Chapter 1

General Introduction

Poultry production is an essential component of total animal production in developing countries, such as Indonesia, and provides a protein-rich source of human food. However, the production of poultry feed creates a dilemma because of the competition for raw materials between a country's human and animal populations and therefore there is often a lack of raw materials for stockfeed or a fluctuation in their supply. The utilisation of alternative and/or unconventional raw materials, accordingly, becomes a necessity to support animal production and, more importantly, the intensive animal industries such as the poultry industry.

Experiments using various alternative protein raw materials for broilers have been conducted and several experiments have concluded that the use of alternative raw materials, in limited amounts, can promote broiler growth and result in economic benefits. Moreover, the use of the main plant protein source in animal production, soybean meal, when fed as the only protein source, often produces lower performance in poultry when compared with a diet that has a combination of protein sources which may have the advantage of complementation between the protein sources.

Peanut is an important part of the human diet in tropical countries. Peanut meal, the residue of peanut-oil production, has high potential in Indonesia as a stockfeed because of its availability and price. Up to now, however, there has not been a concerted effort to examine this protein meal to discover how it may be used most effectively.

Moreover, the utilisation in poultry diets of waste by-products that are unsuitable for humans but readily available, such as peanut shell, may be possible. An understanding of the optimum use of each feed ingredient is crucial to enhance bird performance and to avoid or minimise any associated deleterious effects.

Chapter 2

Literature Review

2.1. Importance of Broiler Production in Indonesia

The broiler industry is the most important sector of animal production in Indonesia and it contributed approximately one third of the total meat production of Indonesia in 1994 (FAO 1995). This industry mainly involves medium and large integrated companies that have breeding farms, feedmills and commercial farms, not only for broiler but also for egg production. Some of these companies grow chickens in partnership with small farmers, providing all the materials needed by the farmers including training and problem-solving services and the marketing of final products.

Broiler production is a business in which volume is necessary to offset the small unit of profit and hence only the larger companies have sufficient capital to overcome most problems faced by the industry, especially the uncertain fluctuation of the poultry meat price. Such companies can also find raw materials for feed locally or can import these materials from overseas if needed. The feedmills in Indonesia have a difficult task in obtaining adequate supplies, in particular of proteinaceous feedstuffs, for the manufacture of animal feeds due to the fluctuation of locally produced raw materials (Wanasuria & Hutagalung 1989). Therefore, the use and evaluation of alternative or unconventional feedstuffs are needed in order to support this industry in terms of both price and availability.

At present, animal protein consumption in Indonesia is very low. FAO (1995) indicated that Indonesians consumed 1.3% more energy than the world average, but consumed 15% less protein. The energy and protein consumed came mainly from vegetable products (96.1% and 84.6%) whereas in Australia only 61.8 % and 31.8% came from vegetable sources. According to Wijeratne and Nelson (1987), plant foods continue to be the major source of both energy and protein for people in developing countries. This is due largely to the higher price of animal protein in Indonesia, given that the availability of animal protein foodstuffs is limited. The inadequate supply of animal protein, however, promotes the development of animal production. In fact, in recent years, animal production in the Asian region has grown rapidly, especially the intensive poultry and pig industries (Leng 1995; Leng & Devendra 1995) although several problems are faced by the industry.

The significant development of the poultry industry can be seen as a result of the flexibility of poultry itself. Poultry meat is widely accepted by all groups in society, whereas pork is unacceptable to the bulk of the Indonesian population for cultural reasons. In addition, the size of poultry is not as great as that of other domestic animals. Thus, it is more readily marketed than others. Moreover, farmers are eager to grow poultry as it can be harvested in a short period so that their capital will be returned earlier. For instance, broiler chickens are usually consumed after just a six-week growing period.

A comparison of amino acid composition of various animal foods can be seen in Table 2.1. Say (1987) observed that the amino acid content of poultry meat represents a good source of lysine and leucine and very satisfactorily complements a cereal-based diet.

The poultry industry has now become the most intensive of all branches of livestock farming. In many countries, particularly in Asia, poultry is ahead of all other livestock in economic importance (Sainsbury 1984), and the world's chicken population was more than twice the world's human population in 1994 (FAO 1995). According to Jordan (1990), total world poultry meat consumption has trebled during the past 25 years. In the UK, poultry meat consumption averaged 8.09 kg/head in 1955, whereas

Table 2.1. Amino acid composition of various animal foods (% of protein) (Oluyemi & Roberts 1979; Say 1987).

Amino acid	Chicken	Poultry (Say 1987)	Beef	Pork	Egg	Milk
Arginine	6.7	6.5	6.4	6.7	6.4	4.3
Cystine	1.8	-	1.3	0.9	2.4	1.0
Histidine	2.0	-	3.3	2.6	2.1	2.6
Isoleucine	4.1	-	5.2	3.8	8.0	8.5
Leucine	6.6	6.5	7.8	6.8	9.2	11.3
Lysine	7.5	7.5	8.6	8.0	7.2	7.5
Methionine	1.8	-	2.7	1.7	4.1	3.4
Phenylalanine	4.0	-	3.9	3.6	6.3	5.7
Threonine	4.0	-	4.5	3.6	4.9	4.5
Tryptophan	0.8	-	1.0	0.7	1.5	1.6
Tyrosine	2.5	-	3.0	2.5	4.5	5.3
Valine	6.7	-	5.1	5.5	7.3	3.5
Glycine	-	10.0	-	-	-	-
Glutamic acid	-	14.0	-	-	-	-
Total	48.5	-	52.8	46.4	63.9	59.2

in 1987, 18.3 kg of poultry meat was consumed (Say 1987). Per capita consumption of poultry meat has increased steadily during the last 40 years and now stands at an all-time high of 34 kg, which now exceeds the consumption of beef in the United States (Cunningham 1993). In Indonesia, poultry meat contributed 35.4% of the total meat production, whereas in Australia it constituted only 13.9%. Poultry meat production in Indonesia reached 588,000 tonnes in 1994, with a chicken population of 640 million (FAO 1995) and an annual growth of 5% (Farrell 1996). Say (1987) suggested that poultry meat is the most appropriate of all livestock meats in many tropical regions as conditions experienced during the dry season limit the development of ruminant production.

2.2. Challenges to the Poultry Industry

The commercial broiler industry is a significant part of the poultry industry in Indonesia. Furthermore, this industry depends largely on the feed industry. The availability (and in particular the limitation) of raw materials is the biggest challenge that hinders the development of the feed industry (Wanasuria & Hutagalung 1989), and hence, poultry meat production. All aspects of a feedmill's activities are influenced by these problems because the cost of raw materials represents the biggest part of the total cost of broiler production, i.e. 66% or more (Oluyemi & Roberts 1979) or 70-80% (Speight 1993). Schang (1993) predicted that the increase in consumption of animal protein will have an impact not only on livestock production, but also on the manufacture of animal feeds and, consequently, on the market for grains and oil-bearing crops. Moreover, the author indicated that the world market of animal feeds (588 million tonnes/year; 31.7% for poultry) has increased significantly over the past decade. This represents 47% of the demand for grain production (excluding wheat) and 100% of the oilseed meal production. Finding alternative protein and/or energy source raw materials is an important goal which can help to minimise the negative effects of the limitation of raw materials. According to Leng and Devendra (1995), three major challenges in nutrition research for monogastric animals in Asia are (1) to determine alternative carbohydrate resources or feeds, (2) to identify potential supplements to balance diets which use non-grain-based feeds for scavenging monogastric animals, and (3) to measure the response relationship to graded inputs of protein meals and/or supplements.

The limitation of raw material supply is caused by several factors, such as season, human demand purposes and the limited alternative raw materials available.

Indonesia is a tropical country that has two seasons: the rainy and dry seasons. These conditions are not suitable for several agricultural plants that provide most of the raw materials for poultry feed. Also, some crops that produce grain, seed and waste products for animals are seasonal plants and for this reason there are contrasts between the different seasons regarding the availability of raw materials. In the rainy season, many plant source raw materials are acceptable, of good quality, of a reasonable price and can be easily obtained. On the other hand, in the dry season there is usually a lack of plant source raw materials. FAO (1995) recorded that only 16.3% of the total land area in Indonesia is arable or has permanent crops. Soil conditions (mineral constraints) are also a major problem in food legume production in Asia (Craswell *et al.* 1987). Shorter *et al.* (1991) described four significant agronomic factors limiting peanut yield in Indonesia: nutritional deficiencies in soil, acid soil, plant population density and irrigation management. Accordingly, the feedmillers often have difficulties getting good quality raw materials. Furthermore, the consequence of an increase in demand is higher prices. In addition, when there is a shortage of raw materials, some suppliers do 'unfair business' in order to make a greater profit. For example, the presence of poor quality raw materials in a truck covered by a 'blanket' of good quality and some adulterant and/or contaminants in raw materials, are common occurrences. Thus, the role of quality control and laboratory inspection or determination is very important.

Similarly, the price of raw materials may preclude their use. Soybean meal, which has become an important constituent of feed formulation because of its nutritional content, has a higher price in Indonesia than in other countries surrounding Indonesia. It is almost impossible for the feedmillers to formulate corn/soybean meal diets, given the price of the feed. At this time, feedmillers are allowed to import about two thirds of their soybean meal requirement, and therefore they depend on domestic soybean companies that supply feedmills at a higher price.

Another constraint to raw material utilisation is that most agricultural products are used directly for human consumption (Karossi *et al.* 1983). For instance, grains are mostly used for human foods in developing countries but are used as stockfeed in developed countries (Vohra 1978) The nutritional requirements of the fowl are competitive with those of man, whose food supply is becoming more and more inadequate (Oluyemi & Roberts 1979). Indonesians consume much more plant source raw materials than animal source foods (FAO 1995) and sometimes there are inadequate raw materials available for human consumption. Therefore, only the fair and poor quality raw materials and agricultural by-products are provided for feedmill usage. Competition occurs for plant source raw materials and also for animal protein source raw materials.

2.3. Alternative Protein Source Raw Materials for Use in Poultry

Bolla (1992) recommended that for broiler strains, it is essential that good quality, high protein rations are fed to allow birds to achieve their full genetic potential. Moreover, broilers need feed which contains more protein and energy than layers or breeders (NRC 1994). Accordingly, alternative feedstuffs are needed. Some kinds of raw materials will complement others, resulting in a balanced diet. Normally, protein and amino acid components of feed are relatively expensive (Nesheim *et al.* 1979; Speight 1993). Therefore, from a practical stand-point, the efficient use of protein, and hence energy, is critical for the economical production of poultry meat.

The 'supplementary effects', such as the complementation of feedstuffs, that will improve the quality of the feed are an additional benefit if the limitations on using several alternative raw materials are considered. Combinations of proteins needed to balance the amino acid requirements have a biological value higher than that of the individual components (Vohra 1993). Another important factor is that using alternative protein source raw materials can reduce the feed price.

Due to their low cost and ready availability, the oilseed meals have potential both as protein and energy sources, although a great deal of research is necessary before they can be used in the most economical way (Farrell 1976).

It is generally recognised that the protein of meat and bone meal (MBM) is inferior to that of soybean meal for growing chickens and that at least half the supplementary protein of broiler diets should come from soybean meal (Bartlett 1974). The investigator reported that soybean meal can be replaced (starter diet/finisher diet) by cottonseed meal (10.9%/6.2%), safflower meal (12.0%/7.0%) and lower levels of rapeseed meal (8.3%/4.9%) and of coconut meal (29.7%/16.4%). However, the performance of chickens on diets containing linseed meal (8.5%/5.0%) or using MBM as the only protein source (26.5%/15 6%) was markedly inferior to that attained on the other diets (Table 2.6). A recent study by Farrell and Green (1991) showed that linseed meal did not impair broiler performance at 5% but depressed performance at 10%. According to Evans (1985), linseed meal contains a glucoside (linamarin) that is toxic to poultry and MBM has unbalanced amino acid profiles and is variable in its nutrient composition, depending on the type of livestock being slaughtered and of the offals included.

Soybean is one of the world's most important oilseed crops (Göhl 1981) and is the most widely used oilseed meal in animal feeding (SCOB 1978; Kalinowski 1993). Soybeans are also the richest in protein of all the common seeds used for animal feed (Göhl 1981) and are the main source of valuable plant protein in poultry diets (Perez-

Escamilla & Vohra 1987). It is a good source of all the essential amino acids as well as a reasonable energy source. However, raw soybean may contain deleterious factors due to the presence of several anti-nutritional factors (Batterham & Egan 1987). It contains a trypsin inhibitor and haemagglutinins (Oram & McWilliam 1976) which block the activity of the digestive enzyme trypsin; and urease, an enzyme that releases ammonia from urea, and therefore cannot be fed together with urea (Göhl 1981). There is a high level of saponin (5.6-56 g/kg dry matter (DM)) in soybean (Oakenfull & Potter 1993), which may depress growth rate (Kalinowski 1993). Soybean meal will contain these anti-nutritional factors if under-processing of the meal occurs. Kalinowski (1993) suggested that raw soybean meal should never be fed to non-ruminants. In practice, under- or over-processing of soybean meal often happens. Accordingly, although soybean meal is considered to be an excellent plant protein source, this protein should be combined with other protein sources to offset any effects from poor processing. Kalinowski (1993) listed the toxins found in soybean and their possible deleterious effects (Table 2.2).

Table 2.2. Possible toxins and toxic effects of soybean (Kalinowski 1993).

Toxins	Toxic effects
Trypsin inhibitor	Decreased protein digestion; pancreatic hypertrophy
Glucosinolate (goitrogenic factor)	Hepatic haemorrhage, necrosis, fibrosis, rupture; enlarged thyroids, decreased growth
Saponin	Decreased growth
Anticoagulant	Haemorrhages
Diuretic principle	Diuresis
Oestrogenic factor	Reproductive disturbance
Haemagglutinin	*In vitro* erythrocytic agglutination; decreased growth
Toxic histone	Decreased growth; death
Antivitamin factor	Increased requirement for vitamin B12

Wilson and MacAlpine (1974) stated that interest in alternative oilseed meals for use in broiler rations in Australia has been stimulated by rising costs of imported protein ingredients and the inadequacy of meat meal as a satisfactory alternative protein source. They studied the replacement of soybean meal with 0, 1/3, 2/3 and all sunflower meal in non-isocaloric diets. Body weight of the birds at 6 and 9 weeks was not affected by dietary treatments but feed conversion ratio (FCR) was slightly decreased with high level of sunflower meal.

Problems of using rapeseed meal in broiler diets include its low metabolisable energy (ME) value and several toxic factors. Meat meal diets without or with rapeseed meal performed better than fish meal diets (Koentjoko 1974). The extra methionine resulted in slight beneficial effects to overcome the depressed performance where very high levels of rapeseed meal inclusion were used. In essence, up to 10% rapeseed meal inclusion does not significantly depress performance in properly balanced broiler diets.

From their two experiments, Peters and Yule (1974) showed that expeller rapeseed meal can be utilised as a protein source replacing sunflower meal for broilers, but some growth depression, increased mortality and downgrading of carcasses will result, the extent being related to the level of expeller rapeseed meal used. The performance of the birds was not affected by lysine supplementation. The inclusion of 3% or more rapeseed meal depressed body weight at 3 weeks of age, but body weight did not differ at 9 weeks. The introduction of rapeseed meal at 3 weeks of age depressed the performance of broilers more than its introduction at day-old. The liveweight yield was decreased by 11.9% and total downgrading increased by 14.8% with 9% rapeseed meal inclusion in the diets (Table 2.6).

Ground pigeon pea (*Cajanus cajan*) seed, fed to chickens from hatch to 6 weeks, at levels between 5 and 30% of the total ration, resulted in body weights as good as or better than those of the control birds fed a starter ration of maize and soybean meal (Springhall *et al.* 1974). All rations, however, were not isocaloric. At 40% pigeon pea meal inclusion, the birds' body weights were significantly lower than those of the soybean-fed birds. This reduced weight gain may have been due to an amino acid deficiency.

In isocaloric diets, there was no significant difference among four sunflower treatments for liveweight or feed conversion by broilers, nor was there a significant sex x sunflower interaction (Wilson & MacAlpine 1974). The replacement of soybean meal with sunflower meal increased economic advantage (Table 2.6).

From two experiments, Yule (1974) demonstrated that there was no evidence of palatability problems when broiler cockerels were offered diets containing up to 15%

sunflower meal. Up to 7.5% sunflower meal can be included in broiler diets with no adverse effect on performance (Yu e 1974). Diets should, however, be adjusted to allow for the lower lysine and energy contents in sunflower meal compared with some protein concentrates. Estimation of optimum or maximum inclusion rates of sunflower meal in broiler diets was not possible from the results of this experiment since 15% inclusion rate was not sufficient to cause a significant depression in broiler performance.

Studies have been performed in Indonesia regarding the use of soybean meal and alternative plant protein sources in the feed, as shown by the work of Wanasuria and Hutagalung (1989) in Tables 2.3 and 2.6. By replacing soybean meal with sesameseed meal no difference in broiler performance was recorded to 21 days of age, although body weight gain decreased compared with soybean meal-fed birds up to 42 days of age.

Table 2.3. Effects of replacement of soybean meal with sesameseed meal on body weight gain and feed conversion ratio (FCR) in broilers (Wanasuria & Hutagalung 1989).

Parameter	Soybean meal 15.2%	Soybean/Sesameseed meal 13.3%/5%
0-21 days: Body weight gain (g/b/d)	24.3	23.0
FCR	1.508	1.512
0-42 days: Body weight gain (g/b/d)	36.2 [a]	34.9 [b]
FCR	1.908	1.909

Means within a row with different superscripts are significantly different ($P<0.05$)

Irish and Balnave (1991) indicated that broilers fed a diet containing soybean meal as the sole protein concentrate showed significantly poorer growth than broilers fed any of a number of the alternative diets. The combination of soybean and sunflower meal produced a better performance in males but not in females. Growth was improved by replacing some of the soybean meal with a mixture of sunflower meal and either meat meal or poultry offal meal. The feed consumption was also significantly lower than that of broilers fed the soybean and either sunflower-meat meal or sunflower-poultry offal meal diets (Tables 2.4 and 2.6).

Table 2.4. Effects of replacement of 25 % of soybean meal (SBM) with sunflower meal (SFM) and the combination of SFM and meat meal (MM) or poultry offal meal (POM) on body weight gain (BWG) and feed intake in broilers of 1 to 42 days of age (Irish & Balnave 1991).

Protein concentrate	Male		Female	
	BWG (g)	Feed intake (g)	BWG (g)	Feed intake (g)
SBM	1598 [a]	3169 [a]	1539 [a]	2986 [a]
SBM/SFM	1778 [b]	3346 [ab]	1586 [a]	2987 [a]
SBM/SFM/MM	1793 [b]	3499 [b]	1714 [b]	3304 [b]
SBM/SFM/POM	1800 [b]	3475 [b]	1704 [b]	3276 [b]

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

In recent studies, Irish and Balnave (1993a, b) reported similar results (Tables 2.5 and 2.6). Soybean meal as the only protein concentrate in a diet produced significantly poorer growth than the combinations of soybean meal and sunflower meal, rapeseed meal and cottonseed meal. The FCR of control birds was also significantly poorer than that of broilers fed the soybean sunflower meal and soybean-cottonseed meal combinations.

Table 2.5. Effects of replacement of soybean meal (SBM) with sunflower meal (SFM), rapeseed meal (RSM) and cottonseed meal (CSM) on body weight gain (BWG), feed intake and feed conversion ratio (FCR) in male broilers of 1 to 21 days of age (Irish & Balnave 1993a, b).

Dietary protein meals	BWG (g)	Feed intake (g)	FCR
SBM (26.3% in diet)	343 [a]	657 [a]	1.92 [a]
SBM/SFM (7.5%)	407 [b]	684 [ab]	1.69 [bc]
SBM/RSM (7.5%)	386 [b]	713 [ab]	1.85 [ab]
SBM/CSM (7.5%)	455 [c]	754 [b]	1.66 [c]

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

Through research on true amino acid digestibility for protein and amino acids, Rhône-Poulenc (1993) noted that the amino acids of soybean meals and sunflower meals were well digested by the test animals and were better digested than rapeseed meal.

The presence of anti-nutritional factors (including non-starch polysaccharides (NSPs) 17.9%) in canola meal has restricted its level of inclusion in poultry feed to about 15% of the diet (Solminski & Campbell 1990). However, enzyme addition to a canola meal

Table 2.6. Summary of previous experiments on use of alternative protein source raw materials.

Source	Control pr. source	Substitute pr. source	Substitution	Broiler age	Sex	Results (% Δ) and comments
Bartlett (1974)	SBM & MBM	CSM, RSM, SFFM, LSM & CM	1/3, 2/3 of SBM	0-5 w. starter 5-9 w. finisher	mixed	BW, FI & FCR NS in CSM, SFFM, ⇓ CM & control (SBM/MBM) : 0-5 w. FI ↓ in ⇓ RSM : 0-5 w. FI & BW ↓ in ⇑ RSM, ⇑ CM, LSM & MBM only : 0-5 w. BW ↓ in LSM, ⇑ CM & MBM only: 5-9 w. FI ↓ in ⇑ LSM & MBM only : 5-9 w.
Koentjoko (1974)	SBM	RSM (screw-pressed)	0, 2.5, 5.0, 10 & 20% 30% sorghum replaced wheat	7-63 d.	?	- 3.40 (BWG); + 4.27 (FCR) in 20% RSM - 6.03 (BWG); + 3.79 (FCR) in 20% RSM/sorghum recommended: 10% RSM
Koentjoko (1974)	SBM 25% /FM 7.7%	RSM (screw-pressed)	25% /MM 10% + 0.5% DL-methionine	7-63 d.	?	- 13.54 (BWG); + 9.45 (FCR) in RSM/FM + 16.76 (BWG); - 9.45 (FCR) in SBM/MM + 3.02 (BWG); - 5.51 (FCR) in RSM/MM - 15.68 (BWG); - 1.57 (FCR) in RSM/FM + meth. + 6.43 (BWG); - 4.33 (FCR) in RSM/MM + meth.

Note:

CM	: coconut meal	FM	: fish meal	MM	: meat meal	RSM	: rapeseed meal	SFM	: sunflower meal
CNM	: canola meal	LSM	: linseed meal	POM	: poultry offal meal	SBM	: soybean meal	SSM	: sesameseed meal
CSM	: cottonseed meal	MBM	: meat and bone meal	PPS	: pigeon pea seed	SFFM	: safflower meal		

pr.: protein; meth.: methionine; d.: days; w.: weeks; M: male; F: female
BW: body weight; BWG: body weight gain; FI: feed intake; FCR: feed conversion ratio
Δ: difference; + or ↑: increase; - or ↓: decrease; ⇑: high; ⇓: low; ** or *: significant; NS: non-significant
?: not mentioned

Table 2.6. (continued)

Source	Control pr. source	Substitute pr. source	Substitution	Broiler age	Sex	Results (% Δ) and comments
Peters & Yule (1974)	SFM (expeller)	RSM (expeller)	3, 6 & 9% + lysine	3 w. starter 6 w. grower 9 w. finisher	M	lysine supplementation NS BW ↓ ** : - 8.44 * FI NS : - 3.43 NS FCR NS : + 6.36 mortality NS: + 75
Peters & Yule (1974)	SFM (expeller)	RSM (expeller)	3 & or 6%	3 w. starter 6 w. grower 9 w. finisher	mixed	diets: a) 3%/3%/3% RSM b) 3%/6%/6% RSM BW ↓ **: - 3.65 * in a - 6.25 * in b FI ↓ * : - 3.37 * in a - 6.07 * in b FCR ↑ * : + 1.69 NS in a + 0.42 NS in b
Springhall *et al.* (1974)	SBM/maize	PPS (ground)	0, 5, 10, 20, 30 & 40% not isocaloric	0-6 w.	?	BW NS or ↑ in 5-30% PPS BW ↓ in 40% PPS - 0.05 NS (BWG); + 7.69 (FCR) in 30% PPS - 8.02 ** (BWG); + 15.38 (FCR) in 40% PPS mortality 0 in 30 & 40% PPS recommended: 30% PPS
Wilson & MacAlpine (1974)	SBM 3.7% pr. diets	SFM (expeller)	0, 1/3, 2/3 & all not isocaloric	6 w. starter 9 w. finisher	?	BW NS : 6 w. & 9 w. FCR slightly ↑ in ⇑ SFM

Note:

CM	: coconut meal	FM	: fish meal	MM	: meat meal	RSM	: rapeseed meal	SFM	: sunflower meal
CNM	: canola meal	LSM	: linseed meal	POM	: poultry offal meal	SBM	: soybean meal	SSM	: sesameseed meal
CSM	: cottonseed meal	MBM	: meat and bone meal	PPS	: pigeon pea seed	SFFM	: safflower meal		

pr.: protein; meth.: methionine; d.: days; w.: weeks; M: male; F: female
BW: body weight; BWG: body weight gain; FI: feed intake; FCR: feed conversion ratio
Δ: difference; + or ↑: increase; - or ↓: decrease; ⇑: high; ⇓: low; ** or *: significant; NS: non-significant
?: not mentioned

Table 2.6. (continued)

Source	Control pr. source	Substitute pr. source	Substitution	Broiler age	Sex	Results (% Δ) and comments
Wilson & MacAlpine (1974)	SBM 4% pr. starter diets 3% pr. finisher diets	SFM (expeller)	0% to all in 4 diets isocaloric	6 w. starter 9 w. finisher	M & F	BW NS FCR NS M BW ↑ & FCR ↓ than F economic advantage
Yule (1974)	SBM	SFM (expeller)	0, 5.0, 7.5 & 15%	7-21 d.	M	BWG ↑ ** (lysine adjusted); SBM diet BWG ↓ * FI NS FCR ↑ ** in >5.0% SFM (lysine not adjusted) FCR ↓ ** in 5.0 & 7.5% SFM (lysine adjusted)
Yule (1974)	SBM	SFM (expeller)	0, 2.5, 5.0 & 10%	7-35 d. starter 35-63 d. finisher	M	BWG NS; BWG tend to ↓ in 10% SFM : 7-63 d. FI NS : 7-63 d. FCR NS : 7-63 d.
Wanasuria & Hutagalung (1989)	SBM 15.2%	SSM	13.3% SBM /5% SSM	0-21 d. 0-42 d.	?	- 5.35 NS (BWG); + 0.27 NS (FCR): 0-21 d. - 3.59 * (BWG); + 0.05 NS (FCR): 0-42 d.

Note: CM : coconut meal; CNM : canola meal; CSM : cottonseed meal; FM : fish meal; LSM : linseed meal; MBM : meat and bone meal; MM : meat meal; POM : poultry offal meal; PPS : pigeon pea seed; RSM : rapeseed meal; SBM : soybean meal; SFFM : safflower meal; SFM : sunflower meal; SSM : sesameseed meal

pr.: protein; meth.: methionine; d.: days; w.: weeks; M: male; F: female
BW: body weight; BWG: body weight gain; FI: feed intake; FCR: feed conversion ratio
Δ: difference; + or ↑: increase; - or ↓: decrease; ⇑: high; ⇓: low; ** or *: significant; NS: non-significant
?: not mentioned

Table 2.6. (continued)

Source	Control pr. source	Substitute pr. source	Substitution	Broiler age	Sex	Results (% Δ) and comments
Irish & Balnave (1991)	SBM	SFM	1/4 of SBM	1-42 d.	M	+ 11.26 * (BWG); + 5.59 NS (FI)
					F	+ 3.05 NS (BWG); + 0.03 NS (FI)
		SFM/MM	1/4 of SBM	1-42 d.	M	+ 12.20 * (BWG); + 10.41 * (FI)
					F	+ 7.26 * (BWG); + 10.65 * (FI)
		SFM/POM	1/4 of SBM	1-42 d.	M	+ 12.64 * (BWG); + 9.66 * (FI)
					F	+ 6.63 * (BWG); + 9.71 * (FI)
Irish & Balnave (1993a b)	SBM 26.3%	SFM	7.5%	1-21 d.	M	+ 18.66 * (BWG); + 4.11 NS (FI); - 11.98 * (FCR)
		RSM	7.5%	1-21 d.	M	+ 12.54 * (BWG); + 8.52 NS (FI); - 3.65 NS (FCR)
		CSM	7.5%	1-21 d.	M	+ 32.65 * (BWG); + 14.76 * (FI); - 13.54 * (FCR)
Kumar *et al.* (1995)	SBM	CNM + enzyme	?	0-6 w.	M & F	recommended: 15% CNM (Solminski & Campbell 1990) economic advantage M BW ↓; if + enzyme NS in high CNM F BW ↓; if + enzyme no effect in high CNM FI NS FCR ↓ if + enzyme

Note:

CM	: coconut meal	FM	: fish meal	MM	: meat meal	RSM	: rapeseed meal	SFM	: sunflower meal
CNM	: canola meal	LSM	: linseed meal	POM	: poultry offal meal	SBM	: soybean meal	SSM	: sesameseed meal
CSM	: cottonseed meal	MBM	: meat and bone meal	PPS	: pigeon pea seed	SFFM	: safflower meal		

pr.: protein; meth.: methionine; d.: days; w.: weeks; M: male; F: female
BW: body weight; BWG: body weight gain; FI: feed intake; FCR: feed conversion ratio
Δ: difference; + or ↑: increase; - or ↓: decrease; ⇑: high; ⇓: low; ** or *: significant; NS: non-significant
?: not mentioned

diet improved the performance of the birds (Kumar *et al.* 1995). With canola price in the international market being 13% lower than that of soybean in 1992-1993, it became an attractive alternative protein source.

From the previous experiments described in Table 2.6, it can be concluded that the use of soybean meal as the sole protein concentrate in broiler diets may reduce the performance of birds (Yule 1974; Irish & Balnave 1991, 1993a, b). A certain amount of alternative plant and/or animal protein source raw materials can be used to replace soybean meal or other protein sources in the diets (Bartlett 1974; Koentjoko 1974; Peters & Yule 1974; Springhall *et al.* 1974; Wilson & MacAlpine 1974; Yule 1974). More recent studies have shown similar results (Wanasuria & Hutagalung 1989; Irish & Balnave 1991, 1993a, b; Kumar *et al.* 1995). Rising costs of imported ingredients and the inadequacy of locally produced raw materials resulted in economic advantages with the use of alternative ingredients (Wilson & MacAlpine 1974; Kumar *et al.* 1995). Similar benefits will be achieved in the Indonesian situation.

It is important to consider that some alternative plant protein sources have lower ME values than those they replace (Koentjoko 1974; Yule 1974) and may also have a higher fibre content. Several anti-nutritional factors can limit the use of those materials (Koentjoko 1974; Solminski & Campbell 1990). Some alternative protein meals also have poorer amino acid profiles (Springhall *et al.* 1974; Yule 1974) and lower amino acid digestibility (Rhône-Poulenc 1993). Therefore, supplementation of the diet by synthetic amino acids may be required (Koentjoko 1974). Palatability may not be affected by the replacement of some of the soybean meal in the diet with another protein meal (Yule 1974).

Effects on performance are usually more severe in the earliest stages of chicken development (Bartlett 1974; Peters & Yule 1974). However, the introduction of alternative raw materials at day-old is better than a later introduction (Peters & Yule 1974). Increased mortality and downgrading of carcasses may occur due to the presence of anti-nutritional factors (Peters & Yule 1974). Males are apparently more resistant than females to the use of alternative ingredients (Wilson & MacAlpine 1974; Irish & Balnave 1991). This difference is perhaps due to the faster growth and greater activity of male broilers.

2.4. Practical Limitations to the Use of Alternative Protein Source Raw Materials in Poultry

Despite the obvious advantages of using alternative protein source feedstuffs, such raw materials may have some negative effects on performance. Aspects of the limitation to the use of alternative raw materials will be discussed below. The limitation on using alternative raw materials is greatest in broiler chicken diets because broilers, being younger, less immune to disease, and stocked at higher densities, are most susceptible to the adverse effects of substandard feed (Oluyemi & Roberts 1979).

Several alternative protein source raw materials are produced in small amounts and in few locations (Farrell *et al.* 1983). With the limited production, changes to the feed formulation used will occur frequently when using these materials. The quality of these materials is also highly variable, especially in their nutritional composition. Some raw materials differ widely in their amino acid composition even when protein levels are the same.

New alternative protein feedstuffs can be and are included in formulated feed, although the necessary information of nutritional composition and deleterious factors may not be clearly specified. Encouraging the use of these materials may therefore produce unpredictable, often negative effects on chickens.

The quality of oilseed meal is influenced by the type and level of heat during processing. Improper processing is the most common cause of variability in quality of oilseed meals, animal protein meals and cereal by-products and generally produces decreased amino acid availability (Parsons 1993). Two of the amino acids most adversely affected by processing conditions are lysine and cystine. Too high or prolonged heat during the extraction process will destroy essential amino acids in protein meals. Miller (1976) indicated that the proteins in oilseed meals are particularly susceptible to damage by heat treatments involved in the oil extraction because of the high carbohydrate concentration of the oilseeds. However, the correct heat processing of oilseeds makes nutrients highly available and destroys anti-nutritional factors (Göhl 1981; Kalinowski 1993).

Anti-nutritional factors contained in alternative protein meals will impart negative effects to the performance of birds, even though some efforts have been made to reduce or eliminate these factors (Cheeke & Shull 1985). It should be noted that different varieties of legumes in one species may differ in their levels of anti-nutritional factors. The more common anti-nutritional factors present in legumes are the trypsin inhibitors, urease, haemagglutinins, goitrogens, saponins, phytic acid and flatulents (Wijeratne & Nelson 1987). The anti-nutritional factors and the limitation to use of plant protein (Table 2.7) and animal protein sources have been reviewed by several workers.

Table 2.7. Anti-nutritional factors or restrictions and maximum limitation to the use of alternative plant protein meals for broilers (Evans 1985; Solminski & Campbell 1990).

Protein meals	Limitation	Anti-nutritional factors or restrictions
Canola meal*	15%	non-starch polysaccharides
Coconut meal or copra meal	40%	can produce rancidity introduced slowly over time to avoid reluctance to eat not for very young stock
Cottonseed meal	10% or 0.01% free gossypol	gossypol and cyclopropenoid contents additional 0.05% Fe is needed
Linseed meal	3%	glucoside (linamarin) should not be used if other alternative proteins are available
Rapeseed meal	5%	glucosinolates can impart 'off-flavours' to the meat
Safflower meal	no limitation	about 60% hulls, high in fibre energy and protein content low
Sesameseed meal	no limitation	high in phytic acid long storage can produce rancidity
Sunflower meal	no limitation	low lysine availability

* Solminski & Campbell (1990)

The lower palatability of some alternative protein source feedstuffs may reduce feed intake which, in turn, produces lower performance. Göhl (1981) found that the raw beans of legumes are not particularly palatable to stock. According to North and Bell (1990), the chickens' ability to taste feeds is relatively high. Oilseed meals (from solvent extraction) are less palatable than oilseed cakes (from pressing extraction) and have a lower fat content, which reduces their energy value (Göhl 1981).

The first limiting amino acid in a protein is regarded as an index of its nutritive value (Dingle & Wiryawan 1994). Some alternative protein sources are deficient in certain amino acids (Springhall *et al* 1974; Yule 1974) or have unbalanced amino acid profiles. The digestibility and availability of protein and amino acids are also considered important (Rhône-Poulenc 1993) and the addition of synthetic amino acids to the diet may have beneficial effects on the birds' performance (Koentjoko 1974). Feed formulation for poultry based on ileal digestibility of amino acids is an accurate method of providing the correct amino acid profile for meat or egg production (Jackson *et al.* 1996). However, feed formulation based on total amino acids is still widely practised. The combined effect of limiting amino acid content, protein and amino acid digestibility, amino acid antagonists, presence of anti-nutritional factors, under- or over-processing, the physical and/or chemical properties, the presence of high levels of fibre, digesta viscosity effects and absorption rate, results in a particular growth response of chickens, and may limit the use of alternative raw materials (Parsons 1993; Dingle & Wiryawan 1994).

The quality of plant protein meal is also influenced by the quantity of the hulls, i.e. high fibre contents of alternative raw materials due particularly to the seed hulls may increase protein loss from the body, increase rate of passage of the food through the gut, decrease the time available for digestion (Dingle 1992), and influence the availability of amino acids (Austic 1983).

Alternative protein sources may contain non-starch polysaccharides (NSPs), such as in canola meal. NSPs are not completely digested by chickens as poultry do not secrete enzymes capable of digesting complex carbohydrates (Dingle 1992), and they usually pass whole through the digestive system. NSPs in one feedstuff will affect the availability of nutrients from all ingredients in a diet and the severity of the effect of NSPs depends not only on their total concentration but also on their concentration relative to each other (Dingle & Wiryawan 1994). Most of the complex carbohydrates (not cellulose) are soluble to various degrees and their solution increases the viscosity of the liquid they are dissolved in (Dingle 1992). Fatty acids, fat-soluble chemicals and cholesterol are especially affected by viscosity. Fat digestion and hence ME show the greatest decrease with increasing viscosity of gut contents (Choct & Annison 1992), but protein digestion is decreased and body protein is also lost (Angkanaporn *et al.* 1992). Increases in viscosity inhibit the activity of digestive enzymes (Annison 1990), increase the food transit time in the intestine, and reduce digestibility and absorption rate (Morgan & Bedford 1995) with the net effect being poor flock performance. Older birds appear capable of more readily transporting viscous material in the gastrointestinal tract and, accordingly, production is not adversely affected in layers or breeders (Classen & Campbell 1990: Volker & Broz 1990; Dingle 1992).

Many other factors, including mould contamination and associated toxins, can impair the nutritional value in alternative protein sources, interfere with the utilisation of feed ingredients for poultry and even produce mortality. Aflatoxin is perhaps the most prevalent and most toxic of all mycotoxins in feedstuffs to be consumed by poultry (Wyatt & Stewart 1990; Speight 1993). It has been reported in a wide variety of products including peanuts, cottonseed, copra, palm kernel, and cereals. Plant protein meals that have been produced from contaminated or mouldy raw materials may contain the toxin and therefore should not be fed to pigs or poultry. Aflatoxins cause loss of appetite and may affect amino acid digestibility, thereby producing poor performance. The utilisation of a mould inhibitor or an aflatoxin binding agent is possible.

Plant and animal tissues contain an enzyme, lipoxygenase, an agent for enzymatic peroxidation (Shafey 1993). Lipoxygenase is found in a wide range of feed ingredients such as corn, wheat, barley, soybean peas, peanut oils and animal tissues. This enzyme introduces oxygen into free fatty acids to produce, primarily, hydroperoxides. Oxidation causes destruction of vitamins and possibly loss of amino acids. Palatability of the diets will also decline. Plant protein meals (from solvent extraction) are less prone to rancidity (Göhl 1981) than cakes (from mechanical pressing) because of their lower fat contents. According to Evans (1985), rancid coconut meals will cause diarrhoea in birds.

Therefore, any consideration of alternative raw materials must include the possible disadvantages through poor bird performance and the downgrading of carcasses. In large quantities, these materials can cause morbidity and death of the animal due to inherent chemical factors (glucosides) or contamination (aflatoxins).

2.5. The Potential of Peanut By-products as Alternative Raw Materials for Broiler Diets

Legume crops play a particularly important role in the nutrition of humans and animals and as a component of farming systems (Higgins 1951; McWilliam & Dillon 1987). According to Beck and Roughley (1987), the two aspects of legumes that make them attractive to the world population are their high protein content and their ability to fix atmospheric nitrogen to enrich soil quality.

The peanut (*Arachis hypogaea*) is a tropical legume that is also known as the groundnut, earthnut, monkey nut, Manilla nut, Chinese nut, pindar or goober pea (Göhl 1981; Evans 1985). FAO (1995) showed that the world's production of peanuts (in shell) in 1994 was 28.5 million tonnes, which was 20.8% of the world's soybean production. The Asian region accounted for 71.7% of total peanut production. The three main peanut-producing countries in Asia are China, India and Indonesia, which produced 47.6%, 41.1% and 5.3% of Asian peanut production, respectively. Wright (1993) stated that drought was identified as a major limitation to peanut productivity in many regions. Peanut is grown for the confectionery trade and, periodically, peanuts are available for stockfeed (Evans 1985). Peanuts are also crushed for oil and the subsequent by-product meal is then available as a stockfeed, as are the shells.

In Indonesia, peanut is the second most important legume crop, after soybean (Saleh *et al.* 1991), and is produced and used almost entirely for direct human consumption. Annual production of peanut in Indonesia is estimated at approximately 0.5 million tonnes of nuts in shell, harvested from more than 0.5 million ha. The Indonesian Government forecasts that annual peanut production by the year 2000 will have to increase to 1.8 million tonnes to meet demand, representing an increase of 250% over current production.

2.5.1. Peanut Kernel

The potential of food legumes, including peanut, as feed for livestock is governed by two factors: their contribution of nutrients to the diet and possible deleterious effects from the presence of anti-nutritional factors (Batterham & Egan 1987). Very few peanuts are available for stockfeed, but they do become available periodically (Evans 1985), especially in the Asian countries like Indonesia.

Peanuts have a high content (47-50%) of oil (Woodroof 1973) and hence energy, and are deficient in the sulphur amino acids and tryptophan. Raw beans of legumes are not very palatable to the stock (Göhl 1981). For monogastrics, the digestibility and availability of amino acids in leguminous seeds should be taken into account, as they are not particularly digestible when fed raw. Therefore, before feeding to poultry some form of heat treatment should be applied to destroy the trypsin inhibitor found in peanuts.

Wijeratne and Nelson (1987) argued that a number of anti-nutritional factors which can also have adverse physiological effects are present in legumes. The more common are the trypsin inhibitors, urease, hemagglutinins, goitrogens, saponins, phytic acid and flatulents. Evans (1985) indicated that trypsin inhibitor is found in raw peanuts. Their effects, and methods of removal, have been studied extensively (NAS 1973). The more nutritionally significant factors are heat-labile, and as such, can be reduced by processing.

Peanuts contain saponin at a significant level 0.05-16 g/kg DM (Oakenfull & Potter 1993) which may reduce growth rate (Kalinowski 1993). The skin of the peanut (3% of the seed weight) is high in tannins and has a bitter taste and these tannins, therefore, may reduce feed intake (Evans 1985). Both trypsin inhibitors and tannins appear to increase the output of endogenous proteins (Green *et al.* 1973; Rostango *et al.* 1973).

Numerous factors such as variety, planting practices, weather conditions, soil characteristics, fertilisation rates and storage conditions, have been shown to affect seed quality (Wijeratne & Nelson 1987).

Peanut kernels have a risk of mould contamination, especially in moist conditions. Care must be taken during the harvesting and processing of the crop to avoid aflatoxin problems. Aflatoxin is the most important toxin in mouldy peanuts and is produced by *Aspergillus flavus* and *A. parasiticus*. These fungi produce toxic and carcinogenic substances and can invade the peanut seed at any stage, even before harvest if the seed is wet (Buddenhagen *et al.* 1987). Sixty to eighty per cent of the marketable peanuts in Indonesia were contaminated with aflatoxin at levels from 40 to 4,100 μg/kg seed (Machmud 1987). Concentrations of the toxins in samples collected in Thailand range from less than 1 μg/kg to higher than 18,000 μg/kg, depending on peanut grade, storage time, storage conditions and sampling location (Nutalai 1984). Fortunately, the development of peanut cultivars with genetic resistance to *A. flavus* is possible (Buddenhagen *et al.* 1987; Pettit *et al.* 1987).

The whole kernels are not normally fed to livestock because of a high unsaturated fatty acid content (Batterham & Egan 1987). However, crushed peanut can be included (Evans 1985) in the diets for poultry (Table 2.11). According to Göhl (1981), whole peanuts are excellent poultry feed and can constitute up to 25% of the diet.

2.5.2. Peanut Meal

Peanut meal is the by-product of the oil-extraction process (Miller 1976; Evans 1985) and is a source of highly concentrated protein for animal feed, of which Indonesia makes significant imports (Wright & Middleton 1991), mainly from India and China. The oil is removed either by solvent extraction or by hydraulic or screw pressing (Göhl 1981). The fat content of the meal depends on the method used to remove the oil. In many countries, mechanical expelling of oil is centred upon the production of edible oil and feed-grade press cake (Wijeratne & Nelson 1987).

The chemical composition of peanut meal, with soybean meal as a comparison, has been reported by a number of authors (Appendices 2-5). Other authors (SCOB 1978; Göhl 1981; Bourdon *et al.* 1987; Ostrowski-Meissner 1987; North & Bell 1990; Pitman-Moore 1993) have examined the chemical composition of peanut meal as well.

Legume proteins are generally considered to be of high protein quality. The amino acid profile in legumes is normally high in lysine and low in sulphur amino acids (Batterham & Egan 1987). Peanut meal is, however, deficient in the sulphur amino acids and also lysine (Miller 1976; Evans 1985). Göhl (1981) indicated that the protein composition of peanut meal is far more variable than that of soybean meal. The phosphorus content of oilseeds in general is fair but calcium content is low (Kalinowski 1993).

Feed formulation based on chemical composition (total amino acids) is still widely practised although digestible amino acid values have begun to be used (Dalibard & Kiener 1993). The calculated protein and amino acid composition of sorghum diets with soybean or peanut meal indicates the deficiencies of amino acids in peanut meal compared with those of soybean meal (Table 2.8).

Table 2.8. The calculated protein and amino acid composition (%) of sorghum (65%) and soybean meal (20%) diet, and sorghum (65%) and peanut meal (20%) diet, compared with the specifications for broilers from NRC (1994).

Chemical composition	Sorghum/ Soybean meal	Sorghum/ Peanut meal	Broilers 0-3 weeks (NRC 1994)
Crude protein	15.35	14.67	23.00
Lysine	0.77	0.45	1.10
Methionine	0.23	0.16	0.50
Methionine + Cystine	0.48	0.39	0.90
Arginine	0.99	1.09	1.25
Tryptophan	0.20	0.15	0.20
Isoleucine	0.76	0.57	0.80
Valine	0.70	0.68	0.90

The quality of peanut meal is influenced by the quantity of hulls in the meal and by the type and level of heat during processing. Processing factors such as heat treatment, moisture level and extraction method are also involved. The seed quality also affects the oilseed meal product (Weigel 1993).

Impaired digestibility and availability of protein meals may result from the presence of high fibre contents, anti-nutritional factors or from damage during processing. The high carbohydrate concentration of the oilseed meals makes their proteins particularly susceptible to damage by the heat treatments involved in the oil extraction (Miller 1976). Adequate processing may remove a range of toxic factors present in the raw materials (Kalinowski 1993). However, Göhl (1981) confirmed that antitrypsin is of no concern in the oilcake.

The nutritive values (including biological value, chemical score, protein efficiency ratio and gross protein value) of peanut meal compared with soybean meal are shown below (Table 2.9).

Table 2.9. Nutritive values of peanut meal and soybean meal (McDonald *et al.* 1988).

	Biological value (rat)	Chemical score	Protein efficiency ratio (rat)	Gross protein value (chick)
Peanut meal	0.58	0.24	1.7	0.48
Soybean meal	0.75	0.49	2.3	0.79

Amino acid digestibility of oilseed meals is very different from one protein source to another (Rhône-Poulenc 1993). In terms of digestibility, lysine is the most variable amino acid in the group of secondary oilseed meals. Rhône-Poulenc (1993) provided the average true digestibility coefficients for protein and amino acids of peanut meal and soybean meal in poultry (Table 2.10). Aflatoxins in peanut meal may affect amino acid digestibility. In overview, the digestibility of peanut meal was lower than that of soybean meal (46/48% crude protein (CP)), particularly in glycine, lysine, cystine and histidine.

Table 2.10. True digestibility coefficients (%) for protein and amino acids of peanut meal and soybean meal in poultry (Rhône-Poulenc 1993).

	Peanut meal	Soybean meal 44% CP	Soybean meal 46/48% CP
Protein	89	87	90
Lysine	77	87	89
Methionine	87	89	91
Cystine	74	79	84
Threonine	85	83	87
Tryptophan	-	84	84
Arginine	93	91	94
Glycine	72	80	86
Serine	85	84	90
Histidine	84	89	91
Isoleucine	90	88	90
Leucine	91	87	90
Phenylalanine	92	88	91
Tyrosine	93	88	92
Valine	89	83	88

Sainsbury (1984) and Evans (1985) recommended the following inclusion levels for peanut kernel, peanut meal and soybean meal in broiler diets (Table 2.11). Peanut meal can be utilised in feeds for pigs and poultry of all ages (Evans 1985). For finisher pigs, a maximum of 10% inclusion of peanut meal in the feed is given to avoid 'soft fat' in the carcass.

Table 2.11. Normal inclusion (Sainsbury 1984) and limitation (recommended maximum inclusion level) (Evans 1985) on using peanut kernel, peanut meal and soybean meal in broiler diets.

	Normal inclusion		Limitation (max.)	
	Broiler minimum	Broiler maximum	Young chickens (< 4 weeks)	Meat chickens (> 4 weeks)
Peanut kernel* (unextracted)	-	-	nl	nl
Peanut meal	0%	10%	nl	nl
Soybean meal	0%	40%	nl	nl

* after heat treatment
nl = no limitation

Classen and Campbell (1990) stated that poultry are sensitive to the anti-nutritional effects of factors contained in feed ingredients. There are no known anti-nutritional factors in peanut meal (Batterham & Egan 1987). However, both the seed and the meal are susceptible to the presence of aflatoxin-producing moulds (Swindale 1987), particularly under moist conditions. Say (1987) stated that the presence of toxic factors is accidental, for instance, in peanut cake made from seed contaminated by moulds when harvested and during storage of the processed meal.

Aflatoxin is perhaps the most prevalent, most toxic (Wyatt & Stewart 1990; Speight 1993) and the most widespread of all mycotoxins commonly encountered in poultry feedstuffs. The presence of aflatoxins in diets of poultry and pigs causes loss of appetite and reduced growth rate or poor level of performance (Evans 1985; Curtis 1990). Aflatoxin B1 is the main component and its effect on livestock is dose-dependent. Say (1987) and Wyatt and Stewart (1990) indicated that young poultry are much more susceptible to aflatoxicosis than mature animals.

Aflatoxins affect growth in poultry at very low levels, with as little as 100 μg/kg producing significantly depressed growth in ducklings or turkey poults (Howell 1982). The most susceptible poultry are ducklings followed by turkeys, goslings and chickens, with adult laying hens the least susceptible (Arafa *et al.* 1981). Morbidity and mortality of mycotoxicoses are usual. Say (1987) added that only peanut cake free of aflatoxin or containing very little (less than 0.25 mg/kg) is usable. If so, it can be extensively used, up to 30% in the feed intended for pullets and layers.

Peanut meal that has been produced from contaminated or mouldy peanuts may contain the toxin. Speight (1993) confirmed that mycotoxins are the result of poor storage at high moisture levels. Finished feeds can also develop moulds and mycotoxins, particularly when stored in moist, warm conditions with poor ventilation. Changes in nutritional composition of the feed and the production of mycotoxins will severely affect a poultry production system (North & Bell 1990). Curtis (1990) and North and Bell (1990) confirmed that mycotoxins associated with mouldy feed can have an immunosuppressive effect and can predispose birds to various infections.

Wyatt (1979) and North and Bell (1990) summarised the biological effects of aflatoxins on poultry health, namely, severe alteration in protein and lipid synthesis, poor growth, impaired feed efficiency, altered immunity, and increased susceptibility to bruising with impaired blood clotting; and lowered resistance to other diseases.

Moisture and temperature are two factors that have a crucial effect on fungal proliferation and toxin elaboration (Wyatt & Stewart 1990). *Aspergillus flavus* grows when the temperature is between 30°C and 35°C and when the moisture content is above 9% in the kernels or above 15% in the oilcake (Göhl 1981). The minimum critical levels for the growth of fungi are 7-15% moisture and 80-85% relative humidity (Bryden 1989). Temperatures at which toxin production can take place vary from 0 to 35°C depending on the fungal species. However, conditions that favour maximum fungal growth may not be conductive to mycotoxin production by the fungus.

Speight (1993) noted the maximum contents of aflatoxin allowed in feedstuffs for poultry (Table 2.12).

Bryden (1989) found that recent Australian experience of aflatoxicosis in broilers and other poultry has been traced to peanut meal as a source. However, the climatic conditions and agronomic practices in this country suggest that mycotoxin is not a

Table 2.12. Maximum contents of aflatoxin permitted in feedstuffs for poultry in the UK (Speight 1993).

Feedstuffs	Maximum content of aflatoxin (μg/kg)
Straight feedstuffs, except *)	50
*) peanut, copra, palm kernel, cottonseed. babassu, maize and products derived from the processing thereof	20
Complete feedstuffs for pigs and poultry (except piglets and chicks)	20
Other complete feedstuffs	10
Complementary feedstuffs for pigs and poultry (except young animals)	30
Other complementary feedstuffs	5

major problem, although locally produced peanuts can have high level of contamination especially in drought years (Graham 1982; Middleton 1987).

Aflatoxin contamination is a significant problem in Indonesia, because the climate there is very conducive to the growth of mould (Ostrowski-Meissner *et al.* 1983) and poor handling of seed after harvesting is a common occurrence. Göhl (1981) stated that the attack of the fungus can be prevented, with minimum damage to the hull or kernel, by careful harvesting and by quick drying and storage in low humidity. If mould or toxin is suspected in peanut meal, the percentage incorporated must be reduced in proportion to the degree of apparent risk. Diagnostic techniques which may be utilised include feed analysis (Fowler 1990). Mycotoxin examination, if available, can be done as a routine check. In warm, humid tropical conditions, the length of storage of a mealy feed should not exceed one or two weeks, and of that of a pelleted feed, one month.

The use of a fungistat (mould inhibitor) or an aflatoxin binding agent is widely practised in Indonesia. A simple method of preventing aflatoxin problems associated with protein meals is binding with bentonite (Leng & Devendra 1995). Many chemicals, including acids, bases, aldehydes, and oxidising agents, have been successful as reagents for the destruction of aflatoxin. Recent techniques, used particularly in Senegal, enable detoxification of peanut cake contaminated with aflatoxin by ammonia treatment (Say 1987). Ammonia appears to be the most promising reagent, but effective processing conditions differ markedly with substrate, for example, for decontamination of corn as compared with cottonseed and peanut meals (Goldblatt & Dollear 1979). Speight (1993) indicated that mould inhibitors based on organic acids such as propionic acid can be used to reduce fungal contamination of feed. Also, chemical control using activated charcoal or bentonite can be applied to limit the growth of fungus.

Cyclopiazonic acid is another mycotoxin (produced by some species of *Aspergillus* and *Penicillium*) that adversely affects broiler performance and health (Suksupath *et al.* 1993). Cyclopiazonic acid has been found in corn, peanuts and cheese. Cyclopiazonic acid produces tissue degeneration in a wide range of organs.

Göhl (1981) indicated that bean cakes (from mechanical pressing), unlike meals (from solvent extraction), may have the disadvantage of developing a rancid, bitter taste after a few weeks of storage because of higher oil content.

2.5.3. Peanut Shell

Increasing costs, in part, through human demands for protein and energy, will make rations for livestock more expensive unless greater use can be made of ingredients (such as peanut shell) that are unsuitable for man (Farrell 1976). Waste by-products are sometimes returned to the ground as organic fertiliser, left in designated refuse areas to decompose, or fed to ruminants (Farrell *et al.* 1983). To a great extent, by-products are cheaper to use in poultry rations since there is little or no competition for them (Oluyemi & Roberts 1979), either from ruminants or man. In Australia, because of dry conditions and widespread crop failure, alternative energy sources from agricultural waste- and by-products may be used as well (Farrell *et al.* 1983).

Peanut shell amounts to 20-30% of the whole pod weight (Göhl 1981) and is often used as poultry litter and as feed for ruminants.

The chemical composition of peanut shell can be found in Appendices 2-5. The composition of peanut waste (hulls) has also been recorded by Farrell *et al.* (1983), and peanut-hull broiler litter by Göhl (1981). Most agricultural by-products are high in fibre (approximately 60% in peanut shell) and consequently have low bulk density.

Farrell *et al.* (1983) noted that waste by-products are high in cellulose and therefore low in digestible energy. Utilisation of many feedstuffs by poultry is limited by the lack of endogenous enzymes necessary for hydrolysis of fibre components (Classen & Campbell 1990). In many cases, crude fibre is a misleading indicator of the digestibility and nutritive value of the feed (Gohl 1981; Janssen & Carré 1989). Many factors, including dietary protein level, amino acid balance and fibre can influence the availability of amino acids (Austic 1983). Rhône-Poulenc (1993) indicated that the lower true digestibility of cereal by-products, for instance wheat bran, is probably related to higher fibre and ash content.

Many researchers have studied the utilisation of ingredients with high fibre content. Farrell *et al.* (1983) found that the growth or production of rats, pigs, chickens and laying hens declined as fibre levels in the diets increased. Chicken diets have been diluted with wheat bran, cellophane, wood pulp or cellulose to improve FCR. However, much of this work has been of doubtful merit, and the results have been particularly unsuccessful (Jones 1994).

The use of 0, 6, 12 and 18% of dried citrus pulp (acid detergent fibre (ADF) 19.8%) and winery pomace (ADF 50.3%) did not affect feed consumption in broilers (Table 2.13), but in general FCR increased compared with chicks on the control diet (Farrell *et al.* 1983). In contrast, Whitaker *et al.* (1995) found that the inclusion up to 6%

Table 2.13. Effects of graded levels of winery pomace (WP) and dried citrus pulp (DCP) on body weight gain (BWG), feed intake (FI) and feed conversion ratio (FCR) in broilers (Farrell *et al.* 1983).

	Control	6% WP	12% WP	18% WP	6% DCP	12% DCP	18% DCP
BWG (g/d)	15.9 [a]	15.0 [a]	14.8 [a]	13.7 [b]	14.3 [b]	15.0 [a]	13.2 [b]
FI (g/d)	26.3	26.3	26.5	26.8	25.9	26.7	25.7
FCR	1.65 [a]	1.75 [a]	1.80 [b]	1.96 [b]	1.81 [b]	1.78 [b]	1.95 [b]
Calculated							
ME (MJ/kg DM)	13.15	12.90	12.38	11.91	12.93	12.46	11.98
C. Protein (%)	22.5	22.2	21.5	20.5	22.2	21.5	21.0
Crude Fibre (%)	3.6	4.4	6.1	7.7	3.4	4.0	4.7

Means within a row with different superscripts are significantly different ($P<0.05$)

cellulose in a standard grower diet may have beneficial effects on the efficiency of conversion of food into liveweight gain, although the reasons for this effect are not clear. Another benefit of the high-fibre-fed or of choice-fed broilers is the development of a large 'normal' gizzard that depresses the oocyst count as a method of coccidiosis control (Cumming 1989, 1992; Muir & Bryden 1992).

Deleterious factors in peanut shell are not clearly characterised. The bulkiness of peanut shell may cause problems in the production of the feed and affect the feed intake of the birds. Also, the lower energy content in peanut shell will result in the increased use of oil in the diet and therefore pellet or crumble quality will decrease.

There are several known effects of a diet high in fibre. There is increased transit rate of food through the digestive tract when insoluble fibre is included in the diet (Burkitt *et al.* 1972). But soluble fibre can have an opposite effect, slowing down digesta transit rate (van der Klis & van Voorst 1993). The increased transit rate may be due to the water-holding capacity of insoluble fibre, and to increased peristalsis which is thought to occur on such diets. Usually high fibre diets are low in energy and in fat content, but excretion of bile acids, which is important in fat absorption, is apparently increased in the presence of dietary fibre (Eastwood 1973; Kritchevsky 1976).

Cellulose fibres stimulate increased secretion of mucus fluid by the fowl and their physical irritation causes increased frequency of peristaltic contraction, thus speeding the rate of passage of the food through the gut and decreasing the time available for digestion. Both the mucosal cells and the mucus fluid contain high levels of protein, much of which is consequently lost from the body (Dingle 1992). In a study using graded levels of dietary fibre (from rice hulls) up to 120 g/kg, endogenous protein secretion into the gut was positively related to the level of dietary fibre (Siriwan *et al.* 1990). It is likely that dietary fibre increases the secretion of enzymes into the gut and desquamation of the lining of the intestinal tract.

The improper handling of waste by-products may result in mould contamination and associated toxins (Sanders *et al.* 1984). During harvesting and processing, contamination may take place, so that purity of the agro-industrial by-products and waste may be greatly reduced (Nitis 1983). Waste by-products may contain toxic residues from insecticides, fertilisers processing chemicals or fungal growth (Farrell *et al.* 1983).

2.6. Conclusions from Literature Review

The broiler industry is an essential part of the meat production sector in Indonesia and it faces the serious difficulty of obtaining adequate supplies, particularly of proteinaceous feedstuffs, for feed production.

Feed for broilers should contain nutrients in amounts and proportions that fulfill physiological needs to maintain optimum growth. Many raw materials will combine, complement and interact with each other, providing complete and balanced nutrients for broilers. The understanding of nutrient contents and evaluation of each feed ingredient are crucial to optimise the benefits and to avoid or minimise the deleterious effects associated with those ingredients.

Soybean meal is considered an excellent diet complement. However, this protein meal should be combined with other protein meals to obtain a better result. Moreover, the cost of soybean meal is higher than other plant protein sources in Indonesia. The use of alternative protein concentrates is possible if the limitation on using those proteins is considered via a better understanding of the nutritional content and effects of these materials. Unconventional waste by-products may also be utilised if feedstuffs are inadequate.

Previous research has shown the important roles of alternative raw materials in broiler diets, including production of sufficient nutritionally balanced diet; overcoming the scarcity of feedstuffs due to competition and seasonal factors; the provision of feed at an economical price; generation of 'supplementary effects', and providing products which satisfy market preference.

In Indonesia, peanut is an important legume not only for human consumption but also for the animal diet (in the form of peanut meal). Peanut shell is also readily available as a feedstuff. Although the chemical composition, nutritional contents and deleterious factors of peanut meal are already well-known, detailed examination of the utilisation and feasibility in broiler diets has not yet been carried out.

The following chapters present a study designed to examine the use of peanut by-products in broiler diets: peanut meal as a substitute for soybean meal, and peanut shell as an unconventional feedstuff ingredient. The interaction of peanut meal and different common cereal grains is also investigated.

Chapter 3

General Materials and Methods

3.1. Chickens

Commercial broiler chickens (Steggles S6 strain) were used in all the experiments. The birds were obtained at day-old from Australian Poultry Ltd., Beresfield, NSW, and transported to the University of New England, by road or air. The first experiment used mixed-sex chickens while the other two experiments used males only.

3.2. Cages

After arrival and prior to experimentation, the chickens were housed in electrically-heated brooders furnished with feed and water troughs, located in the Animal House Complex at the University of New England. Three types of cages were used during the experiments and all cages had wire-mesh floors and external galvanised feed and water troughs.

3.3. Management of Chickens

Prior to experiments, the birds were randomly allocated to treatment groups of equal mean liveweight (8 birds per group). The birds were grown under continuous fluorescent lighting. Feed and water were provided *ad libitum*. Water troughs were cleaned when necessary. Room temperatures were recorded daily.

The birds were monitored each day Any dead birds were replaced during the first 3 days of each experiment with spare chickens of the same or similar body weight. Mortalities were recorded over each experimental period. Birds showing obvious signs of leg weakness or any injury which affected their ability to obtain feed and water, and any bird showing 'ill-thrift', were euthanased by cervical dislocation. Feed intakes were adjusted accordingly for mortality.

3.4. Diets

Before the experiments began, commercial broiler starter crumbles were provided. The diets were supplied by Fielders Agricultural Products, Tamworth and contained an ME of 12.50 MJ/kg and a minimal 20% CP.

Peanut meal (mechanically extracted) containing less than 75 μg/kg aflatoxin was obtained from Queensland Oilseed Crushers, Carole Park, Queensland. Peanut shell was obtained from Baron Processing, Kingaroy, Queensland. Other raw materials were supplied by Fielders Agricultural Products, Tamworth, except for wheat and barley (South Australia).

For the first (I) and second (II) experiments, diets were cold-pelleted (approximately $60^{o}C$) with 5% water addition during mixing. All diets were crumbled for ease of handling and to maximise feed intake by the birds. The third experiment (III) used mash diets because of variable oil contents (0.58 to 7.42%) which may have affected crumble quality.

3.5. Measurements

Each cage of birds was weighed as a group throughout each experiment. Feed intakes were recorded at the same time. Average body weight was computed from total body weight of live chickens divided by the number of live chickens. Average feed consumption values were adjusted for the dead and culled birds.

$$\text{Feed intake} = \frac{\text{total amount of feed consumed}}{(\Sigma \text{ birds} \times \Sigma \text{ days}) - (\Sigma \text{ birds lost} \times \Sigma \text{ days lost})} \times \Sigma \text{ days}$$

Through these data, FCR was thus calculated:

$$\text{FCR} = \frac{\text{total feed intake (per group)}}{\text{total body weight gain (per group)}}$$

Moisture content of the diets and raw materials was measured after drying sub-samples (approximately 3 g) at 105^{o}C for 24 hours.

Apparent metabolisable energy (AME) of the diets was determined in each experiment. For AME determination, excreta were collected and bulked for 4 days for the first experiment (from 19 to 23 days of age), and were then dried at 70-80^{o}C for 24 hours. Excreta samples were collected for 3 days for the second experiment (21 to 24 days of age) and third experiment (23 to 26 days of age), and were dried each day of collection for 24 hours. During Experiment II, for the AME determination of peanut shell, excreta were collected for 3 days when chickens reached 21 days of age. Through this procedure, excreta moisture content and the amount of dry excreta were determined. Energy contents of the diets and excreta were measured using adiabatic bomb calorimetry. AME values were calculated from these gross energy (GE) values on an as-fed basis for the first experiment and on dry-matter (DM) bases for the other two experiments. For the AME (DM) calculation, moisture contents of crumble feed and milled crumble feed were measured.

$$\text{AME (as fed)} = \frac{\text{GE (in) - GE (out)}}{\text{FI (as fed)}} = \frac{\text{(GE feed x FI (as fed)) - (GE excreta x dry excreta)}}{\text{FI (as fed)}}$$

$$\text{AME (DM)} = \frac{\text{(GE feed x FI (as fed) x DM crumble feed/DM milled feed) - (GE excreta x dry excreta)}}{\text{FI (as fed) x DM crumble feed}}$$

Energy metabolisability, which indicates the amount of energy available from the diets, was calculated as follows:

$$\text{Energy metabolisability} = \frac{\text{AME}}{\text{GE}} \times 100\%$$

Where: FI is Feed Intake in kg; GE in MJ/kg; DM in % and AME in MJ/kg.

Protein was measured using a semi micro Kjeldahl method (Ivan *et al.* 1974) for the first experiment. For the second and third experiments nitrogen contents were measured using a Leco FP 228 Nitrogen Analyser. For the last trial the conversion factor of nitrogen to protein of 6.25 was replaced with 5.70 for barley and wheat.

3.6. Statistical Analyses

Data were analysed by ANOVA and regression analysis (Steel & Torrie 1980), using the computer packages NEVA and Minitab. Criteria for statistical significance were taken at the arbitrary probability cut-offs of $P<0.05$ (*), $P<0.01$ (**) and $P<0.001$ (***). Multiple comparisons were made using least significant differences (LSD).