Application of tropical legumes for pig feed

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ABSTRACT

Raw legume seeds are important source of protein and other nutrients for monogastric animals. However, these legume seeds include many kinds of anti-nutritive factors (ANF) such as trypsin and chymotrypsin inhibitors, lectins and tannins. Although these ANF vary by species, cultivation areas and harvesting methods, they play a role in decreasing the utilization of nutrients. The pig is a monogastric animal which is slightly tolerant to the ANF in raw legume seed. Nevertheless, the optimal use of legume seed as a pig feed necessitates a lowering of the toxicity in the raw seed until it is appropriate for incorporation in the feed. There are many methods to improve the utilization of nutrients in legume seed, such as breeding improvement, physical treatments (deortications, dehulling, milling and others), heat treatments (toasting, boiling, extrusion, streaming or autoclave), chelating substances for binding toxics, radiation and soaking. The choice of the treatment depends on the availability of facilities and economic considerations. This article reviews and discusses the nutrients in legume seeds and might offer an important information on legume seeds for pig feed to nutritionists.

Key words: feed, legume seed, pig.

INTRODUCTION

Both the leaf and seed of legumes can be used in animal feed, but in the monogastric animal the seed is more important than the leaf. Legume seeds are an important source of a plant protein in human and animal diets. Many countries are increasing their production of seed legumes (Gatel 1994). In Asia, about 20 legume species, most of them tropical, are cultivated, mainly for human consumption (Ravindran & Blair 1992). Seed rejected for consumption by humans is available for livestock feed. The potential utilization of legume seeds as a source of protein and energy for pigs is, however, governed not only by their essential amino acid and digestible energy (DE) content, but also by the possible presence of anti-nutritional factors (ANF). Therefore, the extent to which legumes are used in pig production is still limited because of problems with their effective nutritional quality. An investigation to decide the most efficient way to utilize available resources for pig diets may thus be useful.

NUTRITIONAL COMPOSITION OF LEGUME SEEDS

The nutritional composition of legume seeds analyzed by several authors are shown in Table 1. The protein content of legume seed is between 20 and 38% and varies between and within species. The metabolizable energy value measured in chickens varied from as low as 8 MJ/kg for pigeon pea and high fiber chickpea to as high as 13.8 MJ/kg for low fiber chickpea. The range of digestible energy measured in pigs was 13.5–15.87 MJ/kg (Visitpanich et al. 1985a).

When the amino acid requirements of growing pigs are compared with the amino acid content of all legumes, legume seeds are generally good sources of

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Received 24 July 2006; accepted for publication 12 October 2006.
lysine but are deficient in both methionine and cystine, while tryptophan is marginally deficient (NRC 1998). Provided that the diet is supplemented with methionine, legume seeds are potential substitutes for soybean meal (SM) in the diets of monogastric animals. Untreated legume seeds, however, contain ANF that are developed for the growth and protection of the legume, but depress animal production when ingested in excessive amounts.

Deosthale and Rao (1981) found that among varieties of pigeon pea, the protein content varies from 19.8% to 23.6%, methionine from 1.2% to 1.9% and tryptophan from 0.43% to 0.62%. Based on the calculation of protein content and protein scores, the pigeon pea is ahead of the cowpea, but behind the soybean in nutritive value. Consequently, protein is much higher in dehusked (22.5%) and mature seed (19.5%) than in immature seed (7.5%). Pigeon pea has a low content of lipids (1.3%).

The mature pigeon pea has a low fiber content (1.3%) and a high carbohydrate content (65.5%), which is significantly higher than in the immature seed (21.8%). The raw pigeon pea has a metabolizable energy value (2.680 kcal/g), that is much lower than the metabolizable energy of the toasted pigeon pea (2.909 kcal/g) (Nwokolo & Uji 1985). The metabolizable energy of the pigeon pea is similar to values for cowpeas and other edible peas and beans (Nwokolo & Uji 1985), and slightly lower than that for full-fat soybean.

In many legume seeds, the potassium content is very high (1.25%), and the phosporus, calcium and magnesium content moderately high. The iron, zinc, manganese and copper content are very low. Table 2 compares the distribution of lipids in the pigeon pea to that in the cowpea, which is similar in both, but is quite different from that in the soybean. The lipid profiles of the pigeon pea and cowpea are similar, but are quite dissimilar to that of the soybean. There is a high content of neutral lipids, a moderate content of phospholipids and a low content of glycolipids in the pigeon pea and cowpea. However, in soybean lipids, there is an extremely high content of neutral lipids (88.1%), a low content of phospholipids (9.8%) and an extremely low content of glycolipids (1.6%). Linoleic acid comprises only 22.5% of the total fatty

<table>
<thead>
<tr>
<th>Nutrients and essential amino acid (EAA) composition of some legume seeds</th>
<th>Black gram</th>
<th>Chick peas</th>
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<tr>
<td>Crude protein (g/kg dry matter)</td>
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<td>Crude fat (%)</td>
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Table 2 Distribution of lipid fractions in some legume seeds

<table>
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<tr>
<th>Legume</th>
<th>Neutral lipids (%)</th>
<th>Phospholipids (%)</th>
<th>Glycolipids (%)</th>
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<td>Pigeon pea</td>
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<td>Soybean</td>
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Salunkhe et al. (1985).
acid content in the pigeon pea, compared with a linoleic acid content of soybean lipid of about 54.5% (Salunkhe et al. 1985).

When expressed as a percentage of total amino acids, the amino acid profile of legumes is similar to those in most beans, peas and edible pulses. However, the concentration of amino acids is inferior to that of most edible pulses, including the cowpea, the kidney bean and the field pea. As is the case of many legumes, there is a deficiency of the sulfur amino acids, methionine and cystine. Other essential amino acids like histidine and threonine are marginally deficient and may need to be supplemented through use of other protein sources that are high in these amino acids. The availability of amino acids in the pigeon pea ranges from 51.5% (proline) to 90.8% (phenylalanine), with a mean availability of 82.3%. The average availability of pigeon pea amino acids is lower than in soybean (Kwokolo 1987). The nutritive value of pea-meal base diets can be improved by the addition of carbohydrases (Cowieson et al. 2003).

THE ANF IN LEGUME SEEDS

Most legume seeds contain various ANF. These may range from the relatively innocuous phytates, oligosaccharides, polyphenols and anti-vitamins, to the harmful enzyme inhibitors, hemagglutinins and saponins. A major constraint on the use of legume seeds and other non-traditional feed ingredients is that they contain a number of naturally occurring substances known as ANF that depress growth performance in animals. It has been suggested that these inhibitors can be used as a means of controlling insects (Boulter et al. 1989). The distribution and physiological effects of ingestion of ANF are presented in Table 3. The main ANF in legume seeds are protease (trypsin and chymotrypsin) inhibitors, lectins and tannins (Wiseman & Cole 1988). Other ANF which may play an important role in decreasing the nutritive value of legume seeds are non-starch polysaccharides (NSP) (Chang & Satterlie 1981). Because of genetic differences, each legume species or cultivar is likely to have different amounts of ANF (Grant et al. 1983; Alitor et al. 1994; Gatel 1994). Elias et al. (1976) reported the existence of trypsin inhibitors in the pigeon pea, and estimated it to be at 10.1 total unit of trypsin inhibitor, in contrast to a much higher content of 25.5 total unit of trypsin inhibitor in soybean. The distribution of ANF in legume seeds is discussed as follows.

### Protease inhibitors

Trypsin and chymotrypsin inhibitors are common constituents of particular legume seeds. Trypsin and chymotrypsin inhibitors have average molecular weights of 10 500 and 15 000, respectively (Godbole et al. 1994). They are readily denatured by heat, acid and alkali. Active trypsin inhibitors have been shown to decrease the utilization of proteins because they inhibit trypsin or chymotrypsin activities (Kakade et al. 1969). The physiological responses of animals to the same level of trypsin and chymotrypsin inhibitors in different legumes may vary. Pigs can tolerate dietary levels of at least 4.7 and 4.5 mg/g of trypsin and chymotrypsin inhibitors, respectively (Batterham et al. 1993). However, in one experiment the growth of pigs fed diets containing a pigeon pea meal which contained a lower level of these two protease inhibitors
was severely depressed. Growth depression from feeding legume seeds is usually due to more than one factor. Kakade et al. (1973) estimated that trypsin inhibitors from raw soybean account for about 40% of the enlargement of the pancreas and 40% of the growth retardation.

**Lectins**

The harmful lectins are phyto-hemagglutinins, which were glycoproteins capable of agglutinating red blood cells, and of binding to receptors on the epithelial cells of the intestinal mucosa, thereby interfering with digestion (Gatel 1994). Lectins are heat sensitive proteins but are resistant to gut proteolysis (Nakata & Kimura 1985). Grant et al. (1983) showed that the nutritional and hemagglutination properties of lectins in legumes in the UK were non-toxic and growth depression was observed after feeding animals these legumes. It therefore appears that this is due to effects other than direct toxicity. Lectins damage the gastrointestinal tract, through extensive damage to the brush border followed by disruption of the functional formation of the brush border membrane (Nakata & Kimura 1985), causing interference with the normal secretion and absorptive function of that region.

**Tannins**

Tannins are defined as water-soluble phenolic compounds, most of which reside in the seed coat (Deshpande et al. 1982; Singh 1993). Tannins have a high protein binding capacity. Tannin-protein complexes, which are extremely hydrophobic (Mitaru et al. 1984), are partly responsible for low protein digestibility and low amino acid availability and thus for increased fecal nitrogen excretion in pigs (Hlodversson 1987). Like other ANF, ingesting a sufficient amount of dietary tannin reduced the daily gain and impaired the feed efficiency in pigs due to the decreased digestibility of the protein (Jansman et al. 1993).

**NSP**

The components of non-digestible carbohydrates of a feedstuff are NSP, consisting of water insoluble cellulose and water soluble gums, hemicelluloses, pectic substances and muclages. These are contained in legume seeds in relatively highly amounts (Brillouet et al. 1988; Smits & Annison 1996). These substances are resistant to endogenous enzymic digestion in the alimentary tract (Classen & Bedford 1991) and their presence decreases the rate of gastric emptying and increases small intestinal transit time (Potkins et al. 1991). Choct et al. (1995) showed that the addition of 40 g/kg NSP to a commercial broiler diet decreased the birds’ weight gain, feed efficiency and apparent metabolizable energy (AME) by 28.6, 27.0 and 21.2%, respectively.

**IMPROVING THE NUTRITIONAL VALUE OF LEGUME SEEDS**

**Plant breeding**

Plant breeding is a long-term process and so are the results, at least for the remove of trypsin inhibitors in peas (Pisum sativum). Some cultivars have a higher trypsin inhibitor activity than one of their parents and cultivars derived from the same cross showed different trypsin inhibitor activities, suggesting that the hereditary transmission was not systematic (Leterme et al. 1992). Reducing condensed tannin content through the genetic manipulation of the faba bean has resulted in the increased digestibility of dry matter and nitrogen in pigs (Van der Poel et al. 1992).

**Physical treatment**

The most widely used methods for the reduction of the negative effects induced by ANF are physical treatments. Decortication is an effective method for reducing the tannin content of grain legumes since most tannins reside in the taste bud (Deshpande et al. 1982; Rao & Prabavati 1982; Singh 1993). Weight gain, feed-to-gain ratio, apparent protein digestibility (APD) and AME were improved by 5.7, 7.0, 16.4 and 13.9%, respectively, when growing chickens were fed dehulled, high tannin peas compared with those fed an untreated pea diet (Brenes et al. 1993). This method can be use for pig feed.

**Heat treatment**

Heat treatment based on the heat denaturation of proteinaceous inhibitors is a good method of decreasing the activity of lectins and trypsin and chymotrypsin inhibitors, and generally improving the nutritional value of legume seeds (Kadam et al. 1987; Van der Poel 1990). The purified inhibitors in solution were stable to heat at 80°C for 15 min and pH 7–10. In the pH range 3–5, 80% of the activity was retained. Autoclaving totally destroyed the inhibitor activity (Godbole et al. 1994). Duke (1981) found that both trypsin and chymotrypsin inhibitors seem to be completely destroyed or inactivated by heat treatment. Cooking, toasting and other heat treatment procedures seem to
be enough to enhance the nutritional qualities of pigeon pea to levels well above that of raw pigeon peas.

Brenes et al. (1993) reported that the inclusion of 47.5% autoclaved (121°C for 20 min) high tannin peas (*Pisum sativum*) into a corn-soy basal diet increased the AME and APD by 21 and 11%, respectively, compared with inclusion of the same amount of unprocessed peas. Comparative studies in rats (Kadam et al. 1987) showed that infrared radiation, autoclaving and boiling in water are effective means of reducing the trypsin inhibitor activity and lectin activity of wing beans. Mekbungwan and Yamauchi (2004) reported that heating the pigeon pea seed meal (PM) with steam at 105°C for 2 h can reduced the activity of the trypsin inhibitor from 99.15% in the raw PM to 54.31% in the heated PM. Toasting seems to improve the digestibility of protein in the pigeon pea. A comparison of protein digestibility in toasted and raw pigeon peas (Kwokolo 1987) has shown that in raw pigeon peas the true protein digestibility was 69.4%, whereas in toasted pigeon peas the value was 80.6%, similar to a digestibility coefficient of 84.1% in cooked soybean.

The ANF in raw PM can be reduced by heating (Visitpanich et al. 1985b; Singh 1988), boiling (Rani et al. 1996), roasting (Simoongwe 1998), extraction (Benjakul et al. 2000) and cooking (Aarti et al. 2001), resulting in improved protein and starch digestibility (Rani et al. 1996). Higher growth rates have been reported in rats (Udayasekhar Rao & Belavady 1978) and pigs (Visitpanich et al. 1985a) given heated PM than in those fed unheated PM. The trypsin inhibitor was decreased by roasting (Simoongwe 1998) and cooking (Sharma & Sehgal 1992) PM. The trypsin inhibitor activity in PM was lowered after boiling (Rani et al. 1996) and was completely destroyed by pressure cooking (Duhan et al. 2001). The net protein utilization of a casein diet was improved from 0.49 in raw PM to 0.57 in cooked PM (Nageswara Rao & Narasinga Rao 1978).

**Chelating substance treatment**

Many anti-nutritive and toxic substances are heat stable during a manufacturing heating process. However, several chelating materials are used to bind these ANF in order to depress their activity. Charcoal acts as an insoluble carrier that non-specifically adsorbs molecules, thereby preventing their absorption. Dietary-activated charcoal is an effective substance for the removal of verotoxins from bacteria extract (Naka et al. 2001). Additionally, it alleviates some toxic effects in broiler chicks (Edrington et al. 1997), and improves broiler growth performance (Kutlu et al. 2001). When activated charcoal was added to diets containing aflatoxins or T-2 toxin, the reductions of feed intake and bodyweight gain of chickens tended to be improved (Anjaneyulu et al. 1993; Edrington et al. 1997). Alternatively, wood vinegar compound liquid, a by-product of charcoal production, has been reported to enhance intestinal calcium absorption in rats (Kishi et al. 1999). In addition, a mixed powder of amorphous charcoal carbon powder and wood vinegar compound liquid (CWVC) has also been shown to induce a significant increase in hen/day egg production, in the feed conversion ratio (Sakaida et al. 1987a), and in broiler hatchability (Sakaida et al. 1987b). Recently, improved feed conversion ratio and activated morphological changes of intestinal villi were observed in chickens fed a 1% CWVC diet (Samanya & Yamauchi 2001). Mekbungwan et al. (2004a) reported that feed efficiency tended to be improved when CWVC was included in pig diets and demonstrated that the CWVC could be incorporated into piglet diets up to a level of 3%, suggesting that the CWVC might activate intestinal functions both at villus and cellular levels.

**Other methods**

The application of infrared radiation of peas fed to young chickens also resulted in a significant increased in AME, APD and starch digestibility (Igbasan & Guenter 1996). Fermented grass pea seed meal can be incorporated in carp diets up to a level of 30%, compared to a level of 10% in raw seed meal (Ramachandran et al. 2005).

**TROPICAL LEGUMES FOR PIG OR MONOGASTRIC ANIMAL FEEDS**

Many varieties of tropical legume can be used in monogastric animal feed and some of them are consumed by humans. Considerably more research attention has been paid to agronomy legumes such as soybean and peanut than most of the other unspecialized legumes such as pigeon peas, cowpeas, field pea, dry beans, broad beans, faba beans and chickpeas. The nutritional values of these legumes have been much less studied than agronomy legumes. The reasons for this are obvious, since their production, or utilization for human food is less than that of agronomy legumes.
The soybean and peanut are used as human food. On the other hand, some kinds of legumes grow well in some regions and a surplus of production can be used for animal feed. In this case, there must some treatment for the food to be appropriately utilized by pigs or other monogastric animals.

THE EXPERIMENT APPLICATION TO USE LEGUME SEED IN PIG OR OTHERS MONOGASTRIC ANIMAL FEED

Feeding raw legumes to monogastric animals generally resulted in their lower growth rate and reduced feed efficiency. Up to 30% raw faba beans can be included in broiler diets without significant negative effects on the birds' performance (Jansman et al. 1989). Recent studies with raw faba bean, field pea, lupin and chickpea showed that up to 36% of the first three legumes can be included in broiler starter diets, while an inclusion of 36% chickpeas significantly reduced weight gain and increased feed conversion (Perez-Maldonado et al. 1997). These reductions were not significant when a diet containing 36% raw chickpea was fed during the finisher period. The feed conversion ratios of meat chickens fed diets containing 10–30% pigeon peas were not significantly different from those fed a control diet. However their feed conversion ratio was increased by up to 14 and 19% when the level of pigeon peas was increased to 40 and 50%, respectively (Tangtaweewipat & Elliot 1989). Thus, the extent of the negative effects of feeding raw legumes depends on the type of legume, the levels of inclusion in the diet and the age of the animals. Comparative studies on pigs fed diets in which 37% of the dietary protein was contributed by either raw chickpea or raw pigeon pea (Visitpanich et al. 1985b), showed that chickpea produced growth performance similar to heated SM. Feeding pigeons pea resulted in a lower growth rate and a lower dressing percentage than feeding chickpeas or heated SM. Falvey and Visitpanich (1980a,b) have already proposed using PM for growing pigs, and Batterham et al. (1993) reported that the addition of PM linearly depressed the growth rate and feed intake, and increased the feed conversion ratio in growing pigs. Visitpanich et al. (1985a) described the inferior growth rate of growing pigs fed diets containing 30% raw PM compared to their growth when fed SM. Castro et al. (1987) reported that no effect on the feed conversion ratio was obtained by a substitution rate up to 50% of PM for SM. Mekbungwan et al. (1999) reported that the PM could be incorporated beyond the 30% level for a piglet diet (a 53.4% substitution rate of PM for SM) and up to the 20% level for a growing pig diet (76% substitution rate of PM for SM).

In studies of using legume seeds in feeds, the intestinal morphological parameters (villus height, cell area, and cell mitosis of the crypt) were lower in recovering in piglets refed PM than those in SM after fasting, demonstrating that PM nutrients might be effectively absorbed even in the raw state, although its absorptive degree is weaker than that of SM (Mekbungwan et al. 2002). Intestinal villus height, cell area and cell mitosis tended to be highest in the SM group and lowest in the PM group. Dome-like cells were seen on the surface of villi in the SM group, but flat cells were observed in PM group. These histological data suggest that intestinal villi are activated much more in pigs fed SM than PM (Mekbungwan et al. 2003). However, the fact that physical damage was not observed on the tips of villi in pigs fed PM suggests that raw PM could be used as a plant protein source by adding CWVC as a supplement to conventional diets (Mekbungwan et al. 2004a). Mekbungwan et al. (2004b) compare the nutrient digestibility of SM and PM as well as morphological intestinal alterations in piglets. The digestibility of crude protein, crude fat and crude fiber was 80.6, 23.6 and 52.4% in the SM group, while in the PM group, values of 49.8, 23.6 and 43.2% were observed, respectively. The digestible energy was 3.26 kcal/g in SM and 3.17 kcal/g in PM. The intestinal digestive and absorptive functions are much more atrophied in the PM group than in the SM group.

Raw PM could be incorporated under the 40% level in piglet feed, but heated PM increased the incorporation rate up to the dietary 40% level. Histological studies showed that intestinal villi might be atrophied in the piglets fed raw PM due to ANF, resulting in their decreased growth performance. Heating PM might abolish such a harmful effect of the ANF on the villus function, resulting in a similar growth performance to the control (Mekbungwan & Yamauchi 2004). Stein et al. (2004) showed that growing-finishing pigs fed diets containing 0, 12, 24, or 36% field peas produced no differences among treatment groups in average daily gain, average daily feed intake, gain per feed, backfat thickness or lean meat percentage, but pigs fed diets containing 12, 24, or 36% field pea had greater (P < 0.05) loin depths than pigs fed the control diet. The apparent ileal digestibility for methionine, tryptophan, cystine and serine were lower (P < 0.05) in field peas than in SM, but no differences for crude protein and all other amino acids were observed.
between the two feed ingredients. The digestible energy values for field pea and corn were similar, but the metabolizable energy of corn was higher than the metabolizable energy of field peas. Therefore, they concluded that field peas may be included in diets for nursery pigs and growing-finishing pigs in amounts of at least 18 and 36%, respectively, without negatively affecting pig performance.

CONCLUSION

The ANF in raw legume seed are trypsin and chymotrypsin inhibitors, lectins tannins and others, which play a role in decreasing the utilization of nutrients. The use of untreated raw legume seed as a pig feed is limited, so the toxicity of raw seed must be reduced until it appropriate for incorporation in feed. There are several methods to treat raw legume seed for increasing the utilization of nutrients, such as breeding improvement, physical treatments (decortication, dehulling, milling or other physical methods), heat treatments (toasting, boiling, extrusion, streaming or autoclaving), chelating substances for binding toxics and soaking. The choice of the treatment depends on the availability of facilities and economic considerations.

ACKNOWLEDGMENT

I am very grateful to Professor Dr Koh-en Yamauchi from the Laboratory of Animal Science, Kagawa University, Japan for his recommendation to this Journal and discussion with me.

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