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REVIEW

Nutritional Value of Palm Kernel Cake and Meal for Livestock and Fish Feeding: A Review

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ABSTRACT

The use of palm kernel cake (PKC) and meal, which are by-products of oil palm processing for livestock feeding has been reported in the literature. The production of these palm kernel by-products in the last decade has been on the increase with Nigeria and Malaysia as leading producers. The cake is reported to have a protein of between 14 and 21%; crude fibre, 21-23% and gross energy of about 20.9MJ/kg. Its high amounts of non-starch polysaccharides (NSPs) mainly in the form of mannan and galactomannan confers on it a low digestibility in poultry. It is also limiting in lysine and the sulphur-amino acids. Due to its high mannan content, feeding PKC to poultry and fish at levels more than 12% in the diet necessitates its supplementation with mannanase and other polysaacharidases such as cellulases and xylanases. Ruminants however, are able to tolerate higher levels of up to 30%. Levels of inclusion of PKC higher than 50% in the diets of sheep and cattle without zinc supplementation can result in copper toxicity and in some cases death of the animal. PKC when supplemented with enzymes or when fermented with fungi such as Aspergillus niger, Trichoderma viride and Trichoderma reesei becomes a useful energy and protein feed for poultry with performance values comparable to those of most conventional plant protein ingredients.

Keywords: Palm kernel by-products; Nutritional value; Anti-nutrients; Livestock; Fish

INTRODUCTION

Palm kernel cake (PKC) and palm kernel meal (PKM) are found in large quantities in a number of tropical countries (Wan and Alimon, 2012). They are by-products of palm kernel oil extraction from the nut of the palm tree, *Elaeis guineensis*. Two methods are used in the production of the cake: the expeller and the solvent extraction methods. According to Okeudo *et al.* (2005), the by-product from the mechanical expeller process is known as palm kernel cake while the one from solvent extraction is palm kernel meal. The expeller process is the more commonly used one because of its low cost of operation and adaptability of use locally. The process of extraction affects the nutrient and chemical composition of the cake although Alimon (2004) reported that the difference in the quality of expeller and solvent extracted PKC or PKM is small. According to Alimon (2004), PKC contains more oil (4-8%) than PKM (1-2%). There has been an increase in the global production of PKC largely due to the increase in production of oil palm nuts in Africa and Asia. For example, in the last 10 years the production of PKC has risen from 185,000 to 365,000 MT in Nigeria and from 176,000 to 2.39 million MT in Malaysia (USDA/Index Mundi, 2007). Increase in production has been stimulated by increase in demand for palm kernel oil for the production of soap and other cosmetics as well as increased demand for PKC for animal feeding in the face of increasing prices of conventional protein ingredients like soyabean meal and groundnut meal. In the last two decades PKC has increasingly become important in animal feeding as a result of two factors; increasing cost of conventional plant protein ingredients and the low cost of PKC.

The European Union for example accounts for 88% of worldwide imports of PKC (FAPRI, 2005). Palm kernel cake can serve as a source of both energy and protein for feeding farm animals. Its value as an energy supplying or supplementing ingredient depends largely on the amount of residual oil in it. The cake is high in fibre with a range of 13.0 – 20.0% as reported by various authors. Although PKC is a good source of animal feed, its energy value is not sufficient for intensive and sustainable animal production. One of the major limitations of the inclusion of higher amounts of PKC in animal feed is its high content of mannan, galactomannan, xylan and arabinoxylan, which confer on it anti-nutritional properties. Whereas ruminant are able to tolerate these non-starch polysaccharides (NSPs) to a large extent, monogastrics are able to do so only to a limited extent. However recent reports indicate that this problem can be overcome by supplementing PKC-based diets with mannanase enzyme or a cocktail of enzymes, which are effective in breaking down the NSPs to reducing sugars and oligosaccharides. The reducing sugars enhance the energy value of the PKC-based diet and the oligosaccharides can act as prebiotics. Thus with enzyme supplementation or fermentation of PKC with enzyme before feeding, PKC is increasingly becoming important as an alternative protein and energy ingredient for feeding livestock.

Nutrient and chemical composition of palm kernel cake

There are variations in the values of the nutrient and chemical compositions of PKC reported by various authors. The variation is due to the differences in samples and the analytical procedures used. The crude protein value of PKC is between 14 and 21%; crude fibre, 21-23% and gross energy about 20.9MJ/kg (Table 1). In some Nigerian samples obtained from three PKC producing plants, a range in crude fibre value of 10.0-18.0 has been reported by Ezieshi and Olomu (2007). According to Alimon (2004) the metabolisable energy of PKC for ruminants is 11.5 MJ/kg; poultry, 7.5 MJ/kg and swine 10.5 MJ/kg. Boateng *et al* (2008) reported the resistance of the crude fibre in PKC to monogastric digestive enzymes. The authors stated that the fibre content of PKC is associated with a decline in nutrient digestibility of the cake especially when fed to monogastrics. This notwithstanding PKC can be a major source of energy and protein for farm animals because according to Sundu *et al* (2006) 49% of the dry matter in PKC is in the form of nitrogen free extractives.

Table 1. Nutrient composition of palm kernel cake

Fraction	Composition	Reference
Dry matter, %	94	Sundu *et al.,* (2005)
Crude protein, %	14-21	-do-
Crude fibre, %	21-23	-do-
Lipid, %	8-17	-do-
Ash, %	3-6	-do-
Gross energy, MJ/kg	11.0	-do-
Metabolisable energy, MJ/kg		
Ruminants	10.5-11.5	Alimon (2004)
Poultry	6.5-7.5	-do-
Swine	10.0-10.5	-do-

The mineral and amino acid compositions in PKC as reported by different authors are presented in Tables 2 and 3, respectively. The content of most of the minerals is within the range acceptable for animal feeding. The values of calcium and phosphorus show that the ratio of Ca to P is low. The sodium content is also low. Diets containing high amounts of PKC particularly when fed with maize silage need to be supplemented with these minerals so as to meet the requirements of most animals for them. The copper content is higher than required by most ruminants. Alimon (2004) reported that sheep fed diets containing PKC above 50% may suffer high accumulation of copper in the liver if fed for too long and with the development of copper toxicity symptoms. Hair-Bejo *et al*. (1995) and Hair-Bejo and Alimon (1995) reported that Malaysian indigenous sheep and their crosses were more susceptible to copper toxicity than exotic breeds. Molybdenum and sulphur as well as zinc sulphate have been reported (Al-Kirshi, 2004) as effective in reducing the copper levels in the liver and kidneys of sheep fed PKC-based diets. The iron content of PKC as reported by Alimon (2004) is high but according to the author this does not adversely affect the animal performance as most ruminants are able to regulate their iron absorption.

The amino acid content of PKC as reported by different authors shows that the cake is limiting in lysine, methionine and cysteine. Lysine appears to be the first limiting amino acid, and then followed by the sulphur amino acids and tryptophan. The availability of amino acids in PKC is lower than in most oil seed meals. Nwokolo *et al*. (1976) and Onwudike (1986) showed that the average availability of amino acids in PKC was 85%. Yeong *et al*. (1981) reported that the amino acid availability for poultry was between 62% and 87% while recently Mustafa *et al*. (2004) reported that the overall true availability of PKC amino acids was 65%.

Table 2. Mineral composition (%) of palm kernel cake

Ca	P	Mg	K	Na	S	Cu	Zn	Fe	Mn	Mo	Se	Source
0.34	0.71	0.33	0.93	-	0.23	28.9	50.0	6.30	340	0.79	0.30	Alimon (2004)
0.23	0.31	-	-	-	-	-	-	-	-	-	-	Devendra (1985)
0.33	0.65	0.33	-	-	-	-	-	-	-	-	-	Rogers (2000)

Table 3. Amino acid composition of palm kernel cake

Amino acid	**Composition (g /100g CP)**			
Alanine	-	-	-	0.65
Arginine	2.18	2.40	2.20	0.89
Aspartic acid	-	-	-	1.87
Cystine	-	-	-	0.14
Glutamic acid	-	-	-	3.10
Glycine	0.82	0.84	-	0.71
Histidine	0.29	0.34	0.27	0.08
Isoleucine	0.62	0.61	0.63	0.93
Leucine	1.11	1.14	1.05	2.30
Lysine	0.59	0.61	0.56	0.18
Methionine + Cystine	0.50	0.34	1.98	0.31
Phenylalanine + Tyrosine	1.11	1.21	1.28	0.83
Proline	-	-	-	0.48
Serine	0.69	0.77	-	0.78
Threonine	0.55	0.60	0.54	0.39
Tryptophan	0.17	0.19	0.19	
Tyrosine	-	-		-
Valine	0.93	0.80	0.90	0.52
Source	**Yeong *et al* (1983)**	**Hutagalung *et al* (1982)**	**Devendra (1978)**	**Iluyemi *et al* (2006)**

Antinutritional factors in PKC and PKM

The major antinutritional factors in PKC and PKM are the non-starch polysaccharides (NSPs). However, Akpaniabiatu *et al* (2001) reported levels of 1.3 to 2.4 mg/100 g of hydrocyanic acid and 15.2 to 30.0 mg/100 g of total oxalate in undefatted dried PKC from two varieties of oil palm in Nigeria. The authors detected no phytate in the samples. Palm kernel cake has been reported (Duffaud *et al.*, 1997) to contain mannan and galactomannan, which are likely to have anti-nutritional properties. Of the NSPs in PKC, 78% was mannan, 3% was arabinoxylans, 3% was glucoronoxylans, which were found to be water-insoluble and 12% was cellulose. On dry matter basis PKC has been reported to have 25-30% β-mannan (Jackson *et al.*, 2003). Instead of starch as the storage carbohydrate, PKC contains β 1-4 linked polymers of D-mannosepyranose mainly in the forms of mannan-based polysaccharides (Figure 1). These polysaccharides exist in 4 different sub-families depending on the type of sugar present in the polymer chain. According to Figure 2, these are (i) pure mannan, (ii) galactomannan, (iii) glucomannan and (iv) galactoglucomannan. Pure mannan is a polymer of mannose, which contains 95% mannose. The presence of galactose, glucose and both galactose and glucose in the side chain form galactomannan, glucomannan and galactoglucomannan.

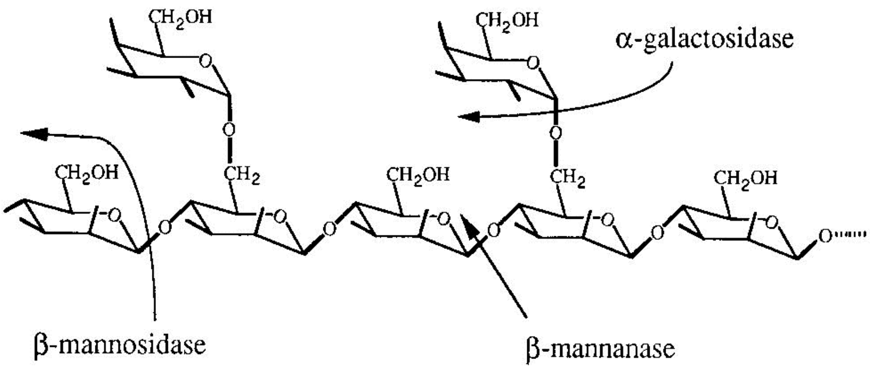

Figure 1. Schematic galactomannan structure (Duffaud *et al.*, 1997).

The polymannose chain (β-linkage) is substituted at every 2 residues by a galactose residue (α-linkage). The arrows represent the glycosidic links recognized by β-mannanase (Endo-), β-mannosidase (Exo-) and α-galactosidase.

··· β- D-Man *p* (1 4)- β- D-Man*p* (1 4)- β- D-Man *p* (1 4)- β- D-Man *p* (1 4) ····
A typical mannan structure

··· β- D-Glc *p* (1 4)- β- D-Man*p* (1 4)- β- D-Man *p* (1 4)- β- D-Man *p* (1 4) ····
A typical glucomannan structure

··· β- D-Man *p* (1 4)- β- D-Man*p* (1 4)- β- D-Man *p* (1 4)- β- D-Man *p* (1 4) ····
β- D-Gal *p* (1 6) Acetyl at C-2 or C-3
A typical galactomannan structure

··· β- D-Glc *p* (1 4)- β- D-Man *p* (1 4)- β- D-Man*p* (1 4)- β- D-Man *p* (1 4) ····
β- D-Gal *p* (1 6) Acetyl at C-2 or C-3
A typical galactoglucomannan

Figure 2. The structures of mannan, glucomannan, galactomannan and galactoglucomannan (Duffaud *et al.*, 1997)

Mannans and glucomannans are polymers with a backbone consisting of β-1,4-linked mannopyranose units. In glucomannans, the main polymer chain also contains glucopyranose units, randomly distributed within the molecule. In galactoglucomannans, D-galactose side groups are linked to the mannose or glucose units of the backbone chain by α-1,6-linkages. Most PKC mannans are extremely hard, highly crystalline and water insoluble. Jarvis (1990) reported that PKC contains mostly linear mannan and a small amount of galactomannan with a very low substitution of galactose. However, PKC mannan and other NSPs have been shown to be susceptible to enzyme breakdown especially the mannanases and xylanase. Mannanases are isolated from a number of organisms including bacteria, fungi, plants and animals, which are capable of hydrolyzing mannanopyranosil linkages. There are 2 types of mannanases, based on the site of lysis in the hydrolytic process; endo- and exo-mannanase. Exo-mannanase is able to remove one or more mannose from the ends of polysaccharide chains while endo-mannanase can randomly cleave bonds within the chain. Three types of enzymes are needed to effectively hydrolyse the linkages of either pure mannan or galactomannan. These are endo-mannananse, exo-mannanase and α-galactosidase. Complete breakdown of mannan, galactomannan, glucomannan or galactoglucomannan results in the production of sugars that can be easily converted to metabolisable energy in animals.

Incomplete hydrolysis can produce mannotriose, mannobiose and some mannose. The positive effect of mannanase enzyme on animal performance has been demonstrated by Jackson *et al* (2003) in chicks, Jackson *et al* (2004) in broilers, Kim *et al* (2003) and Petty *et al* (1999) in swine, Odetallah *et al* (2000) in turkey and Ng and Chong (2002) in fish. Jackson *et al* (2003) even reported that the addition of β-mannanase to the diets of chicks significantly improved performance and reduced lesion scores in disease-challenged birds. A cocktail of enzymes including β-mannanases is needed for the breakdown of mannan in PKC and other plant materials such as soyabean, copra and guar meal. Hagglund *et al.* (2003) conducted studies on the effect of β-mannanase from *Trichoderma reesei* and blue mussel and β-mannosidase from *Aspergillus niger*. The authors reported that β-mannanase from *T. reesei* has a catalytic module and a carbohydrate-binding module (CBM). The CBM of the enzyme has a positive influence on the hydrolysis of complex mannnan substrates containing cellulose with the CBM binding to cellulose but not to mannan. According to the authors, all three enzymes were capable of degrading polymeric mannan in PKC. It thus appears that an extensive breakdown of mannan is achieved only when a mixture of enzyme types from different microbial sources is used. Indeed Dhawan and Kaur (2007) stated that the synergistic action of endo-1,4-β-mannanases (E.C. 3.2.1.78), mannan endo-1,4-β-mannosidase) and exo acting β-mannosidases (E.C.3.2.1.25) is required. Additional enzymes such as β-glucosidases (E.C.3.2.1.21) and α-galactosidases (E.C.3.2.1.22) and acetyl mannan esterases (Tenkanen, 1998) are required to remove side chain sugars that are attached at various points on mannans. The products of the actions of these enzymes were mainly mannobiose, mannotriose and traces of higher oligosaccharides.

Utilization of palm kernel cake in ruminant production

Ruminants have several advantages over non-ruminants as converters of feeds like PKC, which are not in direct competition with humans. Several authors have proved the suitability of PKC as cattle feed. Mixed together with other ingredients, it is the basic supplementary feed of dairy cattle in some countries where it is available in large quantities. Mustaffa *et al (*1987) reported the feasibility and practicability of using PKC for commercial feedlotting. Yusoff *et al* (1987) reported that comparing breeds fattened using expeller pressed PKC, the beef characteristics of the Droughtmaster cattle performed better than the dairy type Local Indian Dairy crossbreds and the Sahiwal-Friesian animals. According to the authors, their respective daily gains were 0.85, 0.63 and 0.65 kg, though their feed conversion ratios of 7.37, 7.80 and 7.83 were not significantly different, an indication of higher intake of feed by the Droughtmaster cattle. The average daily gain of the Australian Commercial Cross (ACC), another beef breed fed with PKC was found to be very promising at about 0.84 kg, with a feed conversion ratio of 6.96 (Hutagalung *et al*, 1986). Sahiwal-Friesian animals were fed with solvent extracted and expeller pressed PKC, with a low fat content of 7% (Yusoff *et al*, 1987) with no significant difference in performance found between the groups of animals. Palm kernel cake has been fed successfully in combination with palm pressed fibre by Cameons (1978). Yahaya and Ibrahim (1985) reported that PKC fed with palm oil mill effluent (POME) produced better carcass measures in Drouhgtmaster breed compared with Brahman breed of cattle.

Local Malaysian indigenous Kedah-Kelantan cattle were fed in a feedlot experiment with rations involving both the solvent extracted and expeller pressed PKC with POME. A ration of solvent extracted PKC and POME in a 50/50 ratio was observed to be the best treatment with a daily gain of 0.6 kg and a corresponding feed conversion of 6.29 (Shamsuddin et al., 1987). Collingwood (1958) reported increased butterfat production when PKM was fed to dairy cattle. In a comparative feed evaluation study with PKM, brewer's dried grain (BDG) and cotton seed cake (CSC) for cattle, Umunna *et al* (1980) reported that calves fed the high PKM diet require significantly less feed than those on the BDG, CSC and control diets. The problem of palatability associated with PKM was according to the authors counteracted by supplemental molasses. The milk protein content tends to be affected by inclusion of PKM in diets of dairy cows. Carvalho *et al* (2006) evaluated PKM in corn silage-based diets for lactating Holstein cows. The authors reported that there were no significant treatment effects on dry matter intake, milk yield, or milk composition with increasing levels of PKM in the diets. Inclusion of PKM according to the authors tended to increase protein and lactose contents of milk and that the control diet with no PKM promoted weight loss. The authors concluded that feeding PKM up to 15% in the diet of Holstein cows decreased feed costs without detrimental effects on productive responses. Gill and Hill (2008) reported that because the palatability of PKM is poor, sheep and cattle find it difficult to eat except it is mixed with molasses or with other feeds. The authors reported an amount of 20 mg/kg copper, 0.25 mg/kg selenium, 40 mg/kg zinc and 0.24 mg/kg magnesium in PKM. This reveals that the copper available in PKC is twice the daily requirement of cattle and four times that of sheep. The amount of selenium available is eight times the daily requirement while zinc is more than adequate. Sheep have a lower requirement for copper and when fed diets containing more than 50% PKC is more susceptible to copper toxicity than cattle. Therefore according to the authors the total concentration of copper in the diet, which includes PKC should not be higher than 15 mg/kg. Gill and Hill (2008) suggested that breed differences is important in the ability of cattle to cope with high copper levels in PKC. According to the authors individual cows and perhaps certain breeds for example Jerseys due to their higher metabolic rate in comparison with Friesians, may accumulate more copper in their livers. The results of performance of different breeds of cattle fed PKC or PKC-based diets obtained by various workers are presented in Table 4.

Table 4. Daily weight gain (DWG) in cattle fed 100% PKC and PKC mixed diets

Feed/diets	Breed of cattle	DWG(kg)
100% solvent extracted PKM	Zebu cross	0.793
100% solvent extracted PKM	Sahiwal-Friesian crossbred	0.760
100% expeller pressed PKC	Local Kedah-Kelantan	0.338
100% low fat expeller pressed PKC	Sahiwal-Friesian crossbred	0.740
100% low fat expeller pressed PKC	Australian Commercial cross	0.600
50% solvent extracted PKM 50% fodder grass	Zebu cross	0.650
50% solvent extracted PKC 50% expeller pressed PKC	Sahiwal-Friesian crossbred	0.700
60% solvent extracted PKM 40% POME	Brahman	0.790
60% solvent extracted PKM 40% POME	Droughtmasters	0.830
60% expeller pressed PKC 40% POME	Local Kedah-Kelantan	0.510
60% low fat expeller pressed PKC 40% POME	Sahiwal-Friesian crossbred	0.590

Source: Hawari and Chin (1985); Mustaffa (1987) and Mustaffa et al (1987).

For sheep and goats, there is an inclusion limit for PKC in their diets, typically according to Islam (1999) and Dahlan *et al*. (2000) not more than 30% of total diet. Excess PKC in diets of sheep can cause chronic toxicity (Abdul Rahman et al, 1989 and Wan-Mohammed *et al* (1989). Death from such toxicity was reported to be mainly due to hepatic necrosis, while jaundice and haemoglobinuria were the most remarkable clinical signs demonstrated. These changes according to Soli (1981) were quite consistent with those of chronic copper toxicity. The level of copper in PKC was found to be relatively high, ranging from 11 to 55 ug/g dry weight (Jalaludin *et al.*, 1991). Hair-Bejo and Alimon (1995) reported that feeding PKC in excess in sheep can cause chronic copper toxicity but that this condition was prevented by zinc supplementation either with or without ammonium molybdate.

Utilization of PKC in poultry and swine feeding

The first use of PKC in poultry diets was reported by Temperton and Dudley (1939), who found that PKC was a satisfactory dietary substitute for wheat middlings in layers diets. In a later report by Babatunde *et al* (1975) PKC was used as a major protein concentrate in the diets of pigs. In the latter study, PKC was included at a level of 50% of the total dietary protein. The authors reported that fattening pigs tolerated it better than growers but weaners were more adversely affected by it. The inclusion of PKC as the major protein concentrate in the diets of all classes of pigs in the studies significantly reduced growth rate, feed consumption and feed/gain ratio, apparent digestibility and retention of major nutrients. The authors further suggested that better results were obtained when PKC diets were supplemented with low levels of blood meal and fishmeal.

Nwokolo *et al* (1976) studied the availability of amino acids in PKC, soy bean meal (SBM), cotton seed meal (CSM) and rapeseed meal (RSM) for growing chicks and found that the availability of amino acids in PKC ranged from 63% in glycine to 93% in arginine with an average of 84.5% compared with amino acid availability of 97.3% in SBM, 92.5% in CSM and 91.9% in RSM. The authors suggested that PKC is a reasonable source of protein for poultry. McDonald *et al* (1982) suggested that PKC should not exceed 20% in broiler diets. When Osei and Amo (1987) fed different levels of PKC in isonitrogenous diets to broilers, they found no significant differences in body weight and feed consumption but feed conversion ratio significantly declined as PKC levels reached 12.5% of the diet or higher. Growing chicks fed isonitrogenous and isocaloric diets containing various levels of PKC had no significant differences in daily feed intake and weight gain (Yeong *et al.*, 1983) but feed conversion ratio significantly improved when diets containing lower levels of PKC were fed.

Perez *et al* (2000) studied the effect of various levels of PKC in diet up to 50% on the performance of layers. The authors reported that egg production was significantly decreased only with 50% PKC in the diet and feed conversion was not significantly affected by any level of PKC. According to the authors, feed consumption, mortality, and egg weight did not differ significantly among treatments and concluded that PKC may be used up to 40% in the diet. Dairo and Fasuyi (2007) reported that PKC and copra meal (CPM) exhibited similar feeding values when fermented and that both can be used optimally at 50% to replace SBM in laying hen’s ration. The need to supplement PKC diets with vitamins when fed to broilers was reported by Oloyo (1991). In a study with broiler chicks, the author included various levels of biotin up to 0.24 mg/kg in guinea corn based diets containing 18% PKC. The PKC diet not supplemented with biotin resulted in significantly poorer feed utilization and carcass measures, higher blood lipid, lower blood glucose, lower pyruvate carboxylase activity in the liver, higher liver and kidney weights, more lipid deposition in these organs, higher mortality due to fatty liver and kidney syndrome (FLKS) and abnormal development of leg bone. In a recent study by Sundu *et al.* (2006), the utilization of 40% PKM in diet by broilers was investigated. The authors reported that PKM has no anti-nutritional properties and that up to 40% of it in diets for broilers was safe, provided the diet is balanced in amino acids and metabolisable energy.

Utilization of PKM in fish feeding

There has been a fast growth rate in aquaculture production necessitating an increase in the production of formulated diets for the cultured aquaculture animals. As reported by Ng (2003), the cost of feed in aquaculture production is about 30 to 60% of the operational cost with protein being the most expensive dietary component. Fishmeal continues to be the major source of dietary protein in commercial aqua feeds. Its escalating cost therefore necessitates the use of alternatives. According to the author, plant proteins including soybean meal have been shown to have commercial success in aquaculture production. Nevertheless soyabean, which is an imported product to most Asian and African countries, has also become expensive. Palm kernel meal is becoming attractive for use in aquaculture production because of its low cost. Three factors, which militate against the use of PKM in aqua culture production, include its relatively low crude protein, deficiency in essential amino acids and presence of anti-nutritional factors (e.g. fibre and the non-starch polysaccharide mannan). Ng (2003) reported that PKM fermented with *Trichoderma koningii* resulted in the protein content of the PKM being almost doubled from 17% to 32%. A feeding trial with hybrid catfish showed that up to 20% raw PKM could be incorporated into catfish diets without any negative effects on growth performance (Ng, 2003). However, at 40% PKM, the author reported that growth was significantly depressed and this was not alleviated with the addition of 1.2% dietary L-methionine; a possible reason being that methionine may not be the first limiting amino acid in PKM. In a study with tilapia, *Oreochromis mossambicus*, Lim *et al* (2001) treated PKM with *Aspergillus flavus* and used the treated and untreated PKM to replace either 20% or 50% soybean meal. The authors reported that weight gains of tilapia fed PKM-based diets were not significantly different compared with fish fed the control diet and concluded that PKM can substitute up to 50% SBM in practical diets for *O. mossambicus* without much adverse effects on fish weight. Solid state fermentation of PKM with *A. flavus* and *T. koningii* has also been reported to significantly improve nutrient digestibility of PKM (Lim *et al*., 2006). The application of feed enzymes to PKM-based diets can be useful in releasing unavailable nutrients to the fish. Studies have shown that tilapia fed PKM pre-treated with commercial feed enzymes consistently showed better growth and feed utilization efficiency compared to fish fed similar levels of raw PKM (Ng, 2003). According to the author, up to 30% enzyme-treated PKM could be incorporated into red tilapia diets without significantly depressing growth, stating that direct inclusion of exogenous enzymes in diets for tilapia has so far not been successful. Other studies reporting the beneficial effect of feed enzymes on PKM-based diets for aquaculture production have been reported by Ng *et al*. (2002) and Ng and Chong (2002). Another method by which PKM can be used in aquaculture production is through the process of bioconversion. Since the proteins and fats locked in PKM can be used only to a limited extent by fish, Hem *et al.* (2008) suggested that PKM can be used as a starter feed source for the Black Soldier (BS) fly to produce maggots. According to the authors, the bioconversion process results in the production of biomass of larvae with 42% crude protein and 30% crude fat which is a viable alternative source of animal protein for aquaculture development, the aim being the development of 'magfeeds'.

Improvement of PKC's nutritive quality for monogastric feeding

The high amounts of NSPs chiefly mannan in PKC necessitate the improvement of its nutritive quality for poultry and swine. Whereas ruminants habour microbes in the rumen that has the capability to degrade the NSPs in PKC and therefore derive energy from it. Poultry and swine are limited in handling the NSPs in PKC. They do not have the full enzyme complement to break down the mannan and other polysaccharides and oligosaccharides in PKC. For PKC to be efficiently utilized by poultry and swine therefore it needs to be fermented before feeding or poultry and swine diets containing PKC must be supplemented with mannan degrading enzymes. The use of enzymes is a common practice in the poultry industry today to improve the nutritive value of diets. Numerous publications in the literature have shown the importance of enzymes especially when indigestible and viscous compounds are included in the diets. According to Sundu and Dingle (2003) advances in microbial technology has improved our understanding of enzymes and their target substrate. The bulk of the reports in the literature are on the application of enzymes mostly β-glucanase, xylanase and β-mannanase on cereals and legumes with reports on the use of enzymes on products like PKC. Our understanding of the ability of fungi like *Aspergillus spp* and *Trichoderma spp* as well as some species of bacteria and yeasts to produce polysaccharide degrading enzymes has in recent years led to research in the application of enzymes mainly from fungi to diets containing PKC. Three main enzymes are needed to improve the nutritive value of PKC judging from the composition of its carbohydrate. These enzymes are mannanase, α-galactosidase, and cellulase to digest mannan, cellulose and α-galactosidic side chain, respectively. According to Sundu and Dingle (2003) the use of these enzymes does accelerate the hydrolytic process of isolated mannan-based polysaccharides and cellulose in PKC.

The inclusion of cellulase in PKC diets aims to breakdown the cellulose as a polymer of glucose and also the linkages between cellulose and mannan (Balasubramaian, 1976). Dowman (1993) developed a method to digest PKC by including cellulase and gamanase in PKC diets and the author reported that cellulase together with mannanase increased the degree of hydrolysis of mannan based polysaccharides from 39.1% to 53.7% and from 15.8% to 31.1% in Konjac and Locust bean gum, respectively. In the same study, the production of sugar increased two times by addition of a commercial cellulase (meicelase) in the locust bean gum. Iyayi and Davies (2006) investigated the effect of supplementing PKC diets with Avizyme on the performance of broilers. The authors reported that inclusion of the enzyme in the PKC diets resulted in 31% and 52% of the maize being spared at starter and finisher phases of growth of the birds, respectively thereby helping to save the use of expensive cereal grains. In the study the authors also reported that birds on the enzyme supplemented PKC diets performed better than those on the maize control diets suggesting the ability of the enzyme to have helped provide the shortfall in energy from the breakdown of the NSPs in the PKC.

CONCLUSION

Oil palm production has increased in the last decade mostly in the developing countries leading to a corresponding increase in the amount of palm kernel cake and other by-products produced in the countries. Demand for PKC and PKM as alternative energy and even protein feed ingredients has also increased because of the relative price advantage they have over the conventional protein ingredients. But the presence of high amounts of NSPs chiefly mannan and galactomannan militate against the inclusion of high amounts of the by-products in diets of monogastrics and fishes. Ruminants on the other hand are better able to utilize them than monogastrics and fishes though copper toxicity in sheep and cattle can result when levels higher than 30-50% of PKC are included in their diets. However, the ability of enzymes from microbes and other organisms to breakdown the mannan in PKC and PKM would make monogastrics and fishes derive some benefits from diets including the by-products. These potential of PKC and PKM justify their use in ruminant diets when antitoxic agent like zinc is included and in monogastrics and fish diets when PKC and PKM-based diets are supplemented with enzymes.

Conflict of interest

There is no conflict of interest of any kind between the authors of the work. The authors all participated in the review and are in agreement with the final version of the paper. There is also no conflict of interest between the authors any organization or other people. The publication was privately funded.

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