerald.
Currently having the largest share of the Australian mung bean market, this variety arose in 1992 (registered 1994) from selection between lines grown at Lawes and Dalby. A tall variety with rather hard seeds that are very uniform in size and shape. Slightly later maturing than Berken and Delta, and moderately resistant to powdery mildew. Trials in Queensland and northern New South Wales indicate better average yields than Berken.

Cowpea cv Caloona.
An erect, short duration, drought tolerant variety. Developed in the 1960's as a *Phytophthora*-resistant line of the then popular variety, Poona, but subsequently became susceptible to damage by some races of *Phytophthora* stem rot, which attacks cowpeas especially in the wetter coastal and subcoastal regions.

Cowpea cv Red Caloona.
Similar to Caloona but with a red seed coat. Developed by interbreeding Caloona with Chinese Red, a *Phytophthora*-resistant variety, Red Caloona is resistant to most of the pathogenic forms of *Phytophthora.*

Lablab cv Koala.
This was developed in Dubbo from a line introduced from France by QDPI. It was bred for its ability to grow and set seed in cooler areas, but it does well in tropical areas. It is a short season, early maturing variety with an upright habit, resistant to *Phytophthora* root and stem rot.

Experimentation

Laboratory analyses

Chemical analyses of all mung bean and lablab and two of the chickpea varieties used for these studies, as well as some varieties not used in the performance trials, were done in the parallel pig research project. The first two poultry trials used materials from the same batches as used in the pig research, and a comparison of the pig and poultry performance results will be made on completion of the latter project. Dry matter, protein (N x 6.25), fibre , ether extract, fat and amino acids were determined for all materials, and starch, calcium and phosphorus were also determined for the majority. Antinutritional factor (ANF) determinations included trypsin inhibitor activity (TIA), chymotrypsin inhibitor activity, condensed tannins, carbohydrate groups, *in vitro* viscosity and phytate.

Dry matter, ash, calcium, phosphorus, ether extract and nitrogen were determined by the methods of the AOAC (1992). Amino acid analyses were undertaken by ion-exchange chromatography (Waters HPLC) after hydrolysis with 6M hydrochloric acid at 110^{o}C for 18 h under reflux conditions. Cystine and methionine were determined as cysteic acid and methionine sulphone respectively, following performic acid oxidation. Tryptophan was measured by alkaline hydrolysis on reverse phase C18 column chromatography.

TIA and chymotrypsin inhibitor activity were determined by the methods of Kakade *et al* (1974). *In vitro* viscosity was measured by the method of Bedford and Classen (1993). Non-starch polysaccharide assay used the method of Choct and Annison (1992). Condensed tannins were determined by the method of Perez-Maldonado and Norton (1996). However, for the tannin results in Table 13 a *Leucaena* standard was used instead of the preferred CT standard because the cost of setting up the latter was prohibitive.

Metabolism studies

The apparent metabolisable energy content (AME) of the experimental legumes was determined either by a modification of the rapid AME method using cockerels (Farrell *et al*, 1991) or the classical total collection method using some of the same hens used in the performance trial. These studies were completed after the performance trials, for which the diets were formulated using nominal ME values.

For the rapid AME method, individually caged cockerels that had been trained to consume most of their daily feed requirement within one hour were used. A basal diet suitable for cockerels was used for maintaining the cockerels and for the control group. The test diets comprised exactly 50% basal diet and 50% of the material whose AME was being determined. All diets were pelleted and each was fed to six cockerels. Prior to the day on which the test diets were presented, the cockerels were given only small fixed amounts of food. The test diets were then given during two 30-minute periods separated by a 20-minute rest period. All excreta voided over the following 42 hours were collected, oven dried at 70 ^{o}C, finely ground, mixed and subsampled. Gross energy of the feed and excreta were measured by combustion in an AC-350 Leco adiabatic bomb calorimeter. AME values were then calculated using the following formula after converting all data to an as fed basis:

AME = { (Feed intake x feed GE) – (Excreta output x excreta GE) } / Feed intake

For the classical method, individually caged hens that were well acclimatised to diets similar to those to be tested were used. Hens laying at a similar rate were selected. A conventional layer diet was used for the control group and the other diets were prepared by replacing exactly one third of the non-limestone component of the control diet by the test material. The hens were fed these diets for a seven-day period and excreta were quantitatively collected from a tray beneath each cage on each of the last four days of the bioassay period. All excreta were rapidly frozen after collection, the four days' collections being combined. Feed intake was measured over the same 96-h period over which the excreta were collected. All diets were fed in mash form and each was fed to seven hens. The drying and GE determination procedures were the same as for the rapid AME method. The AME calculation was modified to take account of the constant limestone component of the diets.

Performance trials

As it was not feasible to include all the required treatments in a single trial, three successive trials were conducted. IsaBrown pullets were used for all trials. These were purchased as day-old chicks from a commercial hatchery (Baiada, Tamworth) and were vaccinated according to recommended schedules for Marek's disease, infectious bronchitis, infectious laryngotracheitis, fowl pox and avian encephalomyelitis. In the rearing phase chicks were brooded until four to five weeks of age in electrically heated multi-tier wire-floor brooders and were then transported to single-tier wire-floor grower cages.

At 17-18 weeks of age the pullets were moved to single-level cages housed in a conventional poultry building provided with adjustable shutters and ridge-vent, and thermostatically controlled fans and foggers. Trials 1 and 2 used the same birds, which were re-randomised for the second trial after a one month rest period. In these trials the experimental units were groups of 7-8 birds accommodated in two-bird cages. In trial 3 a new batch of pullets was used and the experimental units were single birds accommodated in individual cages. The birds in each cage had continuous access to two drinker nipples and the experimental diets were fed *ad libitum*. A day-length of 15½ hours was provided throughout the laying period by a combination of natural daylight and tungsten filament lights.

In each trial, the selected cultivars were included in nutritionally balanced layer diets at a range of concentrations determined on the basis of the laboratory information and existing knowledge of layer (or broiler) responses to the species of legume being tested. Concentrations higher and lower than previously indicated maxima were used. All diets were formulated to the specifications shown in Table 2 and were calculated to be isoenergetic on the basis of published ME values for ingredients.

Table 2. Specifications of all diets used in the performance trials

Nutrient	Minimum	Maximum
Estimated ME (MJ/kg)	11.5	11.5
Protein (g/kg)	160	170 (180 in trial 2)
Calcium (g/kg)	36.0	38.0
Total phosphorus (g/kg)	5.0	7.5
Available phosphorus (g/kg)	3.0	4.5
Sodium (g/kg)	1.5	1.8
Chloride (g/kg)	1.4	1.9
Linoleic acid (g/kg)	10.0 (8.5 in trial 3)	12.0
Arginine (g/kg)	7.4	
Histidine (g/kg)	2.1	
Isoleucine (g/kg)	5.9	
Leucine (g/kg)	9.0	
Lysine (g/kg)	7.7	
Methionine (g/kg)	3.8	
Methionine + cystine (g/kg)	6.7	
Phenylalanine + tyrosine (g/kg)	8.5	
Threonine (g/kg)	4.9	
Tryptophan (g/kg)	1.7	
Valine (g/kg)	5.9	

Each trial ran for approximately four months. Measurements included mortality, daily egg number, fortnightly egg weight, monthly feed intake, body weight at start and finish, monthly egg specific gravity (water displacement method) and one reading of egg yolk colour (Roche fan score). Data were statistically analysed by analysis of variance using Statistix or Genstat packages.

Trial 1

Two cultivars of chickpea (Amethyst and Barwon) and two of mung bean (Delta and Emerald), grown near Dalby in southern Queensland, were evaluated in untreated form. Each cultivar was included in mash diets at three concentrations: chickpea at 100, 200 and 300g/kg, and mung bean at 150, 300 and 450g/kg. There was also a control diet without grain legumes. The compositions of the control diet and the diets containing chickpea cv Amethyst and mung bean cv Delta are shown in Table 3. The diets containing the other legume cultivars differed only slightly from these.

Each of the thirteen diets was fed *ad libitum* for a 16-week period to seven groups of hens in a randomised block design. Each group comprised eight birds accommodated in four adjacent two-bird cages served by a common feed trough.

Table 3. Composition of experimental diets used in Trial 1 (g/kg)

Ingredient	Control	Amethyst chickpea			Delta mung bean		
		10%	20%	30%	15%	30%	45%
Sorghum	566	511	457	386	496	419	320
Wheat	100	100	100	100	100	100	100
Soybean (48%)	164	124	85.5	70	90	27.5	-
Sunflower (32%)	38	32	24	9	31	20	-
Meat & bone (50%)	36	37	38	39	37	38	26
Chickpea	-	100	200	300	-	-	-
Mung bean	-	-	-	-	150	300	450
Tallow	-	-	-	-	-	-	3.6
Blended oil	2.8	2.4	2.0	2.1	1.9	1.3	1.2
Limestone	84	84	83	83	84	84	85
Dical phosphate	3.0	3.0	3.0	3.0	3.0	3.0	6.5
Salt	1.2	1.2	1.2	1.2	1.9	1.9	1.9
Sodium bicarb	0.5	0.5	0.5	0.5	0.8	0.8	0.8
Methionine	1.4	2.0	2.6	3.1	1.9	2.4	2.6
Lysine	-	-	-	-	0.2	-	-
Tryptosine	-	0.5	0.8	0.8	-	-	-
Choline chloride	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Mineral premix	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Vitamin premix	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Yolk pigment	0.04	0.04	0.04	0.04	0.04	0.04	0.04
TOTAL	**999.8**	**1000.0**	**1000.0**	**1000.1**	**1000.1**	**1000.3**	**1000.0**

Trial 2

The materials tested in this trial were chickpea cv Amethyst and mung bean cv Emerald from the same sources as those used in trial 1, and lablab cv Koala grown at the Hermitage research station near Warwick. The test materials were included in mash and steam-pelleted diets: chick pea at 200 and 300g/kg, mung bean at 300 and 450g/kg and lablab at 100 (mash only), 200 and 400g/kg (Table 4). There were also mash and pellet control treatments without grain legumes and all diets were formulated to similar nutrient specifications. Steam pelleting was carried out with a custom-built 3-t/h pelleter (Palmer Engineering, Griffith) at a temperature of 75-80 ^{o}C.

Table 4. Treatments applied in Trial 2

Tr no.	Species	Cultivar	Level in diet (g/kg)	Diet form
1	Nil	-	-	mash
2	Nil	-	-	steam-pelleted
3	Lablab	Koala	100	mash
4	Lablab	Koala	200	mash
5	Lablab	Koala	200	steam-pelleted
6	Lablab	Koala	400	mash
7	Lablab	Koala	400	steam-pelleted
8	Chickpea	Amethyst	200	mash
9	Chickpea	Amethyst	200	steam-pelleted
10	Chickpea	Amethyst	300	mash
11	Chickpea	Amethyst	300	steam-pelleted
12	Mungbean	Emerald	300	mash
13	Mungbean	Emerald	300	steam-pelleted
14	Mungbean	Emerald	450	mash
15	Mungbean	Emerald	450	steam-pelleted

The compositions of the experimental diets are shown in Tables 5 and 6. Pelleted diets had the same composition as the corresponding mash diets. Each of the fifteen diets was fed *ad libitum* to six groups of hens in a randomised block design. Each group comprised seven birds accommodated in four adjacent two-bird cages served by a common feed trough. Following an adjustment period to accustom the birds to pellets, all diets were fed for a 16-week period, except for the lablab diets which were fed for a 12-week period (as only a limited amount of lablab was available).

Table 5. Composition of control and lablab diets used in Trial 2 (g/kg)

Ingredient	Control diet	Lablab diets		
Inclusion level →		10%	20%	40%
Diet nos. →	1 & 2	3	4 & 5	6 & 7
Sorghum	594.17	534.44	474.44	337.11
Wheat	100.00	100.00	100.00	100.00
Soybean meal (48%)	79.00	66.44	54.00	5.78
Sunflower meal (32%)	91.67	63.11	34.67	-
Meat & bone meal (50%)	35.50	36.44	37.56	62.67
Ground lablab (Koala)	-	100	200	400
Limestone (granules)	43.33	44.44	44.44	40.00
Limestone (powder)	43.83	42.89	42.89	40.22
Blended veg. oil	1.067	1.267	1.489	4.489
Salt	1.500	1.489	1.489	1.200
Sodium bicarbonate	0.800	0.800	0.800	0.800
DL-methionine	2.067	2.356	2.667	3.178
L-lysine	2.667	1.822	1.000	-
Choline chloride	0.450	0.450	0.450	0.450
Mineral premix	1	1	1	1
Vitamin premix	1	1	1	1
Yolk pigment premix	2	2	2	2

Table 6. Composition of chickpea and mung bean diets used in Trial 2 (g/kg)

Ingredient	Chickpea diets		Mung bean diets	
Inclusion level →	20%	30%	30%	45%
Diet nos. →	8 & 9	10 & 11	12 & 13	14 & 15
Sorghum	454.50	385.00	414.00	320.50
Wheat	100.00	100.00	100.00	100.00
Soybean meal (48%)	59.50	49.67	9.833	-
Sunflower meal (32%)	50.33	29.67	40.83	1.00
Meat & bone meal (50%)	37.17	38.00	37.33	24.17
Ground chickpea (Amethyst)	200	300	-	-
Ground mung bean (Emerald)	-	-	300	450
Limestone (granules)	43.33	43.33	43.33	43.33
Limestone (powder)	43.00	42.50	43.67	45.17
Blended veg. oil	1.417	1.600	0.917	1.283
Dicalcium phosphate	-	-	-	4.200
Salt	1.333	1.083	1.833	2.333
Sodium bicarbonate	0.800	0.800	0.800	0.800
DL-methionine	2.883	3.283	2.617	2.817
L-lysine	1.250	0.550	0.333	-
Choline chloride	0.450	0.450	0.450	0.450
Mineral premix	1	1	1	1
Vitamin premix	1	1	1	1
Yolk pigment premix	2	2	2	2

Trial 3

The materials tested in this trial were cowpea cv Caloona, cowpea cv Red Caloona and chickpea cv Dooen, all grown at unknown sites in the Darling Downs. A portion of the batch of chickpea was decorticated and a comparison of decorticated and entire chickpea was made at two levels of inclusion. Each of the cowpea cultivars was included in mash diets at 125, 250 and 375 g/kg and the decorticated and entire chickpeas were included in mash diets at 175 and 350 g/kg. There were also a control treatment without grain legumes. The compositions of the experimental diets, which were formulated to similar nutrient specifications, are shown in Tables 7 and 8. Each of the eleven diets was fed *ad libitum* to 25 individually caged hens in a 25-block randomised block design. The treatments were continued for a 15-week period.

Table 7. Composition of control and chickpea diets used in Trial 3 (g/kg)

Ingredient	Control diet	Entire chickpea diets		Hulled chickpea diets	
Inclusion level →		**17.5%**	**35%**	**17.5%**	**35%**
Diet nos. →	**1**	**8**	**9**	**10**	**11**
Sorghum	496.11	380.83	354.17	380.83	354.17
Wheat	198.06	198.06	98.06	198.06	98.06
Soybean meal (48%)	94.72	79.44	70.00	79.44	70.00
Sunflower meal (32%)	68.89	29.44	-	29.44	-
Meat & bone meal (50%)	50.00	43.89	26.94	43.89	26.94
Ground entire chickpea	-	175	350	-	-
Ground hulled chickpea	-	-	-	175	350
Limestone (granules)	41.39	42.22	43.33	42.22	43.33
Limestone (powder)	41.39	42.22	43.06	42.22	43.06
Blended veg. oil	-	-	1.222	-	1.222
Dicalcium phosphate	-	-	4.639	-	4.639
Salt	1.306	1.306	1.000	1.306	1.000
Sodium bicarbonate	0.694	0.694	0.500	0.694	0.500
DL-methionine	1.861	1.944	2.083	1.944	2.083
L-lysine	1.111	0.125	-	0.125	-
Tryptosine (lys + tryptophan)	-	0.417	0.528	0.417	0.528
Choline chloride	0.420	0.420	0.420	0.420	0.420
Mineral premix	1	1	1	1	1
Vitamin premix	1	1	1	1	1
Yolk pigment premix	2	2	2	2	2

Table 8. Composition of cowpea diets used in Trial 3 (g/kg)

Ingredient	Red Caloona cowpea			Buff Caloona cowpea		
Inclusion level →	12.5%	25%	37.5%	12.5%	25%	37.5%
Diet nos. →	2	3	4	5	6	7
Sorghum	416.67	358.33	303.33	416.67	358.33	303.33
Wheat	198.06	172.78	148.06	198.06	172.78	148.06
Soybean meal (48%)	60.28	23.33	-	60.28	23.33	-
Sunflower meal (32%)	58.61	55.00	43.06	58.61	55.00	43.06
Meat & bone meal (50%)	50.00	50.00	34.72	50.00	50.00	34.72
Ground Red Caloona cowpea	125	250	375	-	-	-
Ground Buff Caloona cowpea	-	-	-	125	250	375
Limestone (granules)	41.11	40.83	42.78	41.11	40.83	42.78
Limestone (powder)	41.11	40.83	42.78	41.11	40.83	42.78
Blended veg. oil	-	0.611	1.417	-	0.611	1.417
Dicalcium phosphate	-	-	0.722	-	-	0.722
Salt	1.306	1.000	1.000	1.306	1.000	1.000
Sodium bicarbonate	0.694	0.500	0.500	0.694	0.500	0.500
DL-methionine	1.944	2.028	2.167	1.944	2.028	2.167
L-lysine	0.722	0.278	-	0.722	0.278	-
Tryptosine (lys + trypophan)	0.167	-	-	0.167	-	-
Choline chloride	0.420	0.420	0.420	0.420	0.420	0.420
Mineral premix	1	1	1	1	1	1
Vitamin premix	1	1	1	1	1	1
Yolk pigment premix	2	2	2	2	2	2

Detailed Results

Laboratory analyses

Nutrients

Tables 9-11 show the nutrient compositions of the legumes used in the performance trials and, where applicable, the same varieties grown at different sites.

The mung bean samples (Table 10) contained more protein, starch, phosphorus, lysine, methionine, iso-leucine, valine, threonine and tryptophan than the chickpea (Table 9), and less fibre. Within species, the two varieties of each legume were very similar in nutrient composition, with the exception that sulphur amino acid levels were much lower in Amethyst chickpea than in Barwon (Table 9). Dooen chickpea (Table 11) had a similar composition to Barwon (including sulphur amino acid content).

Koala lablab (Table 10) contained more protein than chickpea but somewhat less lysine and tryptophan. Its sulphur amino acid content was considerably lower than that of mung bean or Barwon chickpea.

Chickpeas grown at the Hermitage site had lower protein levels and lower levels of most amino acids compared with those grown at the Dalby site. The mung bean and lablab varieties showed few significant differences between sites.

Caloona and Red Caloona cowpeas (Table 11) were very similar in composition, although the latter had a lower total sulphur amino acid content. The composition of both cowpea varieties was quite similar to that of mung bean, but their fat content was lower.

Decortication of chickpeas (Table 11) resulted in a product containing much less fibre, more protein and slightly higher concentrations of all amino acids.

Table 9. Nutrient composition of chickpea cvs Amethyst and Barwon grown concurrently at two sites

Legume	Chickpea			
Variety	Amethyst	Amethyst	Barwon	Barwon
Site	Dalby	Hermitage*	Dalby	Hermitage*
Nutrient %				
Dry matter	88.6	88.7	88.3	88.8
Protein	21.62	19.43	21.10	18.20
Fat	4.16	4.08	4.5	4.26
Ash	2.92	3.10	2.74	3.02
Phosphorous	0.38	0.37	0.34	0.34
Calcium	0.21	0.15	0.18	0.12
GE (MJ/kg) 1	17.10	16.94	17.04	16.87
2	17.12	-	17.15	-
Starch	27.11	31.84	29.58	32.86
Fibre	10.37	10.82	9.27	9.68
Amino acid g/kg				
Alanine	7.02	6.14	7.15	6.61
Arginine	19.50	13.81	20.19	15.60
Aspartic acid	19.55	17.06	19.33	18.30
Cystine	1.09	1.14	2.80	3.15
Glutamic acid	28.72	24.47	27.66	26.26
Glycine	6.71	5.95	7.02	6.54
Histidine	4.20	4.09	4.99	4.78
Isoleucine	7.12	6.18	7.23	6.79
Leucine	12.68	11.25	12.53	12.17
Lysine	11.43	10.80	11.76	11.73
Methionine	0.46	0.42	2.7	2.65
Phenylalanine	10.06	8.35	10.17	9.46
Proline	8.07	6.37	7.71	6.63
Serine	8.52	7.42	9.09	8.71
Threonine	5.86	5.35	6.27	6.13
Tryptophan	1.90	2.27	2.05	2.15
Tyrosine	4.60	4.09	4.76	4.47
Valine	7.20	6.27	7.32	6.94
Met+Cys	1.55	1.56	5.50	5.80
Phe+Tyr	14.66	12.44	14.93	13.92

* Asterisked materials were not studied in the performance trials

Table 10. Nutrient composition of mungbean cvs Delta and Emerald, and Lablab cv Koala grown concurrently at two sites

Legume	Mung bean				Lablab	
Variety	Delta	Delta	Emerald	Emerald	Koala	Koala
Site	Dalby	Hrmtg*	Dalby	Hrmtg*	M282	M408*
Nutrient %						
Dry matter	88.6	91.3	91.6	89.8	89.2	90.1
Protein	25.19	25.05	25.02	25.36	24.53	24.04
Fat	3.30	3.32	3.20	3.05	3.03	3.60
Ash	0.92	1.26	0.82	1.25	1.22	1.41
Phosphorous	0.47	0.39	0.44	0.40	0.29	0.46
Calcium	0.10	0.09	0.11	0.09	0.08	0.00
GE (MJ/kg) 1	16.85	16.70	16.84	16.80	16.54	16.49
2	17.02	-	16.95	-	15.82	-
Starch	38.20	33.67	37.34	34.14	34.34	35.05
Fibre	4.49	4.22	4.29	4.66	7.54	7.13
Amino acid g/kg						
Alanine	9.23	9.20	9.36	9.23	8.53	8.83
Arginine	15.74	15.89	15.75	15.38	16.36	15.78
Aspartic acid	23.93	23.41	23.41	22.41	20.62	23.40
Cystine	1.84	1.87	1.80	1.69	1.94	2.21
Glutamic acid	27.09	33.72	34.48	33.85	33.49	32.26
Glycine	8.02	7.91	8.04	7.94	8.42	9.24
Histidine	6.39	6.20	6.03	6.12	6.67	6.91
Isoleucine	9.31	8.86	9.18	9.00	7.97	8.72
Leucine	16.64	16.68	16.43	16.69	17.18	17.39
Lysine	15.41	14.64	15.31	14.81	13.21	14.05
Methionine	3.31	3.42	3.23	3.32	1.52	1.50
Phenylalanine	13.05	12.92	12.99	12.88	10.85	11.43
Proline	13.82	13.30	13.59	13.34	14.79	3.44
Serine	11.24	10.96	11.09	11.03	10.81	11.97
Threonine	7.23	7.20	7.10	7.16	7.21	7.77
Tryptophan	2.89	3.44	3.12	3.83	2.38	2.24
Tyrosine	6.17	6.33	6.22	6.32	7.25	7.61
Valine	10.84	10.59	10.72	10.58	9.32	9.60
Met+Cys	5.15	5.29	5.03	5.01	3.45	3.71
Phe+Tyr	19.23	19.25	19.21	19.20	18.10	19.05

* Asterisked materials were not studied in the performance trials

Table 11. Nutrient composition of cowpea cvs Caloona and Red Caloona and chickpea cv Dooen, entire and hulled

Legume	Cowpea		Chickpea	
Variety	Red Caloona	Caloona	Dooen	Hulled Dooen
Nutrient %				
Dry matter	89.6	88.6	89.5	89.9
Protein	22.4	23.04	17.28	19.67
Fat	1.25	1.24	5.10	6.02
Ash	3.58	3.37	2.60	2.34
GE (MJ/kg)	17.24	16.96	16.44	16.73
Fibre	6.00	5.58	9.58	2.79
Amino acid g/kg				
Alanine	8.66	8.74	5.88	7.04
Arginine	15.43	15.27	14.36	16.23
Aspartic Acid	21.05	21.09	14.03	18.17
Cystine	1.89	2.30	2.48	2.72
Glutamic Acid	32.95	33.71	21.93	27.90
Glycine	9.26	9.37	6.50	7.14
Histidine	6.53	6.75	4.20	4.68
Isoleucine	8.24	8.36	6.22	7.23
Leucine	15.81	16.27	12.03	13.93
Lysine	13.72	13.61	9.48	11.70
Methionine	3.02	3.66	2.91	3.08
Phenylalanine	11.76	12.17	9.38	10.76
Proline	8.64	8.72	6.47	7.48
Serine	11.26	11.55	8.99	10.11
Threonine	8.10	8.35	6.15	6.77
Tryptophan	NA	NA	NA	NA
Tyrosine	6.43	6.65	4.45	5.00
Valine	10.11	10.36	6.51	7.51
Met+Cys	4.91	5.96	5.39	5.80
Phe+Tyr	18.19	18.82	13.83	15.76

Antinutritional factors

Results of ANF assays are shown in tables 12 and 13. The two tables represent assays done at different times by the same laboratory.

The first table indicates that *in vitro* viscosity values were higher for mung beans and lablab than for chickpeas or narbon beans, and were particularly high for navy beans. TIA was consistently lower in mung beans than chickpeas or lablab, and higher in Amethyst than in Barwon chickpeas. Chymotrypsin inhibitor activity was present in some chickpea, mung bean and faba bean samples. Condensed tannin levels were higher in cowpeas, faba beans and narbon beans than in other legumes, and were not detected in chickpeas or lablab. Soluble carbohydrate levels were higher in cowpeas and navy beans than in the other legumes. Levels of non-structural carbohydrates were higher in cowpeas and in mung beans from the Dalby site than in other legumes. Both carbohydrate groups were at lower levels in Amethyst chickpeas than in Barwon. Decortication of chickpea appeared to increase the level of insoluble non-starch polysaccharides, most of this apparent increase being due to glucose.

Trypsin inhibitor and chymotrypsin inhibitor values in the second table may not be comparable with values reported in the first table, but agree in suggesting that cowpeas had lower TIA than chickpeas. This table also indicates that chymotrypsin inhibitor activity was substantially higher in whole chickpeas than in decorticated chickpeas. Total condensed tannin levels in chickpeas were very low, a finding which also agrees with the previous table (although the chickpea variety is different), but the condensed tannin content (especially free tannins) of cowpeas was high. Phytate levels were higher in chickpeas than cowpeas.

Table 12. Antinutritional factors in legume varieties used in trials 1 and 2, in the same varieties grown at different sites and in various other legumes

Material (species, variety, site, laboratory ID no.)		Carbohydrates		Viscosity in vitro (CP's)†	Trypsin inhibitor activity (mg/g)	Chymotrypsin inhibitor activity (mg/g)	Condensed tannins (%)
		Soluble (%)	Non-structural (%)				
Chick peas (Amethyst Dalby)	980324	4.3	32.3	2.1	7.1	ND	ND
Chick peas (Amethyst HRS)*	980325	4.6	31.6	2.3	6.8	2.1	ND
Chick peas (Barwon Dalby)	980326	5.0	34.8	2.3	3.8	ND	ND
Chick peas (Barwon HRS)*	980327	5.1	36.6	2.2	4.5	ND	ND
Mungbeans (Emerald Dalby)	981152	5.7	41.8	3.5	1.9	1.40	0.31
Mungbeans (Emerald HRS)*	981700	5.2	35.2	3.7	2.0	2.0	0.26
Mungbeans (Delta Dalby)	981151	5.0	41.2	3.7	2.9	1.89	0.27
Mungbeans (Delta HRS)*	981701	5.1	35.6	3.6	2.3		0.21
Lablab M282	981430	5.6	37.7	4.1	5.5	ND	ND
Lablab M408*	981431	5.8	37.7	3.8	3.8	ND	ND
Cow peas*	982608	7.6	41.4	3.3	3.1	ND	0.80
Faba beans*	982607	5.5	38.5	3.2	ND	0.91	0.98
Narbon beans*	982609	4.9	33.6	2.1	ND	ND	0.70
Navy bean* (Heat treated)	981153	6.5	33.8	15.3	3.4	ND	ND
Water*				1.0		ND	

* Asterisked materials were not studied in the performance trials
† Bedford, M.R. and Classen, H.L. (1993)
The non structural carbohydrates are mainly sugars, dextrins, starch and fructosans.
The *in vitro* viscosity values are a measure of the soluble non-starch polysaccharides.

Table 13. Antinutritional factors in legume varieties used in trial 3

Material	Non-starch polysaccharides (%)		Trypsin inhibitor activity (mg/g)	Chymotrypsin inhibitor activity (mg/g)	Phytate (%)	Condensed tannins (%)	
	Soluble	Insoluble				Free	Bound
Dooen chickpea	<1.0	7.3	1.27	0.24	0.929	ND	0.189
Dooen chickpea (decorticated)	<1.0	14.2	1.93	1.05	0.786	ND	0.036
Caloona cowpea	<1.0	6.8	0.74	0.85	0.454	3.34	0.447
Red Caloona cowpea	<1.0	6.2	1.14	0.44	0.397	2.74	0.367

Metabolism studies

The results of the AME assays are shown in Table 14. The mean AME of both mung bean varieties was higher than that of the chickpea varieties, while the mean AME of the Koala lablab and the cowpea varieties was very low.

Table 14. Apparent metabolisable energy content of legumes used in the performance trials (mean and 95% confidence interval)

Legume and variety	AME (MJ/kg)
Chickpea (Amethyst)[1]	11.64 ± 1.30
Chickpea (Barwon)[1]	11.65 ± 1.42
Chickpea (Dooen, entire)[2]	11.07 ± 0.57
Chickpea (Dooen, decorticated)[2]	11.88 ± 0.79
Mung bean (Delta)[1]	12.34 ± 0.53
Mung bean (Emerald)[1]	12.48 ± 0.94
Lablab (Koala)[2]	8.78 ± 0.75
Cowpea (Caloona)[2]	8.40 ± 1.19
Cowpea (Red Caloona)[2]	9.36 ± 1.15

[1] AME determined by rapid AME method using cockerels
[2] AME determined in laying hens

Performance trials

The birds maintained good health throughout the trials. However in Trial 1 some isolated groups of birds suffered a temporary depression in egg output. This was not associated with any treatment and although appropriate diagnostic tests and management checks were made the cause was not established. Very few deaths occurred during the trials, there were no significant effects of treatments on mortality and nothing to suggest that the death of any bird was due to the experimental treatment. Mortality rates are therefore omitted from the tables of results. For other parameters, least significant differences are tabulated whether or not any significant effect of treatment on that parameter was observed.

Trial 1

Treatment mean performance results over the four-month experimental period are shown in Table 15. Egg weight and egg specific gravity were unaffected by treatment (P<0.05). Egg number and egg mass output were lower (P<0.05) and feed conversion was poorer (P<0.05) in treatment 7 (300 g/kg Barwon chickpea) and treatment 13 (450 g/kg Emerald mung bean) than in treatment 1 (control). Feed conversion was also poorer (P<0.05) in treatment 10 (450 g/kg Delta mung bean) than in the control treatment. Compared to the control treatment, bodyweight gain was lower (P<0.05) at the highest two levels of Amethyst and the low and high levels of Barwon chickpea. Although no other significant differences from the control were observed, there were trends in the data suggesting that both chickpea varieties had a depressing effect on egg mass output when included in the diet at 200 g/kg.

Table 15. Trial 1 - treatment mean performance results[1]

	Treatment: Legume	Variety	Rate (g/kg)	Egg prodn (%)	Egg wt (g)	Egg mass (g/d)	Feed cons (g/d)	Feed conv (g/g)	Body wt gain (g)	Egg spec grav
1	Control	-	-	85.3^{abc}	62.85	53.60^{ab}	113.6^{abc}	2.127^{d}	115^{a}	1.0889
2	Chickpea	Amethyst	100	87.3^{a}	62.32	54.39^{a}	112.5^{bc}	2.073^{d}	59^{abc}	1.0881
3	Chickpea	Amethyst	200	82.0^{abcd}	63.12	51.74^{abc}	112.3^{bc}	2.174^{bcd}	-24^{cd}	1.0880
4	Chickpea	Amethyst	300	83.0^{abcd}	62.14	51.64^{abc}	112.3^{bc}	2.186^{bcd}	-33^{d}	1.0887
5	Chickpea	Barwon	100	85.1^{abc}	62.98	53.56^{ab}	115.7^{ab}	2.163^{cd}	25^{bcd}	1.0890
6	Chickpea	Barwon	200	82.7^{abcd}	62.08	51.33^{abc}	112.4^{bc}	2.193^{bcd}	63^{abc}	1.0891
7	Chickpea	Barwon	300	77.7^{d}	62.66	48.74^{c}	110.5^{c}	2.289^{abc}	11^{bcd}	1.0888
8	M'bean	Delta	150	80.8^{bcd}	61.73	49.84^{bc}	110.8^{bc}	2.235^{abcd}	60^{abc}	1.0893
9	M'bean	Delta	300	86.6^{ab}	62.88	54.44^{a}	117.7^{a}	2.164^{cd}	82^{ab}	1.0879
10	M'bean	Delta	450	79.5^{cd}	62.74	49.87^{bc}	114.3^{abc}	2.314^{ab}	91^{ab}	1.0884
11	M'bean	Emerald	150	85.4^{abc}	62.98	53.79^{a}	112.7^{abc}	2.096^{d}	36^{abcd}	1.0869
12	M'bean	Emerald	300	83.3^{abcd}	63.23	52.61^{ab}	113.6^{abc}	2.165^{cd}	71^{ab}	1.0898
13	M'bean	Emerald	450	78.2^{d}	62.13	48.54^{c}	113.6^{abc}	2.351^{a}	66^{ab}	1.0900
LSD	*(P<0.05)*			*5.90*	*1.52*	*3.84*	*5.1*	*0.140*	*89*	*0.0035*

[1]Means in the same column with any superscript in common are not significantly different (P<0.05)

Trial 2

Treatment mean performance results over the experimental period are shown in Tables 16 and 17. Only mung bean (cv Emerald) at 450g/kg and lablab (cv Koala) at all three concentrations were associated with significantly adverse effects when compared to the control diets. However, the performance of birds given mash diets containing chickpea (cv Amethyst) at 200 and 300 g/kg was similar to that of the birds given lablab at 100 and 200 g/kg and was thus also apparently inferior to that of the control birds.

Mash diets (Table 16).

When fed as mash, the diet containing 400 g/kg lablab resulted in lower egg number, egg mass output and feed intake, and poorer feed efficiency, than any of the other treatments (P<0.001). Average egg weight of birds given the 400 g/kg lablab diet was lower than that of birds given the 100 g/kg lablab diet (P<0.05). Egg mass output and feed intake were higher with the control diet than with any of the lablab diets (P<0.05). Average egg specific gravity of birds given the 200 g/kg lablab diet was higher (P<0.05) than that of the control treatment and several other treatments.

Egg number and egg mass output of birds given the 450 g/kg mung bean diet were lower than with the control or 300 g/kg mung bean diet (P<0.05). Only the birds given 450 g/kg mung bean showed an average gain in bodyweight over the experimental period, and this weight change was significantly different from that of the control birds and several other treatments (P<0.05). Birds given chickpea or lablab at the highest concentrations lost most weight. Diets containing 300 g/kg mung bean or 200 or 300 g/kg chick pea resulted in higher (P<0.05) average yolk colour scores than the control diet.

Comparison of mash and pelleted diets (Table 17).

Inclusion of the legumes in pelleted diets produced similar trends to those observed with mash diets, except in regard to body weight gain. When diets were fed in pelleted form, only birds given lablab at 200 or 400 g/kg lost weight, and this weight change was highly significantly different from that of the control birds (which had the highest average weight gain). The birds given 300 g/kg mung bean as pellets also tended to gain less weight than the pellet control treatment (not quite significant, P<0.05).

There were no significant differences between mash and pellets for egg number, egg mass output, feed intake, feed conversion or egg specific gravity. Egg weight was higher (P<0.05) when birds were fed pelleted instead of mash diets. Mean yolk colour score was higher (P<0.01) for mash than for pelleted diets. Mean body weight gain was positive for the pellet treatment and significantly different from the mean weight loss shown by the mash treatment (P<0.001). When diets were fed as pellets, egg mass output of the 450 g/kg mung bean treatment was higher (P<0.05) than that of the control treatment. Although there were no significant interactions between diet form and diet composition, trends in the data suggest that the mung bean and high level chickpea diets resulted in improved performance when fed as pellets. This is particularly evident when comparison is made to the respective control diets.

Table 16. Trial 2 - comparison of materials in mash diets[1]

Legume and variety	Level (g/kg)	Egg number (%)	Egg weight (g)	Egg mass (g/d)	Feed cons (g/d)	Feed conv (g/g)	Body wt gain (g)	Yolk colour score	Egg specific gravity
Control	-	85.56^{ab}	67.38^{ab}	57.64^{a}	124.14^{ab}	2.154^{b}	-69.0^{b}	12.10^{bc}	1.0817^{b}
Chickpea	200	78.18^{bc}	67.98^{ab}	53.15^{ab}	128.32^{a}	2.414^{b}	-42.7^{ab}	12.80^{ab}	1.0811^{b}
(Amethyst)	300	81.07^{abc}	67.70^{ab}	54.89^{ab}	127.23^{a}	2.318^{b}	-100.0^{b}	13.11^{a}	1.0832^{b}
M'bean	300	86.33^{a}	66.66^{ab}	57.54^{ab}	125.41^{a}	2.180^{b}	-69.0^{b}	12.77^{ab}	1.0842^{ab}
(Emerald)	450	77.05^{c}	66.73^{ab}	51.42^{b}	123.36^{ab}	2.399^{b}	49.7^{a}	12.48^{b}	1.0838^{ab}
Lablab	100	77.02^{c}	68.13^{a}	52.48^{b}	118.7^{b}	2.360^{b}	-24.4^{ab}	12.40^{b}	1.0833^{b}
(Koala)	200	78.74^{abc}	66.67^{ab}	52.50^{b}	119.2^{b}	2.372^{b}	3.4^{ab}	11.73^{c}	1.0870^{a}
	400	45.99^{d}	65.70^{b}	30.22^{c}	103.4^{c}	4.718^{a}	-101.4^{b}	12.15^{bc}	1.0844^{ab}
LSD (P<0.05)		*8.10*	*2.39*	*5.06*	*5.73*	*0.396*	*103.2*	*0.56*	*0.0036*

[1]Means in the same column with any superscript in common are not significantly different (P<0.05)

Table 17. Trial 2 - effect of steam pelleting on egg mass output, egg weight, feed intake and feed conversion[1]

	Diet composition (legume and level, g/kg):							Mean
	Control	Chickpea		Mung bean		Lablab		and LSD
Diet form		200	300	300	450	200	400	(P<0.05)
Egg mass output (g/d)								
Mash	56.36	52.29	53.08	56.57	51.37	50.39	22.36	48.92
Pellets	50.15	50.21	52.95	53.65	57.39	46.24	28.00	48.36
LSD =7.01 [2]								*2.65*
Egg weight (g)								
Mash	67.26	68.08	67.35	66.30	66.90	66.68	65.68	66.89
Pellets	67.48	68.09	69.21	68.24	67.54	67.19	66.40	67.74
LSD = 2.17 [2]								*0.82*
Body weight gain (g)								
Mash	-69.0	-42.7	-100.0	-69.0	49.7	3.4	-101.4	-47.0
Pellets	149.7	81.3	106.3	42.3	81.3	-51.7	-8.4	57.3
LSD = 111.6 [2]								*42.2*
Feed intake (g/d)								
Mash	124.8	128.5	128.1	126.5	124.6	119.2	103.4	122.1
Pellets	122.9	127.8	123.8	130.0	126.9	119.3	102.1	121.8
LSD = 7.97 [2]								*3.01*
Feed conversion (g feed/g egg)								
Mash	2.218	2.466	2.419	2.251	2.495	2.372	4.718	2.706
Pellets	2.496	2.584	2.355	2.443	2.215	2.589	4.191	2.696
LSD = 0.730 [2]								*0.276*
Yolk colour score (Roche)								
Mash	12.10	12.80	13.11[a]	12.77	12.48	11.73	12.15	12.45[a]
Pellets	11.97	12.27	11.90[b]	12.33	12.50	12.10	12.15	12.17[b]
LSD = 0.56 [2]								*0.21*

[1]Means with different superscripts within the same criterion and column are significantly different (P<0.05)
[2]Least significant difference (P<0.05) between any two diet composition x diet form means

Trial 3

Treatment mean performance results over the experimental period are shown in Table 18. There were no differences in average egg weight between treatments. Moderate levels of cowpea or chickpea tended to increase egg production: 250 g/kg Caloona cowpea or 175 g/kg Dooen chickpea resulted in significantly higher (P<0.05) egg numbers than the control diet. Diets containing low to moderate levels of cowpea or chickpea tended to result in higher egg mass output than the control diet or diets containing high levels of these legumes. Egg mass output was significantly lower (P<0.05) with 350 g/kg hulled Dooen chickpea than with several other treatments (excluding the control), and higher (P<0.05) with 175 g/kg Dooen chickpea or 250 g/kg Caloona cowpea than with 375 g/kg cowpea (of either type) or 350 g/kg hulled chick pea.

Feed intake of birds given 350 g/kg hulled Dooen chickpea was lower (P<0.05) than that of most other groups (including the control). Efficiency of feed conversion was generally improved by the inclusion of legumes in the diet. Significantly better feed efficiency than the control (P<0.05) was obtained with 125 g/kg Red Caloona, 250 g/kg Caloona, 175 g/kg entire or hulled Dooen and 350 g/kg hulled Dooen.

Body weight gain consistently declined (or body weight loss increased) with increasing dietary levels of legumes. The highest levels of legumes used resulted in weight losses of 46-112 g over the experimental period. There were a large number of significant and highly significant differences which can be readily observed in Table 18.

Table 18. Trial 3 - treatment mean performance results[1]

Legume	Variety	Level (g/kg)	Egg number (%)	Egg wt (g)	Egg mass (g/d)	Feed cons (g/d)	Feed conv (g/g)	Bwt gain (g)	Egg spec gravity	Yolk colour score
Control	-	-	79.11^{b}	66.88	52.91^{abc}	126.7^{a}	2.563^{a}	136^{a}	1.0881^{ab}	12.21^{bc}
Cowpea	Red Caloona	125	83.74^{ab}	66.64	55.80^{ab}	125.4^{a}	2.314^{b}	38^{b}	1.0857^{c}	12.12^{cd}
Cowpea	Red Caloona	250	80.15^{ab}	68.22	54.68^{abc}	124.8^{a}	2.374^{ab}	-34^{bc}	1.0883^{ab}	12.49^{bc}
Cowpea	Red Caloona	375	78.24^{b}	66.78	52.25^{bc}	122.1^{ab}	2.489^{ab}	-112^{c}	1.0894^{a}	13.03^{a}
Cowpea	Caloona	125	82.57^{ab}	67.63	55.84^{ab}	127.7^{a}	2.392^{ab}	102^{ab}	1.0861^{bc}	12.38^{bc}
Cowpea	Caloona	250	84.55^{a}	66.59	56.30^{a}	126.0a	2.297^{b}	-28^{bc}	1.0902^{a}	12.59^{b}
Cowea	Caloona	375	77.66^{b}	67.03	52.06^{bc}	123.4^{a}	2.431^{ab}	-106^{c}	1.0887^{a}	12.57^{b}
Chickpea	Dooen	175	84.51^{a}	66.97	56.60^{a}	128.2^{a}	2.320^{b}	92^{ab}	1.0892^{a}	12.49^{bc}
Chickpea	Dooen	350	80.32^{ab}	66.12	53.11^{abc}	125.0^{a}	2.455^{ab}	-46^{bc}	1.0863^{bc}	12.51^{bc}
Chickpea	Dooen *(hulled)*	175	82.00^{ab}	66.98	54.92^{abc}	122.2^{ab}	2.289^{b}	76^{ab}	1.0890^{a}	11.82^{d}
Chickpea	Dooen *(hulled)*	350	78.28^{b}	65.96	51.63^{c}	116.5^{b}	2.281^{b}	-88^{c}	1.0896^{a}	12.13^{cd}
LSD (P<0.05)			*5.08*	*2.48*	*3.80*	*6.7*	*0.202*	*95*	*0.0023*	*0.41*

[1]Means in the same column with any superscript in common are not significantly different (P<0.05)

The average specific gravity of eggs from birds in the 125 g/kg cowpea treatments was lower (P<0.05) than with higher levels of cowpea, and lower than in some other treatments. The average yolk colour score of eggs from birds given the highest level of Red Caloona cowpea was higher (P<0.05) than that of any other treatment, and substantially higher (P<0.001) than that of the control treatment. The excreta from birds on this treatment were also reddish in colour. The average yolk colour score of eggs from birds given the low level of hulled chickpea was lower (P<0.01) than that of several other treatments (excluding the control).

Discussion of Results

In this section the grain legumes studied in the project are compared by highlighting the main findings, and an attempt is made to match the laboratory data to the bird performance results.

Nutritional and ANF data

Apart from the very low methionine and cystine levels recorded for Amethyst chickpea, the nutritional data is consistent with previously reported data. Although the nutrient profile of mung beans was slightly superior to that of the other legumes, the nutrient profiles alone provided no reliable guide as to the relative value of the legumes for laying hens (see discussion of performance results). Among the amino acids the greatest variation occurred in methionine, but this was of little account as it is normal practice to offset deficiencies by supplementation of the diet with synthetic methionine, and this was in fact done in the performance trials conducted in this project.

Notwithstanding the small number of comparisons made between varieties of the same species and between cultivation sites, only chickpeas showed any noticeable variation in these respects. The main concern was the low sulphur amino acid content found in chickpea cv Amethyst, which could have been a spurious result despite the similar values found in samples from different sites.

As would be expected, decortication of chickpea cv Dooen resulted in a product with an apparently superior nutrient profile (see discussion of performance results).

The most consistent differences appearing in the ANF profiles were the higher *in vitro* viscosity and lower trypsin inhibitor activity (TIA) in mung beans compared to chickpeas. Lablab had both high viscosity and high TIA values, while cowpeas had relatively low TIA and phytate levels but high levels of soluble carbohydrates and condensed tannins. The low TIA found in cowpeas is not altogether consistent with previous reports that cowpeas contain high TIA levels. However these reports may refer mainly to the black-eye varieties of cowpea, which are quite different in appearance to the varieties used in the present studies. Amethyst chickpea had higher TIA than Barwon, but lower soluble and non-structural carbohydrate levels. There appears to be no previous information on these varieties.

Metabolisable energy

The AME results for the chickpea and mung bean varieties are consistent with other published data, but the values for cowpeas and lablab are approximately 10-25% lower than average. Within species, there were generally only small varietal differences in AMEs determined by the same method. As expected, the AME of decorticated Dooen chickpea was higher than that of the undecorticated seed.

Performance results

The most common effect of feeding grain legumes to laying hens, observed in all trials, was a decline in bodyweight gain (or increase in bodyweight loss) as the concentration of legumes in the diet increased. This effect, however, tended to be negated when steam-pelleted diets were used. While the bodyweight losses were quite small and not necessarily related to performance factors of economic importance, it is possible that over a longer period weight losses would become large enough to directly affect production capability.

Koala lablab was the least satisfactory of the legumes tested. At dietary concentrations of 100-200 g/kg it gave similar performance results to Amethyst chickpea at 200-300 g/kg. There were indications from both trials that mash diets containing Amethyst chickpea at these levels resulted in poorer performance than the control diets, while Barwon chickpea appeared to be slightly less acceptable than Amethyst. On the other hand Amethyst and Barwon chickpea at 100 g/kg, and especially Dooen chickpea at 175 g/kg, resulted in performance equal to or better than that of the controls. There was also evidence that when diets containing 200-300 g/kg chickpea were pelleted, laying performance was equal to or better than that of birds on the control pellets. However, it is difficult to draw conclusions regarding the possible benefits of pelleting, because the egg output of the pellet control group was lower than that of the mash control (though not significantly). Overall, Dooen appeared to be the most useful of the chickpea varieties: disregarding bodyweight loss; performance was similar to the control treatment when included in the diet at 350 g/kg. Hulling the chickpea resulted in no improvement in performance at either the 175 g/kg or the 350 g/kg inclusion rate.

Both varieties of mung bean gave highly satisfactory results when included in mash diets at concentrations up to 300 g/kg, but appeared to depress egg mass output at 450 g/kg. Furthermore when the diet containing 450 g/kg mung beans was fed as pellets, egg mass output was significantly higher than that of the birds on control pellets, and substantially (but not quite significantly) higher than that of the birds given the same diet in mash form.

Both varieties of cowpea at dietary levels of 125 and 250 g/kg tended to increase egg mass output and improve feed efficiency compared to the control treatment, while the highest level (375 g/kg) gave similar performance to the control. Red Caloona also appeared to contribute a substantial amount of red yolk pigment, but the value of this would need to be assessed by including it in a range of diets containing lower concentrations of supplementary red pigment than were used in the present experimental diets. Overall, cowpea appeared to have similar potential to mung bean and Dooen chickpea.

Relation of nutrients and ANFs to laying performance

Although the determined values of metabolisable energy for cowpeas and Koala lablab were considerably lower than the book values used in formulating the experimental diets, this was not reflected in higher feed intakes of these diets. In fact the feed intake of birds fed the lablab diets was lower than that of the controls; consequently low energy intake could have contributed to the lower egg mass output, particularly in the 400 g/kg lablab treatment.

Unless the digestibility of some of the amino acids in the lablab was very low, it is unlikely that deficiencies of amino acids were responsible for the very poor performance of birds on diets containing 400 g/kg lablab, as all experimental diets were formulated to be nutritionally adequate on the basis of their determined chemical composition. Nor was bird performance with lablab diets related to any individual ANF. Although lablab had relatively high *in vitro* viscosity and TIA values, its viscosity was similar to that of mung bean, and TIA was similar to that of Amethyst chickpea. The relatively poor performance of lablab may therefore have been due to the presence of a specific toxin, such as a cyanogenic glycoside or haemagglutinins, which are known to occur in this species.

The low TIA of mung beans compared to chickpeas, however, is a possible explanation of the lack of any adverse effect of mung bean at dietary levels of 200-300 g/kg. Since trypsin inhibitors are destroyed by heat, it is possible that steam pelleting at a temperature of 75-80°C reduced TIA sufficiently to permit inclusion of mung bean at 450 g/kg in pelleted feed without adversely affecting performance (Table 17). On the other hand, although the reported TIA of Barwon chickpea was lower than that of Amethyst, laying performance with diets containing Barwon was certainly no better than with Amethyst.

Bodyweight change appeared to be a more sensitive indicator of "legume toxicity" than egg production or feed intake. Significant bodyweight loss, or decreased gain, often occurred when legumes were included in the diet at high concentrations. The only ANF that was significantly correlated with bodyweight change was TIA. The relationship of bodyweight gain to TIA contribution to the diet was given by:

Trials 1 and 2:	BWG = 60.3 - 50.6TIA	(R^2 = 0.257, P = 0.019)
Trial 3:	BWG = 94.3 - 320.5TIA	(R^2 = 0.462, P = 0.021)

where BWG is the bodyweight gain (g) over a four-month period and TIA is the TIA (mg/kg) contributed to the diet by the legume. However this cannot be taken as evidence of a causal effect of TIA on bodyweight, since changes in TIA are due mainly to changes in dietary level of legume; therefore some other factor present in all the legumes may account for the bodyweight changes. Also the TIA in the variable (0-16.4%) soybean meal content of the diets was not measured and is not taken into account. TIAs of legumes studied in Trial 3 were not comparable with earlier measurements. The laboratory reported difficulties with maintaining consistency in the methodology for both trypsin and chymotrypsin inhibition activity.

As there is no evidence that any of the other ANFs examined in this study had a significant influence on laying performance, it may be inferred that TIA is probably the chief factor limiting the utility of many legumes in poultry diets. However, many grain legumes contain toxins that are peculiar to the species, in some cases overriding the effects of common ANFs and creating a situation unfavourable to the development of simple, standardised laboratory techniques as a means of screening legumes for use as livestock feed.

Implications

This project was originally seen as having relevance to egg producers, stockfeed manufacturers, grain growers and marketers, plant breeders, poultry and crop industry servicers and researchers, and to policy-makers concerned with the development of sustainable agricultural systems, particularly in northern Australia. The considerable amount of laboratory work conducted in the project (partly in lieu of growth assays and autopsies) is also relevant to laboratory services and animal welfare policy. The implications for these groups are discussed in relation to the project objectives and problems to be solved.

Benefits to stockfeed manufacturers

The immediate beneficiaries of this project are stockfeed manufacturers. The information acquired by this research will enable them to confidently use a range of untreated grain legumes in layer diets, many of them at higher concentrations than previously recommended. This will result in lower feed costs when suitable legumes are available at prices that bring them into least cost feed formulations. At present this is only likely to occur when downgraded batches of legumes become available, but it is anticipated that there will be a trend towards growing pulses specifically for use in intensive livestock feed.

Owing to the falling cost of synthetic methionine, deficiencies of sulphur amino acids are no longer a serious drawback. This implies that most grain legumes have excellent amino acid profiles, the next most limiting amino acid after methionine generally being tryptophan, which is also being increasingly used in synthetic form. Mung beans generally contained approximately 50% more tryptophan and valine than chickpeas, 30-50% more lysine, 30% more isoleucine and 20% more threonine. Although ANFs, particularly TIA, appear to be a problem in many legumes, in this study no relationship was seen between any ANF and laying performance. Standard ANF profiles therefore did not provide a reliable guide to maximum inclusion rates.

This research indicates that current varieties of chickpea, mung bean and cowpea are suitable for layer diets at moderate levels of inclusion (10-30%), while lablab may require further development or treatment before it can be used at worthwhile levels. Some feed suppliers currently tend to use excessive quantities of high-risk sources of animal protein such as poultry offal and feather meal. There is also a tendency to use cotton seed and canola meals, when prices are low relative to soybean, at levels which are on the borderline of toxicity. The information on grain legumes may assist in reducing the risks associated with over-dependency on these ingredients.

Benefits to egg producers

The benefits to the egg industry will flow through mainly from the lower cost diets that will ensue from the wider variety of feed ingredients and higher usage levels of these ingredients. In the long run, the industry will benefit through greater stability of supply of vegetable protein ingredients from local sources. The results (particularly in Trial 3) provide some suggestion that inclusion of certain grain legumes at low to moderate concentrations in layer diets may boost production and improve the efficiency of feed utilisation.

Implications for laboratory services and animal welfare policy

A large number of laboratory determinations of ANFs were carried out at considerable cost to this project and the associated PRDC-sponsored project. A typical cost for ANF analysis is $100 per ANF per sample. In terms of predicting the counter-productive effects of the legumes, the results of these analyses were disappointing. From this point of view a small chick growth assay, possibly supplemented by autopsy mainly to measure pancreas weights, would probably have been a much better guide. However, the need to eliminate animal experimentation when possible is recognised, and the ability to relate diminished productive performance to a specific dietary factor is clearly advantageous, as it enables the implementation of appropriate processing treatments (heat, enzymes etc) and plant breeding strategies. There is an urgent need to develop more reliable, repeatable, cost effective analytical techniques to quantify ANFs in feed ingredients.

Impact on protein seed imports and exports

This project represents a contribution to the increasing research effort into the use of alternative feedstuffs for poultry. This research plays an important part in the promotion of locally grown products as substitutes for imported protein meals, in particular soybean. There is strong evidence that the trend to increasing importation of soybean has now been reversed. Canola meal has so far been the main stimulus for this trend, but it is expected that locally produced grain legumes will make an increasingly important contribution, and in the long run will undoubtedly help the Australian livestock feed industry to maintain self sufficiency. Furthermore, pulses remain the staple protein food of an ever expanding population in the developing world, and are also being used in increasing quantities in the developed countries. The grain legumes studied in this project all show potential for export growth, while at the same time (with the possible exception of lablab) they will command strong interest by the livestock feed sector. A major indirect benefit of this work, therefore, is its contribution to reduced import expenditure and increased export revenue.

Relevance for plant breeders and marketers

It is hoped that the increased knowledge of the particular limitations of different species and cultivars in poultry nutrition will encourage plant breeders to apply appropriate selection pressures to further improve the varieties suited to poultry. This work suggests that legume breeders should try to develop low-TIA varieties of chickpea and cowpea, but lablab may first need more work to determine the principal factor limiting its application to poultry feeding. The chief impediments to mung bean utilisation are simply its scarcity and relatively high cost, and current breeding programs aimed at increasing the yield of export-quality seed may not assist the poultry industry, which at present uses downgraded material.

Breeders, growers and exporters can be confident that most varieties of mung beans, chickpeas and cowpeas will be readily utilised by the poultry feed industry, so there will always be a strong local market for consignments that are unsuitable for export. However, lablab (cv Koala) appears to be relatively toxic in the raw form; pending further research, it cannot be recommended for high level use in poultry feed without further processing. It may therefore have a lower market value as livestock feed.

Relevance to grain growers and sustainable agriculture

Legumes are being strongly promoted for their value in crop rotation systems. In particular, legume cultivation provides one of the most promising methods available to arrest the decline in soil fertility in the northern grain belt, caused by long-term cropping practices that have produced a situation with serious implications for the economic and environmental sustainability of the grain industries in that region. A number of legumes have been trialled from an agronomic perspective for their ability to counteract this problem. Of these, lablab appears to be one of the most promising. Koala, with its superior grain production characteristics, may come to be seen as the preferred variety. Grain growers should therefore be aware that from the point of view of poultry feeding, Koala lablab appears to be the least promising of the grain legumes investigated in the current project. Current varieties of mung bean are of greatest value to the poultry industry, having low toxicity, high energy content and an excellent, consistent nutritional profile that complements either wheat or sorghum. Cowpeas also appear to have great potential and expansion of cowpea cultivation would be welcomed by the poultry industry.

In summary, the greatest impact of this project and similar work on the Australian economy is probably its influence on the reduction of imports, expansion of exports, development of local agriculture and the long-term sustainability of the grain industry. To achieve these benefits to the fullest extent it is important to do research within the poultry sector, but the direct benefits to that sector, though significant, may turn out to be comparatively small.

Recommendations

The results of these studies overall indicate that safe feeding levels of untreated legumes in mash diets for laying hens are approximately as shown in Table19.

Table 19. Suggested maximum concentrations of untreated legumes in layer diets

Species/type	Cultivar	Maximum concentration (g/kg)	
		Long term	Short term*
Chickpea (Desi type) *Cicer arietinum*	Amethyst	100	300
	Barwon	100	200
	Dooen	175	300
Mung bean *Vigna radiata*	Emerald	300	300
	Delta	300	300
Lablab (dolichos) *Lablab purpureus*	Koala	<100	100
Cowpea *Vigna unguiculata*	Caloona	150	250
	Red Caloona	100	250

*Three months maximum

In diets which have been steam-pelleted at a temperature of 75-80^{o}C, it may be possible to increase the long term feeding levels by up to 50%.

Further research on Red Caloona cowpea is required to identify the red pigment it contains and determine its value for yolk pigmentation.

The reliability and cost effectiveness of analytical techniques to quantify ANFs in feed ingredients needs to be improved.

Legume breeders need to be made aware of the requirements of the stockfeed industry and encouraged to develop strains that meet these requirements.

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For a more comprehensive bibliography please refer to the review in Appendix I

APPENDIX I

ALTERNATIVE PROTEIN SOURCES FOR LAYERS

A REVIEW

with special consideration for grain legumes

D. Robinson and D.N. Singh

Queensland Poultry Research & Development Centre

Report to the Rural Industries Research and Development Corporation
August 1999

Contents

ALTERNATIVE PROTEIN SOURCES FOR LAYERS

A review with special consideration for grain legumes

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Scope and Criteria

This review forms part of a project supported by the RIRDC and is relevant to egg producers, the stockfeed industry, grain growers and marketers, poultry and crop industry servicers and researchers, and to policy-makers concerned with the development of sustainable agricultural systems in subtropical regions. The review covers a range of plant products which meet the following criteria:

- protein to energy ratio higher than in standard cereals, protein quality complementary to that of cereals
- limited agronomical and nutritional data available
- the product is not currently in regular use for poultry in northern Australia
- existing knowledge of composition and characteristics indicates suitability for inclusion in layer diets
- shows some potential for development, production or cultivation in the subtropical and tropical regions of Australia

Other factors of importance are the market potential of the primary product, cost of production, various agronomic considerations and the likelihood of a requirement for further processing. All materials of animal origin are excluded (for reviews see Bloushy *et al*, 1985 and Ravindran and Blair, 1993) and microbial products are only briefly discussed. Vegetable products already in common use in northern Australia are excluded unless there is potential for greatly increased development and usage in this region. Of particular interest are species or varieties in which the development of agronomically diverse or nutritionally improved cultivars has been occurring, but which currently have limited use for poultry. The main emphasis is on grain legumes or pulses, which were identified early as providing a genetically diverse resource pool that has excellent prospects for exploitation by the stockfeed industry. Although it has potential for further development, Canola is not reviewed here as its potential is well recognised and it is the subject of another current project at this research centre. In fact Canola (ie “double zero” varieties of rapeseed, which contain very low levels of erucic acid and glocosinolates) now accounts for about one third of Australia’s oilseed production. Other standard feedstuffs omitted from this review include all cereal by-products and protein meals made from soybean, sunflower, cottonseed or peanut (groundnut). Among legumes (other than soybean), field peas and lupins have been well researched and are widely grown in the cooler regions of the country. For this reason they are not considered here, although some varieties have potential for cultivation in the subtropical regions.

In the past, the presence of antinutritional factors (ANFs) in many prospective protein sources has acted as a deterrent to their use. Technological advances are gradually overcoming concerns related to ANFs and this trend will undoubtedly continue. With the development of new varieties, improved methods of processing and the use of supplementary feed enzymes, problems associated with ANFs should be less significant in the future.

The following plant materials are considered:

Non-leguminous:

Oil seeds and nuts:
palm by-products, linseed and Linola, safflower, sesame
Aquatic plants:
algae, *Azolla*, duckweed
Fodder trees and shrubs:
Leukaena, *Trichantera*, neem
Single cell proteins

Leguminous:

Adzuki bean (*Vigna angularis*)
Bambara groundnut (*Vigna subterranea, Voandzeia subterranea*)
Black gram (*Vigna mungo*)
Chick pea (*Cicer arietinum*)
Cowpea (*Vigna unguiculata*)
Faba bean (*Vigna faba*)
Guar (cluster bean, *Cyamopsis tetragonoloba*)
Jack bean (*Canavalia ensiformis*)
Lablab (dolichos, hyacinth bean, *Lab lab pupurens*)
Lentils (*Lens culinaris*)
Lima bean (*Phaseolus lunatus*)
Marama bean (*Tylosema esculentum*)
Moth bean (*Vigna aconitifolia*)
Mung bean (*Vigna radiata*)
Narbon bean (Moor’s pea, *Vigna nabonensis*)
Navy bean (*Phaseolus vulgaris*)
Pigeon pea (dhal, *Cajanus cajan*)
Tepary bean (*Phaseolus acutifolius*)
Winged bean (*Psophocarpus tetragonolobus*)

Introduction

Traditional ingredients in poultry diets are forecast to be in short supply within approximately ten years, with sources of protein in particular being predicted to become scarce and expensive. (Farrell, 1997). Factors contributing to this shortage include competition with human requirements, expanding intensive livestock industries in Asia and elsewhere and the threat of restrictions on the usage of animal protein sources for feeding livestock. The developing economies and increasing affluence of most Asian countries, especially China, will create a sharply increasing demand for animal products in the region. The demand for feedstuffs will be further intensified by the increased rate of development of modern intensive systems in contrast to village production methods. The implementation of the GATT agreement and the recent support of ASEAN nations for trade liberalisation will hasten these changes, leading to an urgent need to find alternatives to traditional grains and oilseeds. The increased world-wide demand for protein feed is expected to be met largely by legumes and canola. In Australia, over the medium term, the combined effects of changes in production and rising domestic feed demand are likely to reduce Australia's ability to be a net exporter of feedgrains. Feedgrain production in Australia is forecast to decline over the medium term. Consequently there is a high probability that Australia will have to import significant quantities of feedgrains in the near future. This trend could be slowed or reversed by a concerted research effort into the use of alternative local sources of protein.

In recent years the range of high-protein plants being grown in Australia has increased substantially. This has been brought about by the development of new varieties with higher yields, improved adaptation to Australian conditions and better acceptability through improved nutritional status (such as fatty acid and ANF profiles); by the expansion of export markets; and through a keener appreciation of the benefits of crop rotation and alternative cropping systems. Yet despite the comprehensive range of crops being grown, there has been an increasing reliance on imported feedstuffs for livestock, a trend which is expected to gather pace over the next ten years. In 1988-89 Australia imported 25,600 tonnes of soybean meal but by 1994-95 this figure had increased to approximately 190,000 tonnes and was estimated to have peaked in the late 1990s at close to 300,000 tonnes (Australian Oilseeds Federation and Bowman Richards & Associates, Melbourne). Over three quarters of all imported soybean meal is used by the poultry industry, the main consumer being the chicken meat industry, where demand has been increasing since 1990 by approximately 16,000 tonnes per year. However the trend in soybean meal imports has recently shown distinct signs of reversing, locally grown canola meal being the chief substitute for soybean when prices are favourable. Australia undoubtedly has the capacity for large-scale production of feedstuffs that could replace imported protein meals, with grain legumes and canola showing the greatest potential for development. A wide variety of legume species and cultivars is available, most of which have the ability to make a valuable contribution to sustainable agricultural systems.

Eggs are a traditional staple food, while consumption of chicken meat has increased dramatically world-wide to become, in developed countries, one of most popular protein foods. However, as long as pigs and poultry compete with human beings for food resources, these industries will become increasingly regarded as hostile to sustainable agriculture. It appears to be desirable to improve the utilisation of by-products of the human food industry by intensive livestock while, at the same time, there is a need for agricultural scientists to develop technologies that will permit increases in both product yield and ecological efficiencies. These factors need to be kept in mind in seeking alternative, efficient feed ingredients for poultry.

Following an intensive search by the New Crops Project at Gatton, Queensland, Fletcher (1993) stated that several thousand potential new crops had been found, relevant to a wide range of industries. Vietmeyer (1990) reviewed some under-exploited tropical crops, based on the results of a research programme carried out by the National Research Council, USA. Among the protein food crops that he highlighted were the groundnuts *Apios americanum* and *Voandzeia (Vigna) subterranea*, yam beans (*Pachyrrhizus* spp.), winged bean (*Psophocarpus tetragonolobus*), adzuki bean (*Vigna angularis*) and a little known South American oil palm (*Jessenia polycarpa*).

There are over 1300 species of the family *Leguminosae*, but only a small proportion are used for animal feeding. In a review of some of the promising "new" grain legumes as animal feed Arora (1995) drew attention to winged bean, jack bean, sweet pea, guar, pigeon pea and cowpea. Because of their genetic diversity, nutritional qualities and ability to contribute to sustainable agricultural systems, grain legumes show considerable potential for development in this country and could be used to provide a local alternative to imported protein feedstuffs. Currently Australia's legume production - chiefly sweet lupins, field peas, faba beans and chick peas - comes mostly from the southern states. However there is a need to shift some of this production northwards, for two reasons. First, there is a distinct asynchrony of supply and demand for grain legumes in northern Australia, due mainly to the high freight cost of delivering grain legumes from the southern states. Secondly, northern Australia does appear to have soils and climatic conditions which are suitable for growing certain grain legumes and which can sustain high yields. This can be inferred both from current research on legumes in Australia and from the successful cultivation of a wide variety of legumes in similar environments overseas. Thus there is a considerable incentive to identify suitable grain legumes for growers and poultry producers in Queensland.

Non-leguminous Plants and Products

Oil seeds and nuts

Palm by-products

There are two by-products of the coconut and oil palm industries that are sometimes included in Australian poultry diets and may have potential for more extensive use. These are copra meal (coconut meal or coconut oil meal) and palm kernel meal. However, both products are currently imported and both would have restricted application in layer diets due to their high fibre content.

Copra meal is the by-product of oil extraction from copra, the dried kernel of the nut of the coconut palm, *Cocos nucifera*. (The term "copra meal" is also sometimes used to refer to a meal made from the dried kernel before oil extraction). The main producer is the Philippines, but much of the material used in Australia is imported from the South Pacific region. Most copra mills in the South Pacific use an expeller process which leaves a residual oil content of about 8% in the copra, but oil residues in expeller meal from other sources may have much higher oil contents (up to 20%). The protein content is normally 20-24%.

Palm kernel meal is the by-product of oil extraction from the fruit of the African oil palm, *Elaeis guineensis*. It is produced mainly in Malaysia, Indonesia, Nigeria and Thailand. Most palm kernel meal is produced by an expeller process which leaves about 6% oil in the meal, while solvent extracted meals contain 1-2% oil. Good quality palm kernel meal has a protein content of about 18%, but poor quality meals may have a considerably lower content.

The oil palm has recently been cited as having potential for development in Australia, as it yields more oil per hectare than any other vegetable oil crop (Hunt, 1998). The oil is varied in composition and finds a number of uses. The palm grows best in regions of high rainfall and low altitude within 10^{O} of the equator, its temperature requirement being $22\text{-}32^{O}$C. However it is a hardy crop and will perform quite well under a range of conditions. The fruit are harvested all year round, but harvesting is not mechanised.

Both copra meal and palm kernel meal are problematic due to their variable oil content, frequent contamination with moulds, susceptibility to oxidation of the oil and high fibre content with high levels of poorly digested non-starch polysaccharides such as galactomannans (Daud and Jarvis, 1992; Swick and Tan, 1995). There is potential to improve the nutritional value of these products with supplemental feed enzymes. The amino acid profiles of copra and palm kernel meal are also relatively poor, as is the digestibility of the amino acids. Both products are deficient in lysine and methionine, but since synthetic sources of these amino acids are becoming inexpensive this may not be a serious disadvantage.

Palm kernel meal appears to be palatable to poultry and can replace wheat middlings in the diet; up to 20% has been included with satisfactory results. Up to 30% has been used satisfactorily in pig diets.

Table 1 Composition of copra meal and palm kernel meal

	Copra meal (expeller - PNG)	Copra meal (expeller - general)	Palm kernel meal (expeller)
Dry matter %	91.8	91.9	92.7
Protein %	23.1	22.1	16.1
Oil %	8.5	9.0	10.6
Fibre %	14.0	11.7	20.5
ME (MJ/kg)	-	6.9	10.8
Amino acids (g/kg DM)			
Arginine	25.0	33.6	14.4
Histidine	3.6	5.5	2.4
Isoleucine	6.2	8.6	4.7
Lysine	5.4	8.1	4.0
Methionine + cystine	11.9	7.6	4.9
Threonine	5.9	7.6	3.8
Tryptophan	2.0	3.5	1.7
Valine	10.0	12.1	6.1

Linseed meal

Linseed is the seed of the flax plant (*Linum usitatissimum*) and is grown throughout Australia, particularly in the cooler regions. Major producers are Argentina, India, China, Canada, USA and Russia. Linseed meal has a similar composition to sunflower meal but contains more tryptophan and has only half as much fibre (approximately 10%). Although former varieties of linseed contained high levels of a glucoside, linamarin, and high levels of linolenic acid, the development of varieties with low glucoside content and/or low α-linolenic acid content ("Linola") has boosted the production of this crop. Linola has a very similar protein and carbohydrate composition to traditional linseed meal, but the residual oil component is much higher in linoleic acid and much lower in linolenic acid. Linola oil is in fact similar in composition to high-linoleic sunflower oil. Linola meal is particularly suitable for ruminant feeding, but research is in progress aimed at reducing the soluble fibre component of Linola, resulting in a meal that is suitable for inclusion in pig and poultry rations.

Table 2. Protein and main essential amino acids in linseed meal (g/kg as received)

Crude protein	346
Arginine	31.1
Histidine	8.4
Isoleucine	13.7
Leucine	21.6
Lysine	12.7
Met+Cys	10.6
Threonine	12.3
Tryptophan	6.5
Valine	11.7
Phen +Tyr	25.6

An international joint venture between CSIRO and United Grain Growers of Canada and interstate field testing are underway (Green, 1995). Linola is suited to wetter, cooler zones and is said to have a place in crop rotation as it can grow in low nitrogen conditions unsuitable for Canola. A new variety of linola, *Argyle*, is claimed to have consistently outperformed earlier varieties (*Eyre* and *Wallaga*) in field trials in the southern states, even though on some farms the earlier varieties have outperformed wheat in gross returns. Linola is a high-value crop that is also completely compatible with cereal harvesting and sowing machinery. Future production of linola will be driven by the oilseed industry and agronomic considerations, but should production increase dramatically the poultry industry will need to look seriously at increasing its use of linola meal.

An alternative way of using linseed for poultry is to include the whole seed in the ration. The health advantages of incorporating the whole seed (entire or ground) in diets of laying hens have been discussed by Van Elswyk (1997). The benefits result from the high levels of omega-3 polyunsaturated fatty acids in the oil. Levels of 10-15% seed in the diet are probably required. Undesirable changes in egg production have been reported only for young pullets.

Safflower meal

Safflower meal is a by-product of the production of oil from the seeds of the safflower shrub (*Carthamus tinctorius*). Undecorticated safflower meal contains approximately 20-25% protein and 60% hulls, which are high in lignin. The decorticated meal contains approximately 40% protein and 15% fibre. Due to the small size of the seeds, however, decortication is a difficult and inefficient procedure. Although safflower is grown throughout the temperate regions of Australia, it accounts for only 1% of the country's oilseed production. Safflower meal is relatively low in those amino acids that are likely to be limiting in poultry diets (Table 3). This, together with the high fibre and lignin content of the meal and the lack of incentive to expand production of the crop, appears to restrict the potential of safflower meal as a protein supplement for poultry.

Table 3. Protein and main essential amino acids in safflower meal (g/kg as received)

	Undecorticated	Decorticated
Crude protein	253	39.1
Arginine	21.6	31.7
Histidine	5.6	9.5
Isoleucine	7.6	12.8
Leucine	14.8	22.2
Lysine	6.9	11.9
Met+Cys	5.8	10.4
Threonine	7.2	12.0
Tryptophan	2.6	4.3
Valine	11.3	17.3
Phen +Tyr	16.8	28.3

Sesame meal

Sesame is a by-product of oil extraction from the seeds of Sesame (*Sesamum indicum*). It is primarily a crop of small farmers in India, China, Myanmar, the Sudan, Mexico and developing countries. It grows well in tropical and temperate climates with low rainfall, but is also well adapted to wet season production in the tropics, the optimum temperature for growth being 27-35^{O}C. Sesame production in developing countries is forecast to fall in the near future, creating an opportunity for Australia to produce more of this high-value crop. It has been stated (Bennett, 1999) that sesame has the potential to follow in the footsteps of chick pea and canola as a "new" commercial crop, provided that it is backed by adequate research and persistence by farmers. The crop is not currently well adapted to mechanical agricultural systems. Australia imports about 6000 tonnes of sesame annually, worth $A12m. Most Australian sesame production comes from the Northern Territory and Queensland but generally amounts to only about 2% of requirements. Four cultivars are recommended for Australian use: Yori 77 and Edith for NT and northern WA, and Aussie Gold and Beech's Choice for Queensland. The crop can be rotated with legumes or cereals.

The nutrient composition of sesame meal compares with that of soybean meal, but it has a higher ash content (10-12%) and contains one third to one half as much lysine and more than twice as much methionine. However, the composition varies widely depending on the varieties used, the degree of decortication and the processing methods employed (Swick and Tan, 1995). The protein content of different varieties ranges from 41% to 58%. Sesame meal is particularly rich in tryptophan and the sulphur amino acids. Its amino acid composition thus complements that of soybean meal and it can be included in layer diets at levels up to approximately 18% (Reddy, 1999). Its main limitation is the presence of ANFs, in particular oxalic acid and phytic acid. The former can be removed by decortication.

Table 4. Protein and main essential amino acids in sesame meal (g/kg as received)

Crude protein	**454**
Arginine	52.8
Histidine	10.7
Isoleucine	16.9
Leucine	29.7
Lysine	11.1
Met+Cys	21.7
Threonine	15.5
Tryptophan	6.2
Valine	21.3
Phen +Tyr	36.3

Aquatic plants

Aquatic plants ostensibly have great potential as an alternative to conventional ingredients, especially in tropical and subtropical regions. Although in the tropics the chief impact of aquatic weeds is the damage they cause to waterways, a wide variety of these plants are finding increasing use in agriculture, in waste water treatment and for human consumption. Currently the main economic use of aquatic plants is for treatment of sewage effluent, as they remove nitrogen and heavy metals from the water. In some natural situations aquatic weeds may be ecologically beneficial in reducing nitrogen levels and thereby helping to prevent the growth of toxic algae. Ly (1993) considered that aquatic floating plants and microalgae should receive the highest priority in evaluating the contribution of plants to protein-deficient animal feeding systems in the tropics. Generally the production of aquatic plants would use animal wastes as the substrate.

There are four main divisions of fresh-water weeds - submerged, floating, emergent and algae. Of these, duckweeds (floating plants of the family *Lemnaceae*) and algae appear to have the greatest potential as animal feed because of their rapid growth rate and superior nutrient composition. Another genus with some potential is *Azolla*, a floating weed related to ferns and widely distributed throughout Australia.

Algae

While the natural growth rate of algae is not as fast as that of some duckweeds, growth can be greatly enhanced by techniques such as those employed in the High Rate Algae Pond (HRAP) system. In this system a nutrient-rich medium is kept oxygenated and exposed to maximum solar radiation by using a paddle wheel. However, the separation of the biomass from the substrate presents a serious difficulty in producing algae. Fuller (1988) states that some of the algae can be separated by filtering, while Lincoln *et al.* (1986) believe it would be economically viable to harvest the algae by flotation or sedimentation, followed by chemical flocculation.

The filamentous algae, *Spirulina*, and *Chlorella* spp may contain in excess of 60% protein (dry matter basis), while some other species may contain as little as 20% protein. Ash levels generally range from 7 to 10%. The amino acid profiles of Spirulina, Chlorella and Scenedesmus are shown below. The last two appear to be rich in threonine and tryptophan.

Growth and production studies suggest that the level of dehydrated *Spirulina* in poultry diets may be limited to around 10% (Ross, 1990). *Chlorella* meal produced by centrifuging has been fed to layers at up to 12% of the diet without any deleterious effects on performance (Lipstein *et al*, 1980), but algae (*Micractinium*) meal produced by flocculation with alum reduced feed intake and egg output at levels as low as 5% (Lipstein and Hurwitz, 1981).

Table 5. Essential amino acid composition of some microalgae (% DM)

Amino acid	*Spirulina*	*Chlorella*	*Scenedesmus*
Arginine	2.73	2.15	0.54
Histidine	0.55	1.40	1.08
Isoleucine	1.05	1.29	1.83
Leucine	3.01	3.44	4.09
Lysine	1.68	3.33	2.90
Methionine + cystine	1.02	1.08	1.40
Phenyalanine + tyrosine	2.96	4.73	3.76
Threonine	1.79	3.23	3.76
Tryptophan	-*	0.97	0.86
Valine	1.19	2.26	3.12

Source: Ako (1985), cited by Hugh *et al.* (1985); INRA (1984); * not reported

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Azolla

The water fern, *Azolla*, is found in most lagoons in the warmer regions of Australia (it prefers a water temperature of 15-35^{o}C). A few authors claim that *Azolla* is the most promising aquatic plant from the point of view of ease of cultivation, productivity and nutritive value (Lumpkin and Plucknett, 1982; Van Hove and López, 1983). There are six species of *Azolla* occurring throughout the warmer regions of the world. *Azolla* lives in a symbiotic relationship with the blue-green alga *Anabaena azollae*. The plant has been widely used in Asia as fertilizer and in diets for pigs, poultry and fish. It is capable of producing up to 19 kg protein/ha/day and contains approximately 27% crude protein (dry matter basis, Pullin and Almazan, 1983), but, as with all aquatic plants, the growth rate and protein content vary with conditions of growth. Analysis of four different species by Kadirvel *et al* (1996), however, showed a narrow range of variation of 24.9 to 27.2% protein, but the ash content was very high (approximately 40%). The tannin content is also high, which restricts its use for fish (El-Sayed, 1992). It has been fed fresh and dried to ducks and chickens. Subudhi and Singh (1978) established that fresh Azolla could be included in the diet of chicks at levels up to 20%. For broilers, dried azolla could replace a combination of wheat bran and fish meal up to 5% in the starter diet or 10% in the finisher diet with no adverse effects, but higher levels impaired performance (Parthasarathy *et al*, 1996).

Duckweed

Duckweeds appear to have great potential as an alternative to conventional ingredients, especially in tropical and subtropical regions. They are apparently faster growing than algae, much easier to harvest and dry and have a better amino acid profile (Ali and Leeson, 1994). None of the duckweeds are classified as noxious weeds in Queensland. Duckweeds are widely used in underdeveloped countries and research into agricultural uses has been done mainly in Bangladesh, Peru, Argentina, Israel and recently at the University of New England, Armidale. A researcher (Louis Landesman) at the University of Southwestern Louisiana makes the following comments on duckweed:

"Duckweed may be the most promising plant for the twenty-first century for the following reasons:

- Duckweed produces more protein per square meter than soybeans
- Duckweed is easier to harvest than algae or other aquatic plants
- Duckweed can be used to feed fish, poultry and cattle
- Duckweed can purify and concentrate nutrients from waste water (sewage effluent)"

In contrast to this accolade, it must be said that possible impediments to the use of duckweed for poultry feed include:

- As duckweed cultivation requires large expanses of water protected against wind, it does not integrate well with conventional agricultural systems
- There may be risks associated with the accumulation of toxic heavy metals
- Levels of dried duckweed of some species >15-20% appear to impair laying performance

Duckweed as a source of protein for livestock has been reviewed by Leng *et al* (1995), as a farming system by Skillicorn *et al* (undated) and as a potential feed ingredient for laying hens in Australia by Robinson (1997). Duckweeds are distributed world-wide and over forty species are known. One species in particular, *Lemna gibba* (commonly known in Australia as *L. disperma*), a very small-leaved fast-growing plant, shows great potential as an agricultural crop for cultivation in temperate to subtropical conditions and is ideally suited to the Queensland climate. The weed grows well in shallow water (20-30cm) in warm conditions (Oron, 1994), and responds very positively to provision of nutrients (e.g. from sewage or manure) and can double its weight every two to three days. Majid *et al* (1992) found that fertilisation of tanks with 5% cow manure produced a greater increase in yield (approximately 400%) than either 1% or 10% cow manure. As duckweed multiplies vegetatively (by clonal growth), there is no particular stage at which harvesting must occur, and in practice it is normal to harvest the crop about twice weekly. Yield varies from 17.8 tonnes to 55 tonnes dry matter/ha (Hillman and Cully, 1978; Oron, 1994). Higher yields might be anticipated from purpose-designed systems.

Duckweed grown in clear water has a high fibre and low protein content, but when grown in sewage or manured water the fibre content is lower (8-12% of DM) and the protein content high (25-45% of DM) (Ali and Leeson, 1994; Haustein *et al*, 1990, 1992; Kraft, National University of Rio Cuarto, Argentina, pers. comm.; Majid *et al*, 1992; Muztar *et al*, 1976; O'Neill *et al*, 1996). Duckweed is a superior source of all the amino acids that are likely to be limiting in layer diets, except for the sulphur amino acids. A typical nutrient profile is shown in Table 6.

Table 6. Typical composition of duckweed (g/kg DM)

Crude protein	**400**
Lysine	40
Methionine	9
Isoleucine	36
Leucine	67
Arginine	45
Threonine	31
Valine	44
Xanthophyll	1.2
Beta-carotene	0.5
Calcium	30
Phosphorus	4
Metabolisable energy	5-8 (MJ/kg)

Source: Rusoff *et al,* 1980, Muztar *et al,* 1977 and others)

In under-developed countries, duckweed is easily harvested using small-mesh nets. There is reference to mechanical harvesting of aquatic plants in developed countries, but no details are available. Optimum harvesting rates are theoretically calculable from knowledge of weed density and growth rate and cost of harvesting. However the quality of the product is greatly influenced by the age of the weed at harvesting, young plants having a higher protein content and lower ash, fibre and tannin content. The fresh weed has a very high water content (90-96%), but can be readily drained and sun-dried. Although centrifugation has been used as an aid to drying, and has been recommended by Kraft (pers. comm.), Ali and Leeson (1994) consider mechanical methods of drying to be of doubtful value. There is no mention of further processing, the dried material apparently being suitable for direct inclusion in poultry feeds or after a minimum of milling.

Although duckweed appears to be intrinsically non-toxic, it should be remembered that aquatic weeds have been used in water purification not only to reduce nitrogen levels but to eliminate heavy metals. There may therefore be a risk of heavy metal accumulation, particularly cadmium, and this aspect of duckweed cultivation may need to be monitored.

Lemna gibba and related species of duckweed have been studied in a number of meat chicken growth trials and have generally shown good results when included at dietary levels up to 15% for chicks or up to 20% for older birds (Haustein *et al*, 1992). The high xanthophyll content of duckweed precludes its use in meat chicken diets in Australia.

Haustein *et al* (1990) evaluated *L. gibba* and another species for feeding laying hens and found that dietary concentrations up to 25% supported performance similar to the controls. Even 40% *L. gibba*, completely replacing the fish meal and soyabean meal in the diet, yielded very satisfactory results and there were no adverse effects on egg quality, including taste. Protein content of the eggs was increased with *L. gibba* levels of 15-25%. 15% *L. gibba* in the diet greatly increased yolk pigmentation but higher levels showed smaller improvement.

Laying hen trials with duckweed of another species (*Spirodela punctata*) have been conducted at the University of New England in conjunction with Bio-Tech Waste Management Pty Ltd. (Nolan *et al*, 1997). Tegel Hi-sex and Super Brown hens were fed diets containing dried *S. punctata* (31% protein, replacing mainly soyabean meal) at concentrations of 1-20% in diets of constant energy and protein. Egg mass output was reduced with *S. punctata* levels above 5-10%, markedly so in the Super Brown strain but only slightly in the Hi-sex. Yolk colour scores increased from approximately 4 to 12 with increasing duckweed levels. The mineral composition of *S. punctata* was analysed; levels were often high and the mineral content of duckweed was therefore considered to be important in formulating diets. This work confirmed earlier studies (O'Neill *et al*, 1996), which also showed that egg flavour was not affected by duckweed.

In Queensland the most widely distributed and prolific duckweed appears to be *Aequinoc tiaois* and should be considered as a possible species for further development.

Data on costs and economic benefits of duckweed production have not been found, as so far this product has been considered relevant only to third-world countries. To be a viable proposition in Australia the cost of the final ingredient (assuming 10% moisture and 36% protein) would need to be approximately $300-350 /tonne at current ingredient prices. This is the opportunity cost obtained by including dried duckweed in least-cost layer diet formulations, and does not take into account the pigmentation value of duckweed (some commercial producers of natural pigment have thought that duckweed might be economic for this purpose alone). However the chief attraction of duckweed lies in the possibility of producing it at a substantially lower cost. Because cultivation, harvesting and processing require no expensive capital resources, production costs could be kept low.

Fodder trees and shrubs

A large number of fodder trees and shrubs have recently attracted attention as possible sources of protein for intensive livestock. These include Ipil-Ipil (*Leucaena leucocephala*), Necadera (*Trichantera gigantea*) and Neem (*Azadirachta indica*). Among the problems associated with the use of fodder trees for non-ruminants are their high fibre content, the presence of ANFs and difficulties of harvesting.

Leucaena is a leguminous shrub native to Mexico but widely utilised in Asia as a fodder crop. It is drought resistant and the dried foliage contains up to 28% of average quality protein, but it has a number of disadvantages. It is low-yielding, difficult to harvest and susceptible to insect damage, and the leaves and seeds contain a toxic amino acid, mimosine. Studies at QPRDC found that the dried leaves were useful as a yolk pigment, but further research on *Leucaena* as a poultry feed cannot at present be justified.

Trichantera gigantea, a non-leguminous tree native to Colombia and Venezuela, has recently received considerable attention for use as an animal feed. It is a multi-purpose tree which has now adapted to a range of eco-systems throughout south-east Asia. The tree grows well in a mixed cropping system with banana plants which provide shade. The dried leaves contain 16-20% crude protein of good quality and the tree can produce from 40 to 60 tonnes/ha of fresh foliage annually (Gómez and Murgueitio, 1991). The leaves have been fed to pigs and poultry with mixed results. Dried leaf at 6% (the highest level tested) was found to be satifactory for laying hens (Nguen Thi Hong Nhan *et al*, 1999).

Neem trees (*Azadirachta indica*) are used increasingly in reforestation projects around the world, so large quantities of neem seed are becoming available. The medicinal properties of neem oil have been known for centuries, and recently over thirty patents have been granted in relation to neem products and processing. Neem has recently been proved to be useful against insect pests and nematodes. It depresses the activity of esterase enzymes in adult leafroller moths. Transmission of potato virus Y to sweet pepper by the green peach aphid is also inhibited by foliar application of neem oil as an aqueous spray. Feeding neem kernel meal to layers at 10% in partial replacement of soybean meal and rice bran had no effect on any performance parameter or on taste or appearance of eggs (Gowda *et al*, 1996). Ground neem seeds can also replace up to 28% of the corn and cotton seed meal in a rabbit ration with no adverse effects.

Single cell proteins

This is a complex area which can only be briefly reviewed here. Algae have been mentioned in the section on aquatic plants. Edible yeasts and bacteria have the potential to produce food from resources which could not otherwise be utilised, as they can be grown on a wide variety of substrates, including petroleum and cellulose products, agricultural and food industry wastes and animal and human wastes, and many species have been investigated for their potential as human and livestock food. The main factors inhibiting their use as animal feed appear to be cost of production, risk of contamination with harmful microbes and the presence of heavy metals and carcinogens. Reviews of this topic include Litchfield (1983), Schlingmann *et al* (1984) and Ingledew (1999).

Surprisingly the single cell protein industry has apparently passed its peak (Ingledew, 1999). Single cell protein production grew into an enormous industry during the war years but eventually failed largely because of carcinogens found in proteins produced on paraffins and oils, and the very high nucleic acid content of these proteins, which caused gout. There is thus a very substantial body of archived technical information, most of which now appears to be redundant. Current interest in micro-organisms as feed supplements is focused on the use of live cell cultures as probiotics.

Three microbial proteins that remain of interest, especially in northern Australia, are torula yeast, generally grown in sugar cane molasses, *Saccharomyces* yeast, a by-product of the alcohol industry, and *Neurospora*, a widely researched filamentous fungus of known food value that can be grown on cellulose-rich materials. Although apparently quite variable in composition, dried yeasts have a high protein content and good amino acid profile, apart from a rather low methionine and cystine content (Table 7). Yeasts are especially rich in lysine and threonine. Torula yeast from sugar cane molasses has been widely used in Cuba (Figueroa and Ly, 1990), while brewers' yeast has been used in Brazil. Either yeast can be included in pig and poultry diets at levels up to at least 15%.

Table 7. Main essential amino acids in yeasts (g/kg DM, data from various sources)

	***Saccharomyces* sp**	***S. cerevisiae* (brewers yeast)**	**Torula sp**	***Torulopsis utilis***
Arginine	15.1	27.0	20.4	33.0
Histidine	7.7	11.4	7.1	13.6
Isoleucine	16.4	24.3	19.5	20.3
Lysine	23.0	41.4	25.7	40.8
Methionine + cystine	9.1	6.1	7.6	10.1
Phenylalanine + tyrosine	22.9	42.1	32.4	38.5
Threonine	17.5	24.7	21.9	23.1
Tryptophan	5.8	-	-	6.9
Valine	19.7	25.2	22.9	25.2

Although large quantities of *Saccharomyces* yeasts are available from the brewing industry, as yet there is no economic method of collecting and processing this material, and bacterial contamination is a problem. One form of *Saccharomyces* yeast, known as brewery activated sludge (or brewers' single cell protein), contains about 45% protein. Studies of this material for poultry in Japan (Goto and Masuda, 1974; Ahn *et al*, 1979) have demonstrated its value as a feed ingredient. Perhaps the main interest in *Saccharomyces* strains, however, is their use in yeast cultures (supplements containing viable yeast cells and a dried preparation of the growth medium) as probiotics. It is assumed that these cultures stimulate the activity of certain micro-organisms in the gut, increasing feed digestibility and thereby improving the performance of the bird; however their mode of action in monogastric animals appears to be little understood.

Neurospora species can be grown on cellulose containing materials such as straw, sawdust, bagasse, bran and clarifier sludge. An aerobic slurry fermentation process has recently been developed at the University of Waterloo in Canada which eliminates the pollution potential by directly converting the solid waste materials into proteinaceous food products suitable for human consumption or for livestock feed. The product consists of up to 95% (dry matter basis) of *Neurospora*, the remaining component being unconverted lignocellulose which is left as dietary fibre. The typical protein content is 450 g/kg and the essential amino acid profile compare favourably with soybean meal. The fermentation process has been tested successfully on a fairly large scale on a range of cellulosic residues. However the current cost appears to be prohibitive. A processing plant generating ten metric tonnes per day of single cell protein from carbohydrate residues is estimated to cost approximately $6,000,000 US and would produce a product competitive to soybean meal selling in the region of $500-$600 US ($800-900 AU) per tonne.

Grain Legumes

New varieties of legumes are becoming available which are suitable for cultivation in a wide range of conditions, especially in the warmer northern regions. However, little is known of their nutritional value for poultry or the extent to which anti-nutritional factors may interfere with their utilisation by poultry and other livestock.

The potential of specific grain legumes for use as poultry feed depends largely on their agronomic prospects and relevance to sustainable agriculture. In Queensland the introduction of pulses is considered a high priority strategy by the DPI and the Grains Research and Development Council. At present pulses are grown on less than 5% of the cultivated area. Agronomically, it is considered that chickpea, mung bean and to a lesser extent faba bean offer the best prospects, with pigeon pea, cowpea, field pea, white lupin, lentil and lablab being other possibilities. (Brinsmead, 1997). Currently in Queensland several wheat crops can be grown between each legume crop, while in Western Australia two wheat crops is the norm. Agronomists are encouraging more regular rotation of grain legumes with wheat crops to break the disease cycle.

Pengelly and Conway (1998) point out that long-term cropping has reduced soil fertility in the northern grain belt, resulting in corresponding declines in grain yield and quality. This deteriorating situation has serious implications for the economic and environmental sustainability of the grain industries in the region. Of the various options available to arrest the decline in soil fertility, increasing the legume content of pastures in crop rotations appears to be the most cost-effective way to further improve cereal crop yields and protein content. Pulses such as chickpea and mung bean can be included in rotations, or forage or ley legumes can be incorporated in the cropping system. The most commonly used tropical ley legume is lablab (*Lablab purpureus*). A joint CSIRO/Queensland DPI project is evaluating various alternative tropical species, either as self-regenerating annuals or as perennial ley pasture legumes for central and southern Queensland. So far the project has identified a number of promising species and confirmed that tropical legumes can produce considerable dry matter on the major cropping soils of the northern grain belt and persist for at least two years under the range of environments encountered.

Least cost feed formulation runs indicate that the opportunity cost of most pulses, relative to Australian soybean meal with a protein content of 45%, varies from 35% to 62% of the cost of soybean when a wide variety of other ingredients are also available. Of all the common legumes, mung bean and chickpea are best able to act as direct substitutes for soybean meal, easily replacing 8-9% soybean (plus part of the cereal component) with 20% legume, with no change in diet cost when the price of the legume is approximately 50-60% of the soybean price. This suggests that the use of legumes in poultry diets can be very economical. Most of these legumes are currently grown for human consumption, for which purpose they attract a considerably higher price. However, downgraded material for livestock use is sometimes sold at well under $200/tonne, making it a worthwhile substitute for soybean and oilseed meals. It is possible that this situation will change, with increasing areas of legumes being cultivated primarily for livestock use, and that the cost to the poultry and stockfeed industry will become highly competitive with other protein sources.

The use of grain legumes for poultry is restrained by uncertainty about the amount and effect of ANFs which they may contain (Wiryawan and Dingle, 1999). Legumes may contain appreciable amounts of protease inhibitors, principally trypsin and chymotrypsin, and phytohaemagglutinins (D'Mello, 1995; Wiseman, 1995). However ANFs can be reduced and nutritional quality improved by plant breeding, dehulling, heat treatment or supplementation of diets with enzymes. An alternative approach which has received little attention is to harvest the seed before it is fully mature. Although total yield is lower, green legume seeds of some species have their uses in the human food industry, their nutritional properties are usually superior to mature pulses, and it may be possible to select varieties which are better suited to early harvesting. An example is given at the end of the section on pigeon pea.

An important consideration for the future of pulses in Australia is the development of food products for the local market. This country has one of the lowest *per capita* levels of pulse consumption in the world, being only half that of the UK and one fifth that of India. Most of the locally grown pulse that is not exported is thus used for animal feed.

Comparative studies of composition of pulses and value for poultry

Much of the research on the nutritional value of tropical grain legumes has been done in Africa and India, where pulses are widely used as part of the staple human diet. However some research that includes tropical legumes has been conducted in Australia and some of this is reported here. Additional reports may be mentioned under each legume species, in particular pigeon pea.

Two varieties each of bambara groundnut (*Vigna subterranea*), kidney bean (*Phaseolus vulgaris*), lima bean (*Phaseolus lunatus)*, pigeon pea (*Cajanus cajan*) and one variety of jack bean (*Canavalia ensiformis*) seeds grown in Nigeria were investigated for their proximate composition, mineral and amino acid contents in raw, cooked and autoclaved form (Apata and Ologhobo, 1994). The crude protein of raw seeds varied from 20.6 to 27.7%, crude fibre 3.2 to 9.5%, ether extract 1.3 to 6.7% and ash 3.0 to 4.8%. All the materials were good sources of potassium and phosphorus but low in sodium. Iron content was highest in kidney beans. The amino acid profile of the protein showed a consistent deficiency of methionine and cystine. Pigeon peas were also low in tryptophan while bambara groundnuts were rather low in threonine. The lysine content of kidney bean *var* Pondo-6 was notably high compared with others. Cooked legume seeds contained relatively lower amounts of most nutrients.

Chemical analyses and feeding experiments using rats were conducted to evaluate the nutritive value of winged beans, mung beans, bambara groundnuts, pigeon peas, field beans, cow peas and soybean, all grown in Tanzania (Mnembuka and Eggum, 1995). The nutritive composition of winged bean was similar to that of soyabean, while the composition of the other legumes differed considerably. This was also the case for antinutritional constituents and minerals. Lysine levels were generally high, winged bean having the highest value (7.5 g/16 g N). However, the concentration of methionine plus cystine was consistently low. Threonine levels were also generally high, especially in winged bean (4.3 g/16 g N). With the exception of field beans, true protein digestibility was comparable to soybean. Energy digestibility was around 80%, soyabean having the highest value of 85.8%. The findings indicated that winged bean in particular is a good alternative protein source in Tanzania.

The proximate, mineral and amino acid composition of different cultivars of three legumes used in Nigeria were compared: African yam bean (*Sphenostylis stenocarpa*), pigeon pea (*Cajanus cajan*) and cowpea (*Vigna* spp; Ene-Obong and Carnovale, 1992). Apart from protein and ash, proximate compositions of all the legumes were similar. The protein content of cowpea was significantly higher ($P<0.01$) than that of the African yam bean or pigeon pea. Ash content was higher ($P<0.05$) in cowpea and pigeon pea than in African yam bean. Two popular cultivars of *Vigna unguiculata* (white and brown) contained about half as much crude fibre as African yam bean and pigeon pea. Cowpea appeared to have a better mineral profile than the other legumes. African yam bean had a superior essential amino acid profile than cowpea or pigeon pea. All legumes were deficient in cystine and methionine, and pigeon pea was also low in valine and isoleucine. The necessity of combining legumes with cereals was emphasised.

Samples of lupin seed (*Lupinus albus*), pigeon peas, cowpeas, lablab, faba beans (*Vicia faba*) and soyabeans, grown in the Sudan, were examined for protein quality (Abdel-Ahmed and Abdel-Nour, 1990). Apart from lupin seed, the protein of all the samples was rich in lysine (5.56 to 6.27 g/16 g N) and had a high availability. Sulphur amino acid concentrations were consistently low. Lablab protein had the lowest (52) and soyabeans the highest (84) protein value and the calculated protein efficiency ratios were 2.38 and 0.95 for soyabean and lablab respectively. The two cowpea varieties differed significantly in protein efficiency ratio. Faba bean proteins were the most susceptible to gastric and pancreatic enzymes. Trypsin inhibition activity was highest in soyabeans.

Yamazaki *et al* (1988) determined the true metabolizable energy (TME) and true amino acid availability (TAAA) in some feedstuffs from the Philippines using the method of Sibbald with adult cocks. The materials examined were maize, rice bran, coconut oilmeal, leaf meal and three pulses. TME values of by-product feeds were greatly affected by crude fat and crude fibre contents. Among the three pulses, mung bean had the highest nutritive value (estimated from TAAA) followed by pigeon pea and rice bean (*Vigna umbellata*).

Aletor and Aladetimi (1989) studied the proximate composition, mineral content and some endogenous toxic constituents of several cowpea varieties and some under-utilized edible legumes in Nigeria. The materials studied included cowpea varieties such as Ife Brown, Ife Bimpe, IT84E-124, K59 and TVX716, and legumes such as pigeon pea, lima bean (*Phaseolus lunatus*), lablab (*Dolichos lablab*), mucuna bean (*Mucuna* sp.) and *Sphenostilis sternocarpa*. The cowpea varieties contained on average 22.5 g protein, 2.60 g crude fibre, 5.89 g ether extract and 3.36 g ash/100 g DM while the under-utilized legumes contained 21.7, 6.10, 2.86, and 3.56 g/100 g DM for protein, fibre, ether extract and ash respectively. The fibre contents of the under-utilized legumes were generally higher than that of the cowpea varieties. Potassium was the most abundant mineral in both the cowpea varieties and the under-utilized legumes, with mean values of 14.5 and 16.6 g/kg respectively, while phosphorus was the least abundant with 13.1 and 8.50 mg/kg respectively. The cowpea varieties generally had higher levels of thioglucosides, trypsin inhibition acitvity (TIA) and lower heamagglutinating activity (mean values of thioglucosides: 38.6 g/kg, of TIA: 13.9 mg/g protein and of haemagglutinating activity: 13.0 HU/mg N respectively), than the under-utilized legumes with mean values respectively of 12.2 g/kg, 9.84 mg/g protein and 22.7 HU/mg N. The nutritional implications of these anti-nutritional components were discussed and some reasons adduced for the under-utilization of some of these legumes, in spite of their apparent similarity in nutritional quality, compared to the more commonly consumed grain legumes.

Broiler chickens, seven days of age, were fed for seven weeks on maize-based diets in which 12.5 or 25% of the soyabean meal was replaced by jack beans (*Canavalia ensiformis*), kidney beans (*Phaseolus vulgaris*), lima beans (*Phaseolus lunatus*), yam beans (*Pachyrhizus erosus*), pigeon peas (*Cajanus cajan*) or bambara groundnuts (*Vigna subterranea*; Ologhobo, 1992). Inclusion of non-soy legumes at either level resulted in significant decreases in weight gain and feed intake. However, feed conversion of broilers given diets containing 12.5% lima beans or pigeon peas or up to 25% bambara groundnuts or yam beans did not differ significantly from controls. Inclusion of jack beans and kidney beans at both levels and lima beans or pigeon peas at 25% adversely affected feed conversion. Weight of liver and brain were altered ($P<0.05$) by the higher levels of legumes. Serum total protein and albumin concentrations decreased with 25% legumes but urea and creatinine increased. Transaminase and phosphatase enzyme activities were increased at the higher level of legume. It was concluded that only pigeon pea and bambara groundnut could be recommended for inclusion in poultry diets and care should be taken if they are to be fed over a long period.

Robinson *et al* (1989) compared the performance of laying hens fed on diets containing opal chick pea, mung bean or pigeon pea at a dietary level of 250 g/kg, or lupin seed or rape seed (*B. napus*) at 200 g/kg. The rate of lay of birds given mung bean was significantly higher than that of birds receiving other legumes, while lupin tended to depress feed intake and body weight gain. In other respects all the legumes supported satisfactory performance.

Perez-Maldonado *et al* (1999) studied the composition and value for laying hens of field peas, faba beans, sweet lupins and chick peas when each was included in nutritionally similar diets at 250 g/kg. The amino acid composition of all species agreed well with previously published data. The soluble non-starch polysaccharide content of the lupin seeds was much higher than that of the other legumes, while the condensed tannin content was highest in field peas followed by faba beans. Faba beans depressed egg production and egg weight, while pancreatic enlargement was observed in birds consuming chick peas. Steam or cold pelleting of lupin and faba bean diets or dehulling of faba beans had little effect on performance.

Australian data on the nutritive value and chemical composition of grain legumes have been collated and tabulated by Petterson *et al* (1997). Table 8 is a summary of nutritional information most relevant to poultry, based on data compiled by these authors for adzuki bean, chickpea, cowpea, lablab and mung bean.

Table 8. Nutrient and ANF composition of some important grain legumes (%, as received)[1]

	Adzuki bean	Chickpea (desi)	Chickpea (kabuli)	Cowpea	Lablab	Mung bean
Dry Matter	89.0	90.1	90.9	89.9	89.3	91.1
Protein	24.5	20.1	21.5	24.6	22.7	25.9
Fat	0.4	3.9	5.0	0.9	1.4	0.8
Fibre	4.8	9.8	2.9	-	9.1	3.8
Arginine	1.92	2.03	2.33	1.76	1.60	1.89
Histidine	0.69	0.54	0.63	0.69	0.67	0.71
Isoleucine	1.00	0.82	0.90	0.91	1.06	1.06
Leucine	1.92	1.47	1.61	1.81	2.09	2.08
Lysine	1.88	1.33	1.39	1.59	1.46	1.77
Methionine	0.35	0.28	0.30	0.32	0.15	0.35
Threonine	0.85	0.74	0.80	0.89	0.94	0.87
Tryptophan	-	0.20	0.18	0.25	0.17	-
Valine	1.22	0.86	0.96	1.09	1.26	1.28
Cys+Met	0.63	0.59	0.63	0.59	0.39	0.55
Tyr+Phe	2.16	1.67	1.90	1.98	2.14	2.30
Oligosaccharides	3.40	1.65	2.08	5.58	4.00	4.32
Phytate	0.89	0.66	0.70	1.23	1.27	1.22
Condensed tannins	0.60	0.04	0.01	0.9	0.001	0.22
TIA	1.64	0.40	0.30	0.51	0.80	0.19
CTIA	0.57	0.77	0.64	0.11	-	n.d

[1] Source: Petterson, Sipsas and Mackintosh (1997)

Adzuki bean (*Vigna angularis*)

The adzuki bean resembles the mung bean but is larger and usually has a dark red coat, although it can vary widely in colour. This legume is native to Japan and China, which remain, along with South Korea, the major consumers. It is also cultivated in India, Manchuria, Taiwan, Thailand, the Philippines, New Zealand and the USA. In Japan it is the second most important dry pulse crop, being used especially in the form of a very sweet paste known as “An”, which is used to make confectionary and cakes. Flour made from the whole bean may be included at up to 10 per cent in bread and other bakery products, soups and savouries. The beans contain 200-250 g/kg protein and about 50 g oil, of which 75 per cent comprises unsaturated fatty acids. They are an excellent source of lysine (see Table 8).

In Australia adzuki bean is grown as a summer crop in New South Wales and Queensland, where it is considered more difficult to grow than mung bean (Desborough and Redden, 1998). It requires a well drained soil, frequent irrigation and competes poorly against weeds. However there is a good, though volatile, export demand and steps are being taken to exploit the Asian market, through improved technology and the development of value added products. The chief varieties grown in Australia are Bloodwood and Erimo.

Bambara groundnut (*Vigna subterranea, Voandzeia subterranea*)

This is a hardy, drought tolerant legume native to Africa. It is grown mainly by smallholders in the semi-arid tropics of Africa, where it is intercropped with millet, sorghum, maize, root crops and other legumes. With good management yields of 2-3 t/ha are generally achieved. In the 1980s, the annual global production of bambara groundnut was estimated to be approximately 350 000 tonnes, of which about half was produced in West Africa. The seeds are used as a vegetable or made into flour.

There is very wide range of varieties in Africa, many of them originating 20-40 years ago with little development since. These varieties differ in appearance and possibly in nutritional quality. Examples (all from Tanzania) are Dodoma, Mwanza, Shinyanga, Singida and Tabora. The varieties tend to be adapted to particular environmental conditions. The seed contains about 200 g/kg protein and has arelatively high oil content (50 to 60 g/kg). Bambara groundnut offal has been used in broiler starter and finisher diets at levels up to 45% and 48% respectively, replacing maize, without any effect on performance.

Despite an enthusiastic following, there is much to be learnt about the agronomy of this legume and at present it appears to have little commercial potential.

Black gram (*Vigna mungo, Azukia mungo*)

This legume is grown mainly in in India, Iran, South-East Asia, Greece and East Africa (Petterson *et al*, 1997). In India, black gram is mainly used in the preparation of fermented foods such as idli, papad, waries and dosa. It is also consumed in split, boiled and roasted forms, or ground into flour and used to make cake, bread and porridge. In composition, black gram compares favourably with the more commonly cultivated legumes. The seed contains about 600 g/kg total carbohydrates and 250 g/kg protein. Most of the protein and fat is in the cotyledons.

In Australia black gram cv. Regur has been grown in Queensland, Northern Territory and northern New South Wales. Currently most of the production comes from south-east Queensland, to which Regur is particularly well suited, the optimum temperature for growth being 27-30^{O}C. The crop is fairly easy to grow, though susceptible to charcoal rot. However harvesting is difficult due to uneven maturity. The pulse is exported to Japan, India and other parts of Asia.

Chickpea (*Cicer arietinum*)

Chickpea (also known as Bengal gram, boot, chana chola, chole, gram, hommes and pois chiche) is globally the third most important pulse crop after navy beans and dry peas (Petterson *et al*, 1997). The species *Cicer arietinum* actually comprises two subspecies, one of the same name, and *C. arietinum* spp. *reticulatum*, which is of little agronomic interest. The subspecies *arietinum* is divided into two distinct types, Macrosperma (kabuli or garbanzo type) and Microsperma (desi type). Kabuli chickpeas are of Mediterranean and Middle Eastern origin; the large (approximately 400 mg) seeds have round, smooth testa, low fibre content and are white to cream in colour. They are consumed almost exclusively as cooked, whole seeds. The best-known variety is Opal. Desi chickpeas are of Indian origin and account for 85-90% of world chickpea demand. The relatively small (approximately 100-200 mg) seeds are somewhat angular with a rough or wrinkled testa, high fibre content and vary in colour from fawn to brown, orange, green or black. These cultivars are normally dehulled and split to obtain a type of dhal, or ground to make a protein-rich flour known as besan. Dehydration and canning are used as preservative measures, while soaking, sprouting, fermenting, boiling, steaming, roasting, frying, parching, puffing and pureeing are commonly used to convert them into a consumable form. Dried chickpea is also an ingredient in a variety of snack foods, sweets and condiments. The best known cultivar in Australia is Tyson.

In the early 1970s a large number of chickpea lines were introduced into Australia and tested in trials throughout the country. The best yields were recorded in northern Australia. It was this work which led to the release of cv. Tyson by the CSIRO and Queensland Department of Primary Industries. At least seven cultivars of desi and five of kabuli chickpeas are now available, and chickpea is currently grown in all states except Tasmania. In Australia the main desi cultivars are Tyson, Amethyst, Dooen and Barwon, another good performer in some regions being Desavic. Tyson was the variety of choice in the 1980s (Beech and Brinsmead, 1980) but in the 1990s Dooen was the top yielding variety in the Darling Downs. Amethyst is said to do well in areas with little spring rainfall while Barwon is resistant to water logging. A forthcoming variety, Jimbour (not yet released at the time of writing), is a cross between Amethyst and Barwon lines, having resistance to Phytophthora and Botrytis. Kabuli cultivars include Kaniva and Garnet, but their yield is considerably below that of the desi varieties, which are better adapted to the low rainfall wheatbelt.

The area sown to chickpea in Australia is expected to double in the next five years, and new higher yielding varieties are soon to be released. Current production of chickpea in Queensland is about 50,000 tonnes and this should increase dramatically over the next few years. Approximately 98% of the Queensland crop goes to India. Other Australian export markets include Bangladesh, Pakistan, Sri Lanka, the UK and the UAE, with increasing demand being shown by non-traditional markets such as the UK, where it is converted to value-added products. “Wastage” will be high, at least 10-20% going to feed grade. Most varieties of chickpea are relatively free from ANFs, and their protein digestibility is generally high in comparison to other pulses. With its high fat digestibility, chickpea is becoming useful as a protein and energy source for all classes of poultry. Chickpea possesses many attributes, not the least of which is its ability to derive more than 70 per cent of its nitrogen from symbiotic nitrogen fixation, which make it a promising crop for Australian conditions. There is some information on a few current popular varieties of chickpea but very limited data on the varietal differences in terms of nutritive value and yield. Some research on chickpea in both layers and meat chickens has been done at the QPRDC with promising results (see above). Chick peas are a good source of lysine and tryptophan and some varieties contain more methionine and cystine than most other legumes (see Table 8).

Cowpea (*Vigna unguiculata*)

The cowpea or southern pea is a native of Africa, where it is an important food legume. There are three distinct subspecies of cultivated cowpeas, two of which are grown in Australia; these are the cowpea proper and the yardlong bean, which is of minor importance. Of the two million tonnes grown annually worldwide, only a small proportion enters international trade. The legume is grown and utilised mainly in Nigeria and other parts of West Africa, India, Myanmar, USA, Brazil, the Carribean and Mediterranean regions. In Africa the seeds are commonly dehulled, soaked and made into a paste, which is used in steamed and deep-fried dishes.

Only small, but increasing, quantities of cowpea are grown in Australia, either for culinary pulse (Qld and NSW), forage (southern Qld) or for green manure (sugar cane areas). The optimum temperature for growth is 30^{O}C. The main agronomic advantage of the crop is its tolerance of drought, while a disadvantage is its susceptibility to stem rot (*Phytophthora vignae)* and a variety of insect pests. Cowpeas range in type from those with small, red seeds to the large black and white seeded type known as blackeye pea. Varieties bred for resistance to stem rot are Red Caloona, Ebony PR and Holstein (Imrie, 1998a), the latter being a derivative of Californian blackeye pea and red Caloona, developed by the CSIRO in Queensland. The varieties most suitable for pulse production are Red Caloona, Big Buff, Banjo and Holstein. Big Buff and Holstein are proprietary brands that can be grown only under contract, while Banjo is not resistant to stem rot and is therefore suitable for growing only under very favourable dryland conditions. The smaller seeded red and buff types are considered most appropriate for feeding to poultry.

According to Petterson *et al* (1997), the protein content of seed produced in Australia is only about 180 g/kg (although Table 8 indicates otherwise), which is lower than that of African seed. Apart from lysine and tryptophan, which are present at higher levels than in many legumes, protein quality is rather poor, methionine normally being the first limiting amino acid. The oil content, at about 10 g/kg, is relatively low.

Feeding studies indicate a DE of 12.2 MJ/kg for pigs and an ME of 10.6 MJ/kg for sheep (Petterson *et al*, 1997). In South Africa studies on the nutritive value of cowpeas have been conducted by Nell *et al* (1992). These researchers sampled 150 different cowpea cultivars and found that the average crude protein content was 28.4% (range 24.5-33.9%). Autoclaving for 15 min at 120°C improved digestible energy and TME ($P<0.05$) when estimated in pigs and poultry respectively. A clear improvement in digestibility due to cooking has also been demonstrated by Fialho *et al.* (1985; Table 9)

Table 9. Chemical composition and digestibility of raw and cooked cow peas

	Composition (% DM)				Digestibility (%)	
	CP	Ash	CF	EE	N	Energy
Cow pea: raw	30.3	5.0	7.6	1.6	66.1	78.0
cooked	26.2	3.7	5.9	1.4	78.2	80.5
toasted	25.7	4.1	7.1	1.4	69.4	73.8

Source: Fialho *et al.* (1985)

Faba bean (*Vigna faba*)

Faba beans are traditionally grown in the cooler regions of Australia, but they have also been grown in southern Queensland. In terms of global legume production this species ranks sixth (Petterson *et al*, 1997), with China being the leading producer. There are two types: the broad bean (*V. faba* major) with a seed weight of approximately 800mg and the horse bean (*V. faba* minor) whose seed weight is approximately 550 mg. While the legume is widely grown for animal feed, especially in the USA and northern Europe, it is is a major source of protein for humans in China, where it has been used for nearly 5000 years, and in Mediterranean and Middle Eastern regions and parts of Latin America. In the Middle East the bean is consumed mainly in the form of a dried cake, but many other types of dish are made, using dried or germinated beans.

Faba beans contain a number of toxins, of which the best known are the favism-inducing glycosides, vicine and convicine. Favism is a haemolytic anaemia associated with a genetically determined deficiency of the enzyme glucose-6-phosphate dehydrogenase. Populations at greatest risk are in the Mediterranean area, particularly Egypt, Israel, Cyprus, Greece and Sardinia, and some African regions. Cooking has little effect on the levels of favism-inducing compounds. There is much variation in vicine and convicine levels, suggesting that selective breeding programs should improve the utility of faba beans as a basic human food, as well as for livestock feed. Other factors that need to be overcome include flatus-producing oligosaccharides, condensed tannins (present mainly in the hull of beans with coloured seed coats), protease inhibitors (also mainly in the hull), phytins and lectins (haemagglutinins).

Table 10. Energy values for faba beans (MJ/kg)

	Mean	Range
DE Pigs[1]	14.5	14.0-15.0
ME Sheep[1]	11.5	11.3-11.7
AME Poultry[2]	11.04±0.41	

[1] Petterson *et al* (1997)
[2] Perez-Maldonado *et al* (1999)

Faba beans are a good source of energy (GE approximately 16.8MJ/kg, which is typical of grain legumes of low oil content), protein, fibre, phosphorus, iron and B vitamins. The ME for pigs, poultry and ruminants (is similar to those for lupins, field peas and soybean meal (Table 10). The amino acid profile of faba beans, however, is poor, especially in regard to tryptophan and the sulphur amino acids, which may need to be added in synthetic form to high-faba bean poultry diets (Table 11). Some feeding studies support this proposition. Dehulling the seeds has been reported to increase protein digestibility from 86% to 92%. The maximum digestibility of crude protein is about 90% but levels as low as 68% have been reported (Petterson *et al*, 1997). Low tannin cultivars or dehulled beans are therefore advisable for best results with livestock feeding. Some studies indicate that dehulling and fine grinding increase the nutritional value of faba beans for non-ruminants. However, Perez-Maldonado *et al* (1999) found that 250 g/kg faba beans in a balanced diet for laying hens depressed egg production and egg weight, and that dehulling of the bean or steam or cold pelleting of the diet had little effect on performance. Thus faba beans can be recommended for poultry only at relatively low levels of inclusion.

Table 11. Nutrient and ANF composition of Faba bean and Navy bean (%, as received)[1]

	Faba bean	Navy bean
Dry Matter	89.7	89.9
Protein	24.1	24.3
Fat	1.3	1.5
Fibre	8.4	7.0
Arginine	2.18	1.60
Histidine	0.59	0.67
Isoleucine	0.88	1.10
Leucine	1.68	2.02
Lysine	1.46	1.66
Methionine	0.18	0.19
Threonine	0.82	1.06
Tryptophan	0.15	0.42 [2]
Valine	1.00	1.25
Cys+Met	0.50	0.39
Tyr+Phe	1.74	2.24
Oligosaccharides	2.71	3.23
Phytate	0.66	1.20
Condensed tannins	0.22	0.49
TIA	0.01	0.52
CTIA	0.04	-

[1] Source: Petterson, Sipsa and Mackintosh (1997)
[2] Evans (1985)

In Europe, high levels (up to 40%) of faba beans are often used in diets for pigs, the best results being obtained with white-flowered varieties. In Australia feed formulations for pigs and poultry sometimes include up to 25% faba bean, but there have been some reports of poor performance.

Guar (*Cyamopsis tetragonoloba*)

Guar or cluster bean, though probably originating in Africa, is grown in tropical regions of Asia, chiefly as a vegetable and fodder crop. It is a summer season annual which is resistant to drought, adaptable to poor soils but intolerant of water logging. The optimum temperature range for growth is 25-30^{O}C.

Guar seed contains a galactomannan gum which has multiple uses in the food, textile and other industries. The seed residue after extracting the gum contains around 35% protein but also contains high levels of ANFs, including trypsin inhibitors, haemagglutinin, polyphenols and saponins. The processing technology for gum removal is not available in this country.

The crop is grown commercially in India, Pakistan and the USA and has been extensively trialed and grown in small amounts in Queensland. Seed yield is up to 4 tonnes/ha. Common varieties are Brooks, ECR67 and CP177. Normal harvesting machinery can be used. However, as yet there is no commercial industry in Australia despite the importation of guar gum for both food and industrial uses.

At present it appears that guar meal has little potential as poultry feed due to its high ANF content and the lack of facilities for processing the seed.

Jack bean (*Canavalia ensiformis*)

The jack bean (also known as canavalia bean, horse bean or gotani bean) is a tropical legume that can produce an annual yield of up to 6 tonnes/ha of shelled beans and 10 tonnes/ha of residues, equivalent to a total annual yield of up to 3.6 tonnes/ha of protein (Escobar *et al.*, 1983). A native of South America, it is now cultivated widely in the tropics and subtropics. The bean contains 230-350 g/kg crude protein (dry matter basis – see Table 12) and is an excellent source of threonine, but true protein is probably lower as the crude figure includes some "non-protein amino acids". Also present are a number of ANFs, including the lectin concanavalin-A, two non-protein amino acids canavine and canaline, urease, polyphenols and saponins (Belmar *et al*, 1999). The AME for poultry is 10.5-11.8 MJ/kg (D'Mello *et al*, 1985; Leon *et al*, 1986). Because of the high levels of ANFs the use of untreated jack bean in poultry diets is limited. It is suggested that no more than 5% should be included in the diet. Autoclaving the bean to reduce the inhibitors has been partially effective (Risso, 1984); soaking and cooking apparently have little effect (Moncada *et al.*, 1990) and extrusion results in low intake and reduced average daily gains in young pigs (Risso, 1989). The results of numerous performance studies with poultry using untreated beans and beans that were treated in various ways are summarised by Belmar *et al* (1999). The main finding was that feed intake remains low even after detoxification treatments.

Table 12. Composition of jack beans (% DM)

Form	Protein	Ash	Fibre	Oil	Source
Raw	28.4	-	-	-	León *et al.* (1990) *a*
Extruded	27.9	-	-	-	
Raw	31.0	-	-	4.0	Mora (1983) *b*
Raw	29.6	3.0	9.7	4.0	ICA (1988) *c*
Cooked	27.1	2.8	8.3	3.5	
Raw	35	-	10.5	-	Garcia and Pedroso (1989)
Autoclaved	28.7	4.5	14.6	-	Dominguez and. Ly (1992) *d*

a cited by Michelangeli *et al.* (1990); *b* cited by Escobar *et al.*(1983); *c* cited by Moncada *et al* (1990); *d* unpublished data

Table 13. Essential amino acid profile of jack bean (g/kg DM)

Amino acid	*a*	*b*
Arginine	15.6	17.0
Histidine	8.0	8.0
Isoleucine	12.3	11.0
Leucine	24.9	22.6
Lysine	16.2	16.6
Methionine + cystine	8.0	6.3
Phenylalanine + tyrosine	27.4	22.6
Threonine	13.4	11.6
Tryptophan	-	2.8
Valine	14.2	13.0

Source: *a* Arora (1995); *b* Kessler *et al.* (1990

The main essential amino acids in jack beans are shown in Table 13. The pulse contains low levels of tryptophan and sulphur amino acids, and lysine is also lower than in most other legumes.

Although this is a fairly high yielding crop, its export potential appears to be limited. There are thus a number of factors which give this legume less credibility than many others as a potential protein supplement for poultry.

Lablab (*Lablab purpureus, Dolichos lablab*)

Lablab (dolichos or hyacinth bean) is a widely adapted, vigorous, short-lived, annual or perennial twiner native to India, cultivated mainly for its edible seeds. The bean, also known as Bonavista, Dolichos or Indian butter bean, is a staple protein food in parts of Asia, especially south India. The pulse is used as a vegetable, in curries and made into a type of dhal ("val dhal"). In Myanmar, the pulse is soaked and fried for use as a snack food. The pods and seeds contain small quantities of a cyanogenic glycoside but have been fed to animals as concentrates without any obvious deleterious effects. In Australia, on the other hand, lablab has been used mainly as a forage crop, or for ensilage or green manuring. Two varieties that are commonly grown, Rongai and Highworth, have been selected specifically for forage use. However, research is being carried out on development of the crop for grain production, and recently a cultivar, Koala, selected for grain production has become available. This cultivar was selected from a line introduced into Australia as Q6880 by the Queensland Department of Primary Industries from France in 1962. Evaluation for grain production was commenced in 1984 and several lines were evaluated in field experiments in northern New South Wales from1991-94, and in observation plots in southern Queensland in 1993-94. Unlike Rongai and Highworth, the cultivar has an upright habit, reaching 0.4-0.8 m at maturity (Lucy *et al*, 1999) and has been selected for early maturity to enable seed set before the onset of frosts in the cropping zones of northern New South Wales and southern Queensland. Experimental yield of Koala averages about 1.1 t/ha (range 0.1-2.8t/ha). On the Darling Downs the yield is 0.5-2.0 t/ha, or 1.5-3.0 t/ha under irrigation (Lucy *et al*, 1999). Koala has been compared with mung bean which is also a well adapted summer grain crop for the region. In trials that included mung bean as a treatment Koala outperformed mung bean by 17%. The protein content of Koala lablab grown on five sites in 1992-93 varied from 196 to 283 g/kg (dry grain basis; Holland and Gammie, 1994). By comparison the protein content of other lines grown in Australia is generally low at around 185 g/kg.

As mentioned above, lablab is being used increasingly in crop rotations in the northern grain belt as a means of improving soil fertility and wheat yields. Experiments in central Queensland showed that, compared with many other legumes, lablab offered the best returns in net nitrogen fixation and effect on subsequent cereal crops. Lablab production is therefore likely to increase in northern Australia because it is both a forage and a grain legume crop and it fits well into sustainable agriculture in the subtropics.

Lablab is especially low in the sulphur amino acids and tryptophan (Table 8). The nutrient composition and ANFs of *Dolichos lablab* seed was studied by Deka and Sarkar (1990). The mature seeds of five cultivars were analysed for some nutritional and antinutritional factors. The cultivars showed considerable variation in their composition. On a dry matters basis, the percentage of crude protein varied from 22.4 to 31.3, crude fibre, 7.62 to 9.63 and total carbohydrate, 54.2 to 63.3. The amounts (mg/100g) of calcium, phosphorus, phytate phosphorus and iron ranged from 36.0 to 53.5, 388 to 483, 282 to 380 and 5.95 to 6.90, respectively. All the cultivars tested contained moderately high levels of TIA and 2400-3200 TIU g-1, on a dry weight basis, of the seeds. Phytic acid and tannins varied from 1000 to 1350 and 2000 to 2205 mg/100 g, respectively.

Five diets containing 0, 5, 10, 15 and 25% lablab meal and 25, 20, 10, 5 and 0% soyabean (Glycine max) meal were fed to Cobb broilers until 8 weeks of age. Liveweight gain was highest (28.6 g/day) for the diet containing 25% soyabean and lowest (26.6 g/day) for the diet containing 25% lablab meal (not significant). Treatment had no effect on feed intake or mortality rate. (Sarwatt *et al*, 1991).

Lentils (*Lens culinaris*)

The lentil plant is an annual legume which normally grows to a height of 200-700 mm. Lentils are the fifth most important pulse crop in the world, being grown and used worldwide almost exclusively for human consumption, in the form of the split pulse, whole seed or ground into flour. In India and the Middle East lentils are mainly consumed as a type of dhal, while in Europe and North America they are most often incorporated into soup. They are rich in starch and protein, which is easily digested, and are widely regarded as a health food. However, the quality of protein in lentils is poor, being low in sulphur amino acids and tryptophan. Levels of ANFs, including condensed tannins, protease inhibitors, lectin, phytate and oligosaccharides, are low.

There are two types of lentil; red and yellow (or green). The colour type is determined by internal colour rather than the seed coat. Red lentils (also called microsperma or Persian) are small (3.5-5 mm) with a red-orange cotyledon and grey or speckled seed coat; they are consumed whole or as the decorticated, split pulse. Yellow lentils (also called green, macrosperma, Continental or Chilean) are larger (5-7 mm) with a pale green to brown seed coat, and are generally consumed whole.

Australia is an importer of lentils, currently bringing in 2-3,000 tonnes annually. The main producing/exporting countries are Turkey, Canada, USA and EU countries. There is thus an opportunity to turn an importing situation into an export market, at the same time providing further diversity in cropping over a wide area of Australia, with a spin-off for the livestock feed industry. At present, however, prices are very volatile.

Although winter growth of lentils is slow, in Australia they are currently grown in the cooler regions, mainly in South Australia and Victoria. However they also do well much further north, particularly in northern New South Wales. They will tolerate dry conditions and a variety of soils, but do not tolerate water logging and compete poorly with weeds. Harvesting lentils is difficult as the plant is short and the crop matures unevenly.

Cultivars of red lentil grown in this country include Aldinga, Callisto, Cobber, Digger, Kye and Northfield or its precursor, ILL 5588. The common yellow cultivars are Matilda, Laird and Invincible. The variety that does best in northern New South Wales is said to be Digger. A variety, Crimson, recently released in the USA is said to be adapted to low early rainfall.

Recently red lentils have received bad press as a result of exportation from Australia, probably fraudulently, of a cheap look-alike, the seed of a cultivar of the common vetch, *Vicia sativa* ssp. s*ativa* cv Blanchefleur. This legume contains high levels of two toxins, glutamyl-cyanoalanine and vicine. An article in Nature (Tate and Enneking, 1992) led to a ban on its importation by India and Egypt. However the lesson was not learnt, and recently the vetch seed has apparently been exported to Bangladesh, Pakistan and Sri Lanka.

Lima bean (*Phaseolus lunatus*)

The Lima bean, a relative of the navy bean, is a summer crop which does best at a temperature of 20-35^{O}C and an annual rainfall of 600-1000 mm. Lima beans are currently imported from the USA but could easily be grown more extensively in Queensland, where the climate is suitable and the right type of harvesting equipment is available. In the north of the State lima beans could be grown as a winter crop. Varieties of the baby green type suitable for Queensland include Improved Kingston and Mendoza bush. It is estimated that gross margins would be 20% higher than for navy beans. A potential export market is Japan, which currently imports much of its lima bean requirements from Myanmar. In Australia the beans are used mainly as green baby limas and in salad bean mixes. The composition of the bean is similar to that of navy bean and it probably contains similar ANFs. Little is known about the use of the bean in poultry diets. At present market prospects appear limited and sufficient quantities are unlikely to be cultivated to make a worth while contribution to the livestock feed industry.

Marama bean (*Tylosema esculentum*)

This legume is a perennial, prostrate vine-like plant adapted to the Kalahari desert region in Botswana and Namibia. It will grow in areas that receive only erratic rainfall as well as in areas with falls up to 800 mm. It is a rich source of protein and energy, and the tubers as well as the seeds are eaten. The protein content of the seeds is higher than in most other legumes, ranging from 30-39%, while the oil content is 36-43%, or approximately twice that of soybean. Like other legumes, the protein is rich in lysine and deficient in methionine. However the beans contain ANFs and are never eaten raw. The tubers are normally eaten when they are young, weighing about 1 kg, but they will grow up to a weight of 10 kg.

This legume is said to be one of the least researched and developed and perhaps has great potential for improvement and wider utilisation. In Australia it could have potential in arid regions, but much more agronomic research is required before it can be considered for feeding animals. The two main drawbacks appear to be its prostrate habit, which would make harvesting difficult, and the obvious presence of ANFs.

Moth bean (*Vigna aconitifolia*)

The moth bean is grown mainly in the arid regions of north-western India and Pakistan, where it is too dry for other legumes. It forms a low-lying mat which reduces moisture loss, soil erosion and weed growth, but makes harvesting difficult. In India the pulse is used whole or split and the pods are eaten as a vegetable. The plant is also grown as a pulse crop in south-eastern regions of Asia and is used as a fodder crop in the USA. The crude protein content of the bean is 22-31% and the amino acid profile resembles that of mung bean.

In Queensland experimental yields of 600-2600 kg/ha have been achieved but average commercial yields are much lower. The rainfall requirement is 500-750 mm for optimum yields, but it will tolerate as little as 50 mm during the growing period. The plant will tolerate salinity but not water logging, and it shows little susceptibility to pests and diseases. The best variety trialed in south-eastern Queensland was IPC MO 950 (CPI 96943). No information is available on the use of the bean for poultry. Until more basic development of the agronomy and market for this legume occurs, there is little incentive to pursue its use as poultry feed.

Mung bean (*Vigna radiata*)

The mung bean, a native of the Indo-Burma region also known as green gram, is an erect annual with a short growth period (75-90 days) and, like other tropical legumes, it requires no nitrogen fertiliser and less water than many other crops. Approximately 90% of the world production of mung bean comes from India, Myanmar, Thailand, China and Indonesia. In Australia mung bean is grown as a warm season opportunity crop in rotation with cereals. Its chief drawback is that it is difficult to produce premium grade seeds, but this does mean that considerable quantities of the pulse become available for use as livestock feed.

Mung beans are easily digested and relatively free from anti-nutritional factors. Their chief culinary use in India is as a type of dhal (moong dhal), a thick soup made from the split pulse. The pulse is widely used throughout the subcontinent, in some regions forming an important part of the staple diet. Mung bean sprouts are rich in vitamin C and may be used as a green vegetable when other vegetables are scarce. A flour made from the pulse can be incorporated at up to 30% in vermicelli or spaghetti, giving it a higher protein content and greatly improved amino acid balance. In other parts of Asia, mung beans are used for making a range of desserts, snacks, soups, main dishes and processed products. By-products of mung bean noodle production are used to make protein-rich foods and animal feed. Mung bean has some valuable culinary properties. Due to the heat-stable viscosity of its starch, it is a useful ingredient for products which need high consistency at high temperatures (Petterson *et al*, 1997). Replacing 5-10% of wheat flour with mung bean flour improves the mixing properties of dough and produces acceptable bread.

In Australia mung beans are grown from the Northern Territory through to southern New South Wales, most of the production (about 30,000 tonnes per annum) coming from Queensland and northern NSW. Of this, approximately 10-20% goes into stock feed at $150-200/t, 50-70% is for processing at $400-450/t and the rest is for prime sprouting and cooking at $600-700/t. Most of the crop is exported to Taiwan, the Philippines, USA, UK and elsewhere. There has been a concerted effort by the Australian Mung bean Association to promote the growing and marketing of the crop. Cultivation and exports are expanding as production is on the decline in some Asian countries.

Mung beans can be grown all year round on a variety of soils, but the optimum temperature for growth is 27-30^{O}C (Imrie, 1998b). The most important disease is charcoal rot (*Macrophomina phaseolina*). The leaf spot, *Curtobacterium flaccumfaciens*, is another serious disease, while in the tropics the bruchid beetle is an important post-harvest pest. The fungus *Sclerotinia sclerotiorum* can completely replace the seed in the pod. At harvest, this fungus resembles rat or mouse droppings among the seed. However, an experiment with pigs fed mung beans containing the fungal bodies found no adverse effects other than a slight drop in growth rate owing to changes in nutrient content caused by fungal attack.

Mung beans typically contain 230-260 g protein and has a low oil content of 7-10 g/kg (see Table 8). The protein is an excellent source of lysine and tryptophan: the amino acid profile, in proportion to protein content, is comparable to that of soybean, with methionine and cystine being the limiting amino acids, and it is also rich in vitamins A, B1, B2, C and niacin. The green seed coat is low in tannin and only small or zero amounts of trypsin inhibitors and other ANFs appear to be present in the seed.

Limited studies on mung bean as a feed source for poultry and pigs indicate that it is approximately half as valuable as solvent extracted soybean meal. Experiments have shown that up to 28% mung beans can replace part of the soybeans in a wheat or sorghum based diets without affecting performance.

Net energy content and protein levels vary according to the weather during growth. Complex changes occur from water and nutrient stress to the plant. Water damage at harvest leads to sprouting with an initial improvement in energy content which falls off after about two days.

Many varieties of mung bean are grown, some popular ones being Emerald, Berken, Celera, King, Delta and Satin. A new higher yielding variety (cv CP198867) that is resistant to leaf spot disease has recently been released. Other new varieties are VC1973, which is similar to Emerald and Berken, and HS23, which is seen as a replacement for Celera. Little research has been conducted on the varietal differences in terms of nutritive value of the crop and yield. Seed size and colour vary but chemical compositions appear to be similar.

Table 14. Nutrient composition of mung bean varieties

Variety	Fibre	Protein	Ca	Avail P	Lys	M + C	Tryp	Thre	Isol
	%	%	%	%	%	%	%	%	%
Berken	3.5	24.8	0.10	0.23	1.67	0.55	0.43	0.84	1.07
Celera	3.9	25.0	0.12	0.23	1.73	0.54	0.43	0.84	1.08
King	3.9	26.1	0.11	0.24	1.81	0.56	0.43	0.87	1.05
Average	3.8	25.3	0.11	0.23	1.74	0.55	0.43	0.85	1.07

(Adapted from A. Takken, Agdex 440-64)

Narbon bean (*Vigna narbonensis*)

The narbon bean or moor's pea, a relative of the faba bean, is used as feed for animals in the Middle East and has been evaluated in southern Australia as an alternative to peas and lupins (Petterson *et al*, 1997). More recently further evaluations of a large number of varieties have been carried out in Victoria. Although yields have been good (up to 3.5 t/ha, which is better than for field peas), there has been no incentive to develop an industry owing to lack of an existing market and the presence of unpalatable factors in the bean. The bean has a flavour resembling garlic which makes it unpalatable to humans, pigs and poultry. Recently the chemical molecule that causes this flavour has been identified, opening the way for improvement by post-harvest treatment or breeding.

Narbon beans are said to be unaffected by many common diseases of legumes, tolerant to drought and high pH and unlikely to be attacked by mice and birds. The crop may be useful for rotation in a range of conditions and has potential for use as a drought supplement, green manuring and feed grain production.

The fat content of narbon beans is low and the fibre content high, resulting in a gross energy value of about 18.5 MJ/kg (Petterson *et al*, 1997). No ME values for non-ruminants are available, but the ME can be expected to be comparatively low. The protein content is about 250-270 g/kg. Feeding trials with young chickens indicate that they are can be fed at dietary levels up to 10%. Narbon beans appear to contain ANFs which may limit their use in pig and poultry diets.

Navy bean (*Phaseolus vulgaris*)

The navy bean is just one type of bean belonging to the species *P. vulgaris*, generally known as dry beans or fieldbeans (not to be confused with faba beans, which are also sometimes known by that name). *P. vulgaris* was probably domesticated in Central America and Peru about 7000 years ago and have become the foremost grain legume crop (as opposed to oilseed legumes such as soybean and groundnut), with an annual yield of 20 million tonnes or 30% of world pulse production. Major producers are Brazil, Mexico, USA and Europe. Fieldbeans are conveniently divided into two main classes: navy beans proper, which are small (120 to 220 mg) and have white seed coats, and culinary beans, which vary in size (250-600 mg) and seed coat colour (white, red or multicoloured). Culinary beans include the red kidney, Great Northern and Borlotti types, with many sub-varieties, and are mainly used as a green vegetable or as dried or canned beans. Navy beans are mainly consumed as processed "baked beans". Fieldbeans are a staple protein food in Brazil and other parts of Latin America and throughout East Africa.

In Australia navy beans are grown mainly in New South Wales as a high value summer grain legume ($700+ per tonne). They require a soil temperature of 18^{O}C and tend to suffer heat stress at air temperatures above 35^{O}C. However, cultivation of navy beans is spreading from the subtropical areas into cooler regions. It is expected that the increasing production will partly replace imported beans and perhaps lead to development of an export industry. The Queensland DPI has been conducting an intensive breeding program which has resulted in the release of a number of varieties suited to a range of conditions in Queensland and elsewhere. Recently released cultivars from this program include Spearfelt, Rainbird and Sirius.

Navy beans and culinary beans differ little in their nutritive value and data have been combined for have been combined for tables 25-27. The protein content (220-240 g/kg) is similar to that of field peas and is low in methionine (0.9 g/16 g N) but relatively high in lysine, threonine and tryptophan (see Table 11).

ANFs present in navy beans include lectins and protease inhibitors; which must be removed or reduced before feeding to poultry. This can be achieved by blending with a high-fat ingredient followed by extrusion processing at approximately 135°C. Downgraded beans may be incorporated in untreated form in feed for ruminants.

Pigeon pea (*Cajanus cajan*)

Pigeon pea is cultivated extensively in India, Southeast Asia, parts of Africa and the West Indies. While most of the world's production of pigeon pea is consumed by humans, grain of poor quality may be used as animal feed. The split pea is generally either boiled with condiments to make dhal, or used in flour preparation. (While true dhal is made from pigeon peas, several other pulses are used in a similar way throughout the Indian subcontinent and elsewhere to make other kinds of "dhal"). Cooking quality is an important consideration, with a desirable cooking time for the dhal being about 20 minutes (Petterson *et al*, 1997). In India pigeon pea has long been used as animal feed. It is expected that the use of grain will spread as its value as animal feed becomes more widely recognised, particularly in those areas where the crop should outperform other grain legumes (Petterson *et al*, 1997).

A revival of the pigeon pea industry in Australia is anticipated now that new lines with extra short duration to flowering have been obtained for evaluation. Pigeon pea is suited to tropical and subtropical conditions and has potential as a field crop in Queensland. It is a shrub that grows from one to a few metres tall and up to 2m wide, unless special short-season varieties are chosen. Grown as a summer legume, it has the usual ability to fix nitrogen. Other attributes include (Meeken *et al*, 1987):

- Being perennial, if one flush of flowers or pods is lost another is produced. This enhances recovery after temporary setbacks such as drought, waterlogging or insect attack
- Because of its deep root system, pigeonpea is drought resistant and grows well under dry conditions
- It is less sensitive than other legumes to low nutrient soils.

On the other hand the plant is intolerant to waterlogging and frost and highly attractive to pod-boring insects, and harvesting is not as easy as with some other legumes. They are said to thrive best where annual rainfall ranges from 500-1,500 mm. According to Morton *et al* (undated), the range of suitable elevations varies quite strongly with latitude even within the tropics. In Venezuela, for example, they are grown up to 3,000 m, in Jamaica up to 1,100 m but in Hawaii they failed to set seed at 1,000 meters. The pigeon pea is noted for greater soil adaptability than other legumes and can endure a pH of 5-8 and soil salinity of 0 5 mg NaCl/g.

Pigeon pea has a variable but usually high food value: a protein content of 180-290 g/kg, starch content around 500 g/kg and high vitamin B content. The amino acid profile is rather poor, being wanting not only in methionine and cystine but also in iso-leucine and threonine. Research has shown that the crop has use both as a forage and in rations for pigs and poultry. Protein digestibility is reported to range from 77% to 99%, and cooking the peas substantially improves digestibility (Fialho *et al*, 1985; Table 15). From the point of view of feeding to poultry, the chief disadvantage of pigeon pea is its high trypsin inhibitor activity (Table 16).

Table 15. Chemical composition and digestibility of pigeon pea

	Composition (% DM)				Digestibility (%)	
Form	**Protein**	**Ash**	**Fibre**	**Oil**	**N**	**Energy**
raw	23.8	4.3	10.6	1.4	71.5	77.4
cooked	23.0	3.4	10.3	1.1	81.6	83.4
toasted	22.4	3.9	10.6	0.9	76.3	83.4

Source: Fialho *et al.* (1985)

Table 16. Trypsin inhibitor activity (TIA) and chymotrypsin inhibitor activity (CIA) of raw and cooked pigeon pea samples of high and normal genotypes

Genotype	TIA				CIA		
	Raw		Cooked		Raw		Cooked
	a	b	a	b	a	b	
HPL 8	7.2	25.1	0.4	1.5	3.5	12.2	ND
HPL 40	5.4	17.4	0.7	2.3	3.8	12.4	ND
C 11	4.8	19.4	0.4	1.7	2.2	8.9	ND
ICPL 211	6.9	24.8	0.3	1.3	2.4	10.4	ND

[a]Enzyme units inhibited per mg meal. [b]Enzyme units inhibited per mg protein. ND = Not detected.

Pezzato *et al* (1995) studied the effects of autoclaving at 100°, 110° and 120°C for 10, 20 and 30 min on ANFs in pigeon pea meal. A 3 x 3 factorial trial with broilers using soybean protein as control was conducted. Underheating and overheating during inactivation of proteinase inhibitors were evaluated by urease activity and protein solubility, after the grains were dried and ground. After 28 days' feeding, it was concluded that, for optimum feed conversion efficiency, autoclaving for 20 minutes was best, irrespective of temperature. There were no histopathological changes in kidney, liver, pancreas, heart or intestines.

Amino acids, fatty acids and mineral contents of pigeon pea were analysed: by Oshodi, Olaofe and Hall, (1993). Protein contained nutritionally useful quantities of most essential amino acids but was low in sulphur-containing amino acids. Linoleic and palmitic acids were the predominant fatty acids, 54.8 and 21.4% respectively of the oil content. Caprylic, lauric, oleic and eicosenoic acids were present only in small quantities. Potassium, magnesium and calcium were the most abundant minerals, while sodium content was low.

Kumar *et al* (1991) studied the variation in quality traits of pigeon pea cultivars. Physico-chemical composition and nutritional quality of six promising varieties of pigeon pea were investigated. The ranges of values were: tested weight 66.1-73.5g, dhal in grain 66.45-68.50%, yield 1395-2185 kg/ha, moisture 10.0-11.0%, protein 18.2-19.8%, protein yield 254-433 kg/ha, digestibility of protein. 32.1-38.1%, energy 3123-3267 kcal/kg, tryptophan 0.37-0.46g/16g N, tryptophan yield 0.94-1.99kg/ha, methionine 0.98-1.10g/16g N, methionine yield 2.49-4.63 kg/ha, chemical score, 29.17-32.74%, biological value 57.28-59.38, total minerals 2.30-2.95%, calcium 115.05-122.30 mg/100g, iron 8.0-9.2 mg/100g, available iron 1.90-3.41 mg/100g, ascorbic acid 2.35-3.40 mg/100g, vitamin A 108.0-118.7 I.U. thiamine 0.40-0.47 mg/100g and riboflavin 0.09-0.12 mg/100g. Overall “Type-21” was considered to be the best of the varieties analysed.

Table 17. Main essential amino acids in pigeon pea (%DM)

Arginine	1.28
Isoleucine	0.78
Leucine	1.63
Lysine	1.42
Methionine + cystine	0.57
Phenylalanine + tyrosine	1.85
Threonine	0.83
Tryptophan	0.25
Valine	0.94

Source: D'Mello *et al.* (1985); CPNSA (1991)

The nutritional quality of newly developed high-protein genotypes of pigeon pea was evaluated by Singh *et al*. (1991). Two high-protein genotypes, HPL 8 and HPL 40, were analysed and compared with normal-protein genotypes (C 11 and ICPL 211). The protein content of the high-protein genotypes was higher on average by nearly 20% but their starch content was lower by about 8%. The higher fraction (about 7%) of globulin, the major storage protein, was associated with a lower glutelin fraction in the high-protein genotypes. The amino acid composition (g/100 g protein) of the high-protein genotypes was comparable with those of the normal-protein genotypes. However, the sulphur-containing amino acids methionine and cystine were noticeably higher (about 25%) in high-protein genotypes when results were expressed in g per 100 g sample. No large differences in true protein digestibility, biological value or net protein utilisation were observed between HP and NP genotypes. True protein digestibility was significantly increased by cooking in both whole-seed and dhal samples. The values for utilisable protein were considerably higher in high-protein genotypes.

Table 18. Chemical composition of pigeon pea of high and normal protein genotypes[a]

Genotype	100-seed mass (g)	Protein	Starch	Soluble sugars	Fat	Ash	Crude fibre
		(g/100 g)					
HPL 8	10.7	28.7	54.3	4.3	2.6	4.9	1.4
HPL 40	9.3	31.1	55.6	5.1	2.5	5.1	1.1
C 11	11.0	24.8	58.7	4.8	2.9	4.9	1.2
ICPL 211	12.7	23.1	59.3	4.2	3.1	5.0	1.4
SE	±0.34	±0.09	±0.30	±0.06	±0.02	±0.03	±0.03

[a]Averages of two determinations and expressed on dry weight basis.

Table 19. Protein fractions of pigeon pea sample of high and normal protein genotypes[a]

Genotype	Protein (g/100 g)	Albumin	Globulin	Glutelin	Prolamin	Total
		(g/100 g protein)				
HPL 8	28.7	9.1	63.5	20.2	2.9	95.7
HPL 40	31.1	8.0	66.2	19.7	3.2	97.1
C 11	24.8	7.7	60.5	23.3	3.6	95.1
ICPL 211	23.1	8.6	60.3	22.8	2.1	94.5
SE	±0.09	±0.34	±1.08	±0.75	±0.06	-

[a]Averages of two determinations and expressed on dry weight basis.

Table 20. Amino acids (g/100 g protein) in high and normal protein pigeon pea genotypes

	HPL 8	HPL 40	C 11	ICPL 211	SE
Lysine	5.5	5.8	5.8	6.0	±0.07
Histidine	3.2	3.2	3.2	3.3	±0.03
Arginine	5.7	6.3	5.8	5.6	±0.02
Aspartic acid	8.7	8.7	8.7	8.9	±0.14
Threonine	2.0	2.9	3.0	3.0	±0.11
Serine	4.1	4.0	4.1	4.3	±0.07
Glutamic acid	20.5	20.0	21.2	21.3	±0.21
Proline	3.7	4.1	4.4	4.8	±0.12
Glycine	3.4	3.2	3.4	3.3	±0.05
Alanine	3.6	3.7	3.9	4.0	±0.03
Cystine	0.8	0.8	0.7	0.7	±0.01
Valine	3.6	3.7	3.9	4.1	±0.08
Methionine	1.0	1.0	1.1	1.1	±0.02
Isoleucine	3.4	3.2	3.5	3.6	±0.03
Leucine	6.4	6.4	6.7	7.0	±0.08
Tyrosine	2.6	2.5	2.7	2.7	±0.03
Phenylalanine	8.3	7.9	8.1	8.7	±0.09
Protein (g per 100 g)[a]	29.9	32.5	25.7	24.2	±0.09

[a]Analysis of defatted dhal samples (N x 6.25, dry weight basis).

Table 21. Biological evaluation of raw and cooked whole seed samples of high and normal protein genotypes[a]

Raw					
Genotype	Protein[b]	TD	BV	NPU	UP
HPL 8	25.6	58.5	68.7	40.2	10.3
HPL 40	27.3	58.0	70.5	40.9	11.2
C 11	21.9	59.5	64.3	38.3	8.4
ICPL 211	21.0	60.6	64.0	38.8	8.1
SE	±0.48	±1.08	±1.13	±0.64	±0.23

Cooked					
Genotype	Protein[b]	TD	BV	NPU	UP
HPL 8	24.4	79.4	68.5	54.4	13.3
HPL 40	27.6	75.8	66.4	50.3	13.9
C 11	22.2	75.6	62.5	47.3	10.5
ICPL 211	20.9	74.9	64.5	48.3	10.1
SE	±0.32	±1.35	±1.07	±1.01	±0.31

[a]TD = True protein digestibility, BV = biological value, NPU = net protein utilisation (TD x BV/100), UP = utilisable protein (protein x NPU/100).
[b]Protein = N x 6.25 (dry weight basis).

Table 22. Biological evaluation of cooked and raw sample of dhal of high and normal protein genotypes[a]

Raw					
Genotype	Protein[b]	TD	BV	NPU	UP
HPL 8	28.7	71.5	75.8	54.2	15.6
HPL 40	31.1	69.8	73.6	51.4	16.0
C 11	24.8	72.3	73.6	53.2	13.2
ICPL 211	23.1	70.8	76.4	54.1	12.5
SE	±0.28	±0.98	±1.14	±1.23	±0.34

Cooked					
Genotype	Protein[b]	TD	BV	NPU	UP
HPL 8	27.6	83.7	67.0	56.1	15.5
HPL 40	30.8	82.9	65.3	54.1	16.7
C 11	23.9	84.3	66.7	56.2	13.5
ICPL 211	22.8	85.7	62.9	53.9	12.3
SE	±0.26	±2.14	±1.68	±1.06	±0.25

[a]TD = True protein digestibility, BV = biological value, NPU = net protein utilisation (TD x BV/100), UP = utilisable protein (protein x NPU/100).
[b]Protein = N x 6.25 (dry weight basis).

Table 23. Comparison of some nutritional constituents of green and mature pigeon peas on a dry-weight basis

Constituent	Green Seed	Mature Seed
Protein (%)	21.0	18.8
Protein digestibility (%)	66.8	58.5
Trypsin inhibitor (units/mg)	2.8	9.9
Starch (%)	44.8	53.0
Starch digestibility	53.0	36.2
Amylase inhibitor (units/mg)	17.3	26.9
Soluble sugars	5.1	3.1
Flatulence factors (g/100g sol. sugar)	10.3	53.5
Crude fibre (%)	8.2	6.6
Fat (%)	2.3	1.9
Calcium (mg/100g)	94.6	120.8
Magnesium (mg/100g)	113.7	122.0
Copper (mg/100g)	1.4	1.3
Iron (mg/100g)	4.6	3.9
Zinc (mg/100g)	2.5	2.3

Source: ICRISAT, (International Crops Research Institute for the Semi-Arid Tropics) Pantancheru, Andhra Pradesh 502 324, INDIA.

Although pigeon peas are most commonly grown to produce a mature, dried pulse crop, the seeds can also be consumed as a "vegetable" – a common use in Indonesia, where the green seeds are included in salads.. When required for this purpose, the peas are harvested when the seeds are fully grown but before they lose their green colour. At this stage the seed is more nutritious as it contains more protein, sugar and fat, its protein is more digestible and there are lower levels of flatulence factors (Table 23). The level of trypsin inhibitors is also markedly lower, suggesting that early harvesting may be a way of reducing ANF levels - an important consideration when feeding pigeon peas in untreated form to poultry.

According to ICRISAT, the best vegetable pigeon pea cultivars have long pods, containing up to nine large, sweet seeds. At suitable temperatures (15-30^{O}C) yields of up to 11 tonnes/ha of green pods in five pickings from one plot have been obtained. Because pod colour at harvesting differs among varieties, seeds may need to be sampled to decide the best time to harvest. In the Caribbean, harvesting has been mechanised by adapting green bean pickers.

Tepary bean (*Phaseolus acutifolius*)

The tepary bean is a native of the Sonoran desert in North America and is said to have been used as food by native Americans for over 5000 years. It is a promising crop for semi-arid to arid regions with infrequent but heavy rains and extreme heat (NAS, 1979). The leaves and pods are used as fodder. There are many varieties, the plant varies from a bush in dry conditions to a vine in wetter areas and the seeds vary greatly in appearance. Tepary beans do well in areas with as little as 500-600 mm annual rainfall, and have produced up to 1500 kg/ha with falls as low as 200 mm. The legume is highly resistant to blight, a trait which has led to their incorporation in *P. vulgaris* breeding programs. The crop has been grown successfully in dry areas of Africa and has a reputation for recovering after stress. Studies by the USDA have found that tepary beans perform best and yield more than the navy bean under higher temperatures in dry regions, protein content ranges from about 18 to 27% and ANF levels are generally lower than in the navy bean.

Despite the success of some farmers with this legume in dry regions, low yield and poor flavour are considered to be the main hindrance to commercialisation. The bean also has an extremely long cooking time and is apt to cause flatulence. The plant is intolerant of high humidity and night-time temperatures below 8^{O}C, which may preclude its development in Queensland. Little research has been put into development of this legume and a better understanding of its agronomy is required before evaluating it as a poultry feedstuff.

Winged Bean (*Psophocarpus tetragonolobus*).

The wing bean is considered in some quarters to be one of the most promising plant protein and vitamin sources for the future (Arora, 1995; NRC, 1981). In terms of nutrient content and digestibility, it is similar to soybean and is sometimes referred to as "the soybean of the tropics". The mature dry seeds are the most nutritious part of the winged bean. Their outstanding nutritive quality is due to their high protein content (30-42%), favourable amino acid profile, edible oil content (15-20%) and mineral component (3.3-4.9%). Like other legumes, winged beans are deficient in the sulphur amino acids but are rich in lysine. Chimmad *et al* (1998) analysed thirteen genotypes of winged bean and found the following average composition (g/kg): moisture 95.7, protein 324.9, fat 179.5, crude fibre 55.7, carbohydrates 301.1, minerals 43.3, calcium 21.7, iron 12.4, tannins 12.9, free phenol 1.62 and phytic acid 3.55. Trypsin inhibitor activity was 1309 TIU/g. There was significant variation among genotypes. Protein content and trypsin inhibitor activity also appear to vary with maturity (Prakash *et al*, 1991).

The metabolisable energy content of winged bean seeds for poultry varies from 11.9 to 12.2 MJ/kg (dry matter basis). Heat treatment is necessary to adequately remove the anti-nutritional fractions so as to render the protein more digestible. De Lumen *et al* (1982) reported that replacement of soyabean meal by up to 50% defatted autoclaved winged bean did not affect body weight gain and feed conversion of broiler chicks.

The main drawback of winged bean is that it must be grown on trellises and cannot be grown as a broad acre crop. It is thus not easily adaptable to Australian agronomic systems and its use as a livestock feed will depend on the development of appropriate technology for large-scale production.

Summary of Findings

The following summary provides comment on the potential of the materials described and classifies them as being “doubtful” or “promising” from the point of view of development as a source of protein for poultry.

Oil seeds and nuts

Doubtful

Copra and **palm kernel** meal have a high fibre content and low levels of some important essential amino acids, notably iso-leucine, lysine and threonine. Large plantations of coconut or oil palm are unlikely to be established in Australia.

Safflower meal protein is of rather poor quality, the crop is better suited to temperate climates and there are no special features indicating greater usage of safflower by the poultry industry.

Promising

Linseed meal has a well-balanced amino acid profile, apart from a deficit of lysine, and **Linola** is a promising oil seed that may have a bright future in cooler regions of Australia. The grain industry, however, views Linola as a niche market and is providing a higher level of support for the development of canola and sunflower. Linola is likely to be developed as a winter crop for temperate regions and current varieties appear to be unsuitable for warm climates.

Sesame meal is a high protein product which, although very low in lysine, has a high tryptophan content and a useful amino acid profile overall. Sesame appears to have excellent prospects as a crop for northern Australia. Its main shortcomings are related to ANFs and small seed size.

Aquatic plants

Doubtful

Algae are a valuable source of tryptophan but wanting in iso-leucine and methionine. Harvesting is problematic and acts as a deterrent to the development of algaculture.

Promising

Duckweeds probably have a better amino acid profile than any other edible plant and can produce more protein per hectare. The leaf meal contains about 40% protein. Harvesting should be unproblematic, but the cultivation technology for Australian conditions needs to be developed. Large areas of sheltered water are needed.

Azolla spp appear to contain protein of excellent quality but the protein content of the dried leaf meal is lower than that of duckweed, the ash content is 40% and high tannin levels could be a problem. Yield per hectare is generally lower than for duckweed, and cultivation problems are similar.

Fodder trees and shrubs

Doubtful

Leucaena, ***Trichantera*** and **Neem** were considered. Tree leaf material is difficult to harvest and *Leucaena* has the additional drawback of ANFs. Neem seed could have potential but at this stage there is insufficient information to make a useful judgment.

Single cell proteins

Doubtful

The fact that there was once a thriving industry which has all but disappeared tells the story. However it could revive at any moment, pending the development of a cost effective production system utilising a safe, but otherwise useless, growing medium. Yeasts generally have a well-balanced amino acid profile apart from their very low sulphur amino acid content.

Grain legumes

The legumes as a group show tremendous potential for production of protein for poultry and other livestock in northern Australia. They comprise an extremely rich and diverse genetic resource and have a special ability to contribute to sustainable agricultural systems. Many species have been well developed, mainly to supply international markets with food grain, and new varieties suitable for cultivation in a wide range of conditions are continually being released. Although many grain legumes have a rather low sulphur amino acid content, this problem is of dwindling concern as the cost of adding synthetic methionine to poultry diets is falling.

A number of legumes, including mung bean (Vigna radiata), chickpea (Cicer arietinum) and lablab (Lablab purpureus), have been identified as providing the greatest potential for increased use in intensive livestock.

Doubtful

Faba beans faired least well of all the legumes considered, owing to their relatively unbalanced amino acid profile, presence of ANFs which seem hard to eliminate, observed depression of layer performance at modest levels of inclusion and the adaptation of the plant to temperate rather than warm climates.

The utility of several other legumes for poultry cannot be pursued at this stage due to lack of basic knowledge on various aspects of their production, commercial potential or ANF profile, or perceived difficulties with factors such as harvesting, processing and marketing. This category includes **bambarra groundnut, black gram, guar, Jack bean, lentils, lima bean, marama bean, moth bean, narbon bean, tepary bean and winged bean**.

Of these, some species, such as the **marama bean, moth bean** and **winged bean**, look sufficiently interesting to deserve more investigation at the agronomic level, with more effort being put into their development.

Promising

Adzuki beans have a relatively good amino acid profile and probably contain more lysine than other legumes. However they contain ANFs including tannins which may limit their use for poultry. The crop is rather difficult to grow, but there is an export market to be exploited.

Chick peas are available in a range of types, most of which appear to have a better amino acid profile than most other grain legumes. This legume has undergone improvement, it is well established, production is increasing, its potential unquestionable and the newer varieties need to be assessed as feed for layers. ANFs remain a problem, though less severe than in some other legumes.

Cowpeas appear to have a protein quality similar to that of chick peas and, while trypsin inhibitor activity may be higher, other ANFs are apparently less significant. The crop is well suited to conditions in northern Australia and it therefore deserves similar attention to chick pea. African varieties are apparently superior to currently available Australian varieties, suggesting that importation of breeding stock is required.

Lablab is still in the process of development as a pulse crop and has a relatively poor amino acid profile, being deficient in tryptophan and sulphur amino acids. However its wide use (as a forage crop) in environmentally sensitive cropping systems establishes it as an important legume which demands attention by the stockfeed industry.

Mung beans, like lablab, are an important component of cropping systems and the development of high yielding grain varieties has already occurred. It has a very useful amino acid profile, being an especially good source of tryptophan, though low in methionine and cystine. The bean has already shown itself to be the most viable legume supplement for inclusion in the raw form in poultry diets. Cost is the limiting factor at present. The newer varieties need to be investigated for use as poultry feed.

Navy beans, apart from their deficiency in methionine and cystine, possibly have the best amino acid profile of any legume, and many varieties are suited to Queensland conditions. Their main disadvantage is their high ANF levels which must be reduced by heat treatment before feeding to poultry.

Pigeon peas have only a moderately good protein quality. Considerable research has been done on the composition of Australian varieties, but evaluation as poultry feed is lacking. The crop has some useful agronomic properties, as well as difficulties. Its high importance as a provider of human food overseas suggests that more studies with monogastric animals would be worthwhile. Trypsin inhibitors are a problem.

Conclusions and Research Priorities

This review finds that **grain legumes** as a group show the greatest potential for production of protein for poultry in Queensland and other subtropical regions of Australia. Other species that appear to merit an increased research input into development as feed sources for intensive livestock are the oilseeds **Linola** and **sesame** and the **duckweeds**.

Among the legumes that have already undergone considerable development, either in this country or overseas, **chick pea, cowpea, lablab, mung bean** and **pigeon pea** look most promising for use in northern Australia. Considerable research has been done on the nutrient composition of recent varieties of pigeon pea, and perhaps more agronomic research is needed before doing extensive nutritional evaluations with poultry. There are also some lesser known and less well developed legumes, such as **marama bean, moth bean** and **winged bean**, which merit research at a more basic level.

Immediate research is required to evaluate varieties of the better known grain legumes, and to find ways of utilising them in layer diets without the need for costly further processing. Detailed nutrient and ANF profiles are required and laying hen trials are needed to determine the maximum levels at which the legumes can be fed, either in the raw form or with minimal processing. It is also desirable to know whether there is likely to be much variation in chemical composition due to different soils and climates.

The following cultivars were identified as being most appropriate for Queensland conditions. Being quite recently released varieties, little is known about their value for poultry.

Chick pea	Amethyst, Barwon
Cowpea	Red Caloona, Caloona (buff)
Lablab	Koala
Mung bean	Emerald, Delta, CP198867, VC1973

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