

## Improving Nutritional Values of Palm Kernel Cake (PKC) as Poultry Feeds: A Review

Sharmila<sup>1</sup>, A., Alimon<sup>1,2</sup>, A.R., Azhar<sup>1</sup>, K., Noor<sup>3</sup>, H.M. and Samsudin<sup>1,2\*</sup>, A.A.

<sup>1</sup>Department of Animal Science, Faculty of Agriculture, <sup>2</sup>Institute of Tropical Agriculture,

<sup>3</sup>Department of Pre-Clinical Veterinary Science, Faculty of Veterinary Medicine, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.

\*Corresponding author: anjas@upm.edu.my

### Abstract

Palm Kernel Cake (PKC) is a by-product of palm kernel oil extraction and provides moderate nutrition with approximately 16-18% of crude protein (CP) and 13-20% crude fiber (CF). Usage of PKC is common in ruminant diets, but limited in the non-ruminant diets especially in poultry diets due to the high fiber content of PKC. Numerous works have been conducted to increase the nutritional contents of PKC as one of the measures to reduce and/or eliminate the constraints of utilizing PKC in poultry diets. The method used to achieve this target is either through physical, chemical, biological or combination of these treatments. However, only chemical and biological treatments of PKC seem to improve the nutrient values of PKC. Recent works cite solid-state fermentation (SSF) using fungi to increase the nutrient values of PKC. This method is considered as the most suitable treatment for PKC. Through solid-state cultures of PKC, the concentration of CP has increased while the CF has decreased. Furthermore, this method is considered practical because the whole end product will be utilized for animal feeds. Hence, emphasis should be given to improve nutritional values of PKC in order to reduce feeding cost of poultry.

**Key words:** nutritional value, palm kernel cake, palm kernel expeller, palm kernel meal, poultry feeds

### Introduction

The African oil palm (*Elaeis guineensis* Jacq.) is a native of West Africa; mainly distributed in Sierra Leone, Liberia, the Ivory Coast, Ghana and Cameroon and the equatorial regions of the Republic of Congo and Zaire (Cheng Hai, 2011). The development of oil palm plantation in South East Asia started in the Botanic Gardens in Bogor Indonesia in 1848, where the oil palm seed (*dura*) was introduced from Mauritius and Amsterdam (Cheng Hai, 2011).

In Malaysia, the development of oil palm plantation began in 1911, when the first oil palm estate was established at Rantau Panjang, Selangor introduced by the Frenchman, Henri Fauconnier through his

association with M. Adrien Hallet who first planted oil palms in Sumatra. In the early oil palm development, the research regarding oil palm was carried out by the Department of Agriculture; however, in 1969 Malaysian Agricultural Research and Development Institute (MARDI) took over the mandate of undertaking research and development in agriculture for the country. The task was later handed to the Palm Oil Research Institute of Malaysia (PORIM) following its establishment in 1979. PORIM was then merged with the Palm Oil Registration and Licensing Authority (PORLA) to form the Malaysian Palm Oil Board (MPOB) in 2000 which is mandated to support the security of the oil palm industry in Malaysia in all aspects of its activities through research and

development along with services (Yusof and Chan, 2004).

There is an increase in the oil palm planted area from 5.08 million ha in 2010 to 5.23 million ha in 2013, an increase of 3.0%

mainly due to an increase of planted area in Sarawak (MPOB, 2013). However, Sabah is still the largest oil palm planted area (1.48 million ha), followed by Sarawak (1.02 million ha) (Table 1).

Table 1. The distribution of oil palm plantation in Malaysia 2013

State	Mature	%	Immature	%	Total	%
Johore	639,946	87.58	90,748	12.42	730,694	13.97
Kedah	77,843	91.38	7,339	8.62	85,182	1.63
Kelantan	94,320	67.35	45,715	32.65	140,035	2.68
Malacca	49,635	94.18	3,069	5.83	52,704	1.01
Negeri sembilan	142,452	83.77	27,596	16.23	170,048	3.25
Pahang	609,962	85.89	100,233	14.22	710,195	13.58
Perak	344,271	89.52	40	10.48	344,311	7.35
Perlis	190	68.35	88	31.65	278	0.01
Penang	13,263	97.65	317	2.37	13,580	0.26
Selangor	125,122	91.33	11,881	8.67	137,003	2.62
Terengganu	137,289	80.99	32,231	19.01	169,520	3.24
Peninsular Malaysia	2,234,193	86.14	359,540	13.86	2,593,733	49.6
Sabah	1,330,039	90.17	145,069	9.33	1,475,108	28.21
Sarawak	961,857	82.85	199	17.15	962,056	22.2
Sabah & Sarawak	2,291,896	86.95	344,110	13.05	2,636,006	50.4
Malaysia	4,526,089	86.55	703,650	13.45	5,229,739	100

Source: MPOB, 2013

In Malaysia, besides producing palm oil, the plantations of oil palm also abundantly produce a number of useful by-products such as oil palm fronds (OPF), oil palm trunks (OPT), palm press fibre (PPF), empty fruit bunches (EFB), palm kernel cake (PKC), palm oil mill effluent (POME; also called sludge and decanter cake) and palm kernel shells (PKS) throughout the year and this guarantees their supply and availability as major ingredients for livestock feeding (Marini *et al.*, 2005).

The oil palm fruits generate two types of oils: crude palm oil (CPO) from the outer mesocarp and crude palm kernel oil (CPKO)

from the nut or kernel. The nut of oil palm has three forms characterized by the shell thickness trait known as *E. guineensis* fo. *dura*, *E. guineensis* var. *pisifera* and *E. guineensis* fo. *tenera* (Figure 1). For the commercial planting, hybrid between thick-shell *dura* and shell-less *pisifera* called the thin-shelled *tenera* is commonly used (Yusof and Chan, 2004). The oil palm fruit consists of three different layers of shell known as pericarp which comprises of exocarp (outer shell), mesocarp (fibrous material) and inner-shell, endocarp and kernel or endosperm (Figure 2).

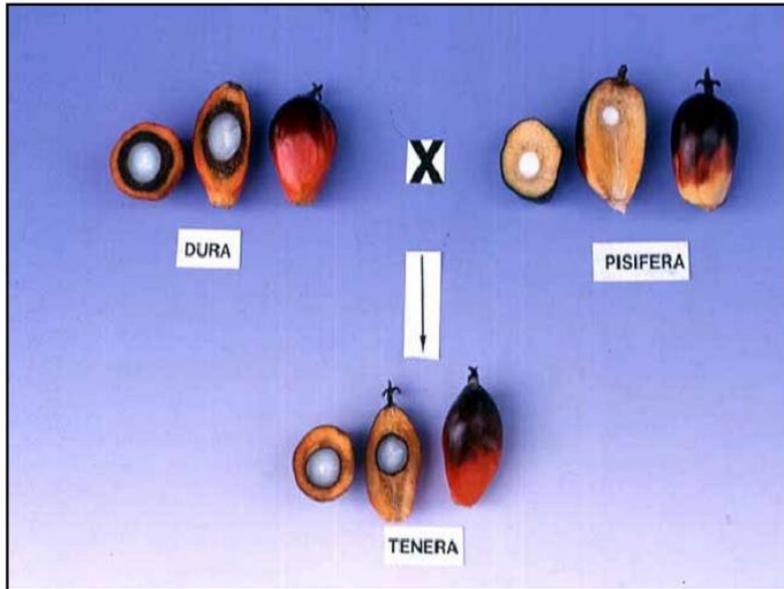


Figure 1. *E. guineensis* fo. *dura*, *E. guineensis* var. *pisifera* and *E. guineensis* fo. *tenera*. Source: Cheng Hai, 2011

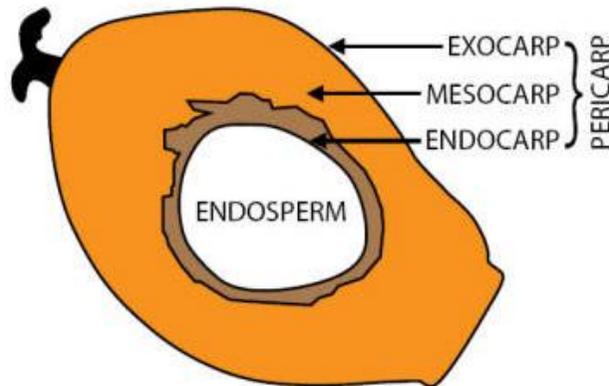


Figure 2. The oil palm fruit and its shells Source: from [http://www.etawau.com/OilPalm/Elaeis\\_guineensis.htm](http://www.etawau.com/OilPalm/Elaeis_guineensis.htm)

Generally, PKC is obtained from two stages of oil extraction from the palm fruit; the first stage is the primary extraction of palm oil from the pericarp portion of the fruit, which also produces the kernel and by-products of palm oil sludge (POS) and palm press fiber (PPF), then the extraction of oil from crushed kernels that also results in the production of PKC and palm kernel shell as by-products (Chin, 2008). The nutrient

contents of Malaysian palm kernel and its by-products PKC are shown in Table 2. The kernel of oil palm fruit consists of tiny cellulosic sack containing fat embedded with proteins and carbohydrates; where the insolubilization of PKC protein may be partly due to the entrapment or binding of proteins or polysaccharides under the influence of the heat and pressure of oil-extraction processes (Aghazu *et al.*, 1979).

Table 2. Typical composition of Malaysian palm kernel and PKC (% dry matter)

Chemical contents	Palm kernel	PKC
Oil content	49.0	7.9
Protein	8.3	14.8
Crude fiber	8.1	16.7
Moisture	6.5	6.4
Ash	2.0	3.9
Carbohydrate	26.1	50.3

Source: Nuzul Amri, 2013

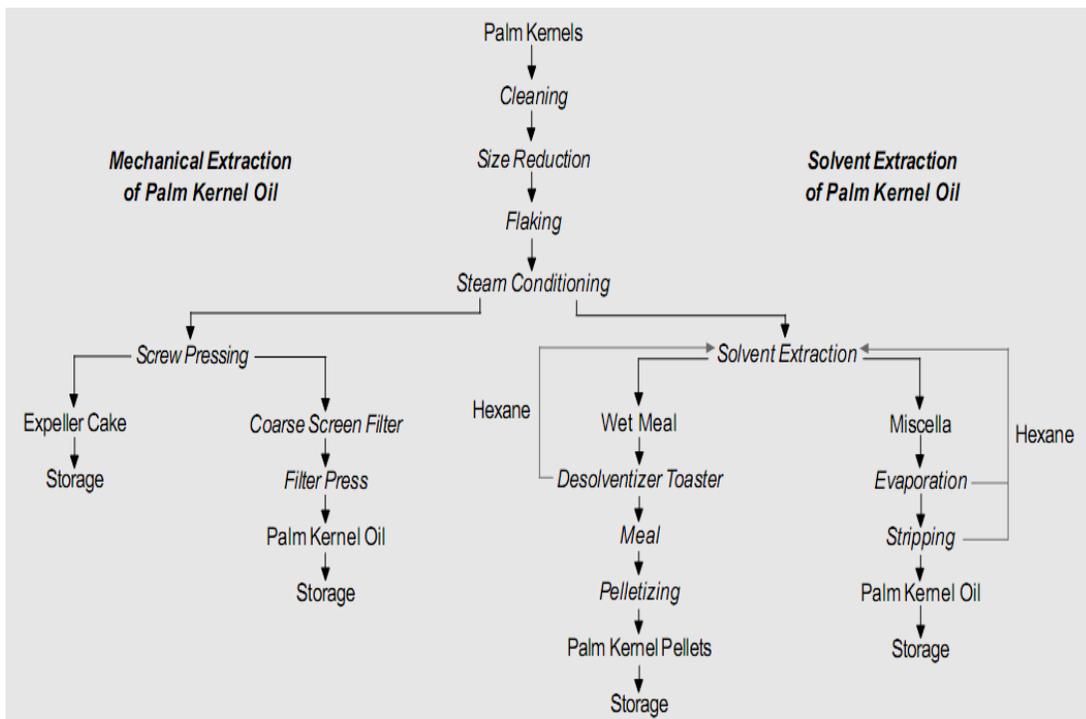


Figure 3. Extraction of palm kernel oil

Source: Hishamuddin, 2001

In Malaysia, three methods of palm kernel oil extraction have been reported; mechanical extraction (screw-pressing), solvent extraction and pre-pressing followed by solvent extraction (Saw *et al.*, 2012). The production of PKC from mechanical extraction and solvent extraction is shown in Figure 3. Alimon (2004) reported that most of the PKC produced in Malaysia were from

expeller extraction because the production cost was lower than solvent extraction. The PKC produced from screw-pressing contains higher oil content than those produced from solvent extraction and pre-pressing solvent extraction; however other composition, such as protein, crude fiber, and carbohydrate are almost similar (Tang and Teoh, 1985; Saw *et al.*, 2012).

PKC is an important by-product that generates substantial export earnings for Malaysia, where it is exported to European countries, mostly Germany and Netherlands (Ahmad Borhan *et al.*, 2005). Export of Malaysian PKC declined (8.8%) in 2011 compared to the previous year. Most of the PKC were exported to the European Union (EU) (39.5% or 0.88 million tonnes), followed by New Zealand (25.6% or 0.57 million tonnes) and South Korea (20.2% or 0.45 million tonnes) (MPOB, 2011).

In Malaysia, MPOB closely monitors the quality of PKC traded in the country, where every consignment of PKC must undergo quality testing by independent laboratories or surveyors, which are contracted by traders and approved by MPOB. Besides quality assurance, emphasis is also given to the quality improvement of PKC, where continuous quality development seeks improvement of machinery, raw materials, labor utilization and innovation in production or processing methods (Ahmad Borhan *et al.*, 2005).

PKC which is a solid by-product or a high protein residue (Daud and Jarvis, 1992; Hair-Bejo and Alimon, 1995) have been extensively used for feed application to ruminants (Wong and Wan Zahari, 2011), poultry (Ao *et al.*, 2011), swine (Adesehinwa, 2007) and fish (Ng *et al.*, 2004) since it does not contain aflatoxins and edible oil that contains considerable amount of nutrients comprising of 50.3% carbohydrate, 19.8% protein, and 16.7% crude fiber and 8% (Nuzul Amri, 2013). It is abundantly produced in the three main areas of the equatorial tropic of South East Asia, Africa and South America. Attempts have been made to feed it to livestock (Rhule, 1996) practically and widely used most in ruminant diets compared to non-ruminant diets.

PKC supplies both protein and energy, but it is looked upon more as a source of

protein. The CP content of PKC varies between 10.0 to 19.8% (Yeong and Mukherjee, 1983; Ramin *et al.*, 2010; Nuzul Amri, 2013). Besides that, PKC also contains high amount of CF ranging between 13 to 20% (Alimon, 2004). The higher amount of CF contributes to the low digestibility in non-ruminants especially poultry. There are many treatments available to breakdown the cellulose chain in PKC to make it more digestible. The chemical and biological treatment of PKC appears to improve the nutritive values of PKC, but in contrast, the physical methods seem do not so. The solid-state fermentation of PKC appears to increase the protein value and bioavailability of nutrients (Marini *et al.*, 2005; A'dilah *et al.*, 2011), however the most suitable microorganisms for treatment of PKC using this approach are yet to be identified (Ramin *et al.*, 2010).

### Nutritional Content of PKC

PKC varies considerably in chemical composition (protein, fiber or lipids), depending on the sources (Rhule, 1996), the methodology of oil removal, the proportion of endocarp remaining (Adesehinwa, 2007) and the efficiency of oil extraction from the kernel (Onwudike, 1986; Onuh *et al.*, 2010). The metabolizable energy (ME) of PKC reported previously by several researchers were varied, where Alimon (2004) reported that the ME was between 1553 to 1792 kcal/kg, but Sundu *et al.* (2005) reported it contained 1479 and 2260 kcal/kg. PKC produced through mechanical processing result in higher ME value compared to solvent extracted PKC as observed by Olumu and Ezieshi (2007) where they found that the PKC obtained through mechanical extraction contained higher residual oil almost 8% compared in the palm kernel cake produced via solvent extraction (1%) while Marini *et al.* (2005) found that the oil content in the

solvent-extracted PKC was low, around 0.5 to 3%, whereas the expeller-pressed PKC contained between 5 to 12% oil. The protein content of PKC had poor amino acid balance, with methionine (Rhule, 1996) and lysine, histidine and threonine content (Ezieshi and Olumu, 2007) being the major limiting amino acids.

The fiber content of PKC was about 13-20% which is responsible for the grittiness and poor digestibility of PKC (Onuora and King, 1985; Alimon, 2004). The principal neutral sugar content in the cell wall of PKC fiber was mainly contributed by 56.4% of mannose, followed by 11.6% of glucose, 3.7% of xylose and 1.4% of galactose (Anon, 2002; Marini *et al.*, 2005). In a study

conducted by Olumu and Ezieshi (2007) found that the composition of crude fiber (CF) of solvent extracted PKC was higher compared to mechanically extracted PKC, due to the degree of oil extraction in which, solvent extraction method provides a better oil removal efficiency, leaving PKC with higher CF contents. Besides that, the use of different varieties of oil palm, different methods of separating the shell from kernel and different processing methods employed before extraction of the oil is carried out may also affect the CF values of PKC. The nutrient values of PKC have been extensively studied and described by Alimon (2004) and Dairo and Fasuyi (2007) (Table 3).

Table 3. Nutrient composition of PKC

Ingredients (%)	Alimon <sup>1</sup>	Dairo and Fasuyi <sup>2</sup>
Dry matter	88.0-94.5	91.8
Crude protein (CP)	14.5-19.6	20.0
Crude fiber (CF)	13.0-20.0	-
Ether extract	5.0-8.0	15.47
Ash	3.0-12.0	8.6
Calcium	0.2-0.3	-
Phosphorus	0.48-0.7	-
<u>Metabolizable energy, MJ/Kg</u>		
Chicken	6.50-7.50	-
<u>Amino acid, g/16 g N</u>		
Lysine	2.68	-
Methionine	1.75	-

Source: <sup>1</sup>Alimon (2004) and <sup>2</sup>Dairo and Fasuyi (2007)

### PKC Utilization in Poultry

PKC is one alternative feed resource that can be used in poultry feeds, where it virtually has no competition between man and farm animals (Kperegbeiyi and Ikperite, 2011). Agro-industrial by-products such as PKC could be used to spare conventional feed ingredients such as maize and soyabeans in poultry diets because of their low pricing

and availability (Onuh *et al.*, 2010). Many studies have been carried out on the nutritional value of PKC in monogastric animal feeding with more than two-thirds of which were carried out on various classes of poultry (Anaeto *et al.*, 2009; Onuh *et al.*, 2010 and Oluwafemi and Akpodiete, 2010).

PKC supplies both protein and energy; however, it has high fiber content and it is reported to have a low ME value for poultry

(James and Wheeler, 1949; Kperegbeyi and Ikperite, 2011). The use of PKC in poultry feeding is limited due to its high fiber content and there exists wide variation in the optimum inclusion level of PKC in poultry rations. The inclusion of PKC in poultry can be varied depending on the classes of poultry, age, sex and may be due to the origin and variation in the oil and shell content of the PKC used (Alimon, 2004).

The digestion of non starch polysaccharides (NSPs) of the cell wall of PKC in poultry is variable due to low digestive enzymic activity and their tendency to create a viscous environment in the intestinal lumen (Choct and Anisson, 1992; Józiefak *et al.*, 2004). However, it can be broken down with the help of enzymes produced by the caecal microflora or by supplementation of poultry diets with specific enzymes (Choct *et al.*, 1999; Józiefak *et al.*, 2004). For an example, in a study conducted by Zanu *et al.* (2012) showed that layers could utilize PKC-based diet up to 5 and 10% inclusion without adverse effects on their production performance and there was a decrease in feed cost and a higher net return from birds fed PKC based diets thus, more profit to the poultry farmer. Although the inclusion of

PKC in poultry diets has been studied by several researchers (Onwudike, 1986; Zulkifli *et al.*, 2003; Mustafa *et al.*, 2004) the recommended levels of inclusion seem to vary from one study to another (Chong *et al.*, 2008).

There are large quantities of PKC available for feed, but the use of PKC in the feed industry is usually limited to the ruminant sector, because of the higher fiber content (Chong, *et al.*, 2008). Non-ruminant animals such as poultry and swine have simple stomachs which limit the use of PKC in their rations due to low fiber digestive enzymic activity in their gastrointestinal tract. In poultry, the digestion of NSP fractions tends to be more variable due to lack of digestive enzymes and their tendency to create a viscous environment in the intestinal lumen (Choct and Anisson, 1992; Józiefak *et al.*, 2004).

However, several studies have shown that supplementation of exogenous enzymes or enzyme addition on diets containing PKC could improve its nutritive quality, and make it more available, especially poultry (Daud *et al.*, 1997; Sekoni *et al.*, 2008; Chong *et al.*, 2008). The recommended level of PKC for various animal classes has been described by Wan Zahari and Alimon (2004) (Table 4).

Table 4: Recommended levels of PKC in livestock feeds

Livestock	Recommended level (%)
Beef cattle	50-80
Dairy cattle	30-50
Sheep	Maximum 30
Goat	30-50
Poultry-broiler	15-20
Poultry-layer	15-25
Swine	15-25
Fresh water fish	10-20

Source: Wan Zahari and Alimon (2004)

## Improving Nutritional Values of PKC for Poultry

### Physical treatment

Lui *et al.* (1999) reported that, some physical treatments of crop residues could not enhance their ADF, NDF and hemicellulose content. However, Ng (2004) demonstrated that there is an alternative way to increase the protein content of high fiber by-product such as PKC and this can be achieved by extracting and isolating the protein of PKC through combination of physical and chemical processes. This will essentially eliminate the problem of low nutrient availability of PKC. However, to date no study has been reported on the effect of physical treatment of PKC on its nutrient contents.

### Chemical Treatment

The nutrient contents of PKC can be improved through chemical treatment processes using either acid or alkaline solution. For example, acid solution such as acetic and formic acids can be used as delignification agents to remove lignin of PKC. The degradation of lignin could be affected by the concentration of the acid solution. The higher the concentration of the acid used, the more lignin will be degraded (Ng, 2004).

Chenost and Kayouli (1997) also reported that the use of an alkaline agent to treat the high fiber feeds works by absorbing into the cell walls and thus chemically breaking the ester bond between lignin, hemicellulose and cellulose which finally make the structural fiber to swell. The treatment of PKC using acid (acetic and formic acids) or alkaline (ammonium hydroxide) solution has been found to improve the PKC nutritive values by

reducing the CF content and increasing the CP content (A'dilah and Alimon, 2011).

### Biological Treatment

The high level of NSP contents of PKC contributes to the low digestibility of its nutrients (Dusterhoft and Voragen, 1991). However, the addition of fibrolytic (carbohydrate-degrading enzyme) or proteolytic enzymes to the PKC based diets has a great potential in releasing its unavailable nutrients and energy (Ng, 2004). Apart from using commercial enzymes, multi-enzyme complexes produced from fungi could also be used as an agent to improve the nutrient contents of PKC. Such enzyme extracts have the potential to breakdown the NSPs in PKC thereby enhancing its nutritive values especially for broiler feeding (Lawal *et al.*, 2010). The enzymes applied on the PKC extracted from *Aspergillus niger*, *Trichoderma viride*, *Rhizopus stolonifer* and *Mucor mucedo* and sprayed at the rate of 250 ml/kg and allowed to be fermented for 7 days before applying to the poultry feed, for example, resulted in a significant increment in CP value observed, ranging between 35.6 to 43.49% where the highest was from *T. viride* treated PKC (Lawal *et al.*, 2010).

Effect of enzyme supplementation in PKC on its nutrient content analysis (Chong *et al.*, 2008 and Saenphoom *et al.*, 2011), nutrient retention trial (Sekoni *et al.*, 2008; Ao *et al.*, 2011), effect on the performance of various classes of livestock such as broiler chickens (Soltan, 2009), layers (Chong *et al.*, 2008), pigs (Ao *et al.*, 2011) and fish (Ng and Chong, 2006) have been evaluated. The study of nutrient composition of PKC incubated with enzymes was carried out by Chong *et al.* (2008) and Saenphoom *et al.* (2011). Similarly, in these studies the supplementation of enzymes resulted in the increase of the total sugar released. However,

there was only an increment in the gross energy (GE) observed by Chong *et al.* (2008). The composition of crude fat, NDF, ADF, hemicellulose and cellulose contents of enzyme treated PKC was significantly decreased by approximately 34.6, 26, 20, 35.7 and 22.1%, respectively, showing that exogenous enzymes used to treat PKC effectively broke down complex hemicellulose and cellulose - suggesting the effectiveness of exogenous enzymes in hydrolyzing the structural carbohydrates into monosaccharide sugars (Saenphoom *et al.*, 2011).

A nutrient retention trial was conducted by Sekoni *et al.* (2008), over a 24-d period on broilers in which PKC was included in the diet at 0, 10, 20, 30 and 40% and treated PKC with Maxigrain® at 10, 20, 30 and 40%. Maxigrain treatment improved nutrient retention of protein, fat and nitrogen free-extract (NFE) on a relative basis but to maximize the benefit of enzyme supplementation of PKM, which could have contributed to the higher body weight gain observed in birds fed Maxigrain® treated diets and maximized at 20% PKC inclusion compared with control and other diets with or without Maxigrain® and a more specific cocktail of enzymes containing mannanase must be included (Sekoni *et al.*, 2008). However, in a feeding trial on pigs, no difference was detected in dry matter, N and energy digestibilities between the control and 5% palm kernel meal diets with 0.1 or 0.2% carbohydrase cocktail (Ao *et al.*, 2011).

The use of enzymes in animal feed rations targets the specific undigestible parts of the dietary components in which several studies in poultry have reported the benefits of using enzymes in the diets on growth performance of poultry (Ao *et al.*, 2011). In poultry diets, PKC is included as a partial replacement for soybean meal (SBM) due to its high price. The efficacies of replacing SBM by PKC in the diet of broiler chicks

with or without enzyme supplementation were evaluated by Soltan (2009) using formulated diets containing 0, 5, 10, 15 and 20% PKC. PKC inclusion at 20% with enzyme resulted in comparable weight gain and feed efficiency compared with control diet; meanwhile PKC at 10% inclusion level without enzyme supplementation had no significant effect on the broiler chicks' growth performance. From these results, the use of PKC with enzyme is recommended to escalate bird production and economic efficiency (Soltan, 2009).

In contrast to the study conducted by Soltan (2009), Saenphoom *et al.* (2013) conducted a feeding trial on exogenous enzyme pre-treated PKC diets on growth performance, villus height and digesta viscosity of broiler chickens. The fiber content of enzyme pre-treated PKC was reduced and there was an improvement in the ME value; however, this nutrient improvement was not reflected on the growth performance of broiler chickens compared to those receiving un-treated PKC. An inclusion up to 5% in the grower diet and 20% in the finisher diet is suggested without any detrimental effect on broiler feed efficiency. Even though the fiber in PKC is hydrolyzed to the smaller units of sugar, mostly mannose, it has been reported that the assimilation of mannose is much lower than glucose, particularly when glucose is present in the system and therefore, even though enzymatic treatment of PKC releases great amount of sugars, they are primarily mannose which are weakly absorbed and thus of little use to the chickens (Saenphoom *et al.*, 2013).

An enzyme mixture of mannanase,  $\alpha$ -galactosidase and protease at three different amounts; 0, 1 and 2 kg/t were tested on solvent-extracted PKC (0, 12.5 and 25% inclusion in the diets) on the performance of 28-wk-old laying hens (Chong *et al.*, 2008). Laying hens consuming 12.5 and 25% PKC

in the diets showed no detrimental effect on their egg production; however, they consumed a lot more PKC-based feed that resulted in notably lower feed efficiency than diets without PKC. The enzyme addition in 12.5 or 25% PKC-based diets did not show any significant difference in true dry matter retention between birds fed the control layer diet. Enzyme supplementation significantly reduced feed consumption and improved FCR in the PKC-fed groups (Chong *et al.*, 2008).

The inclusion of PKC in the pig diets has not been widely evaluated because it can decrease the growth performance of finishing pigs at an inclusion level of only 4% (Kim *et al.*, 2001), which was attributed by its high NSP content, poor palatability and low availability of energy and amino acids (Ao *et al.*, 2011). The evaluation of the growth performance and nutrient digestibility as well as blood profiles and meat quality in finishing pigs fed diets containing 5% PKC together with carbohydrase cocktail (at 0, 0.1 or 0.2% inclusion levels) supplementation was carried out by Ao *et al.* (2011). The supplementation of the diet containing 5% PKC with carbohydrase cocktail improved the growth performance and energy and nutrient digestibilities in finishing pigs. The improvement of energy and nutrient digestibilities in this study would reflect the enhancement in the growth performance. The results indicated that the carbohydrase cocktail effectively cause the hydrolyzation of the NSP in PKC; and thus provide the energy to the pigs (Ao *et al.*, 2011).

Currently, the production of aquaculture is the fastest animal production sector worldwide; where it is mostly pronounced in Asia, contributing 90% of the global aquatic animal production (Ng, 2004). The cost of feed and feeding of aquaculture constitutes almost 60% of the total production cost with protein feed materials such as fish meal and SBM being the most expensive. As the prices

of protein feed sources keep rising over the years, the use of locally produced by-product such as PKC in fish diet becomes popular. However, due to high fiber content of plant protein by-product, the supplementation of exogenous enzymes in aquaculture feeds becomes popular (Ng and Chong, 2006). A study by Ng and Chong (2006) to evaluate the use of commercially available enzymes in red tilapia diets containing only 40% of PKC together with unsupplemented PKC diets at 10 and 20% of PKC, replacing SBM in the basal diet. The growth performance, FCR and protein efficiency ratio of red tilapia fed 20% PKC without enzymes was the same with tilapia fed diet without PKC. A significant improvement in terms of DM and energy digestibility of the 40% PKM supplemented with enzyme was observed, however this improvement was not reflected as been beneficial on the growth performance and FCR of red tilapia. On the other hand, a feeding trial of tilapia fed with Ronozyme VP (commercial enzyme) pre-incubated 21% PKC showed significantly better performance and net protein utilization compared to fish fed raw PKM (Boonyaratpalin *et al.*, 2000). One explanation for the increased performance was the ability of exogenous enzymes in eliciting the maximum potential effect of these enzymes in PKM-based aquaculture feeds (Ng and Chong, 2006). The previous study demonstrated the potential of partially substituting SBM with PKC could end up to 20% without depressing the performance of aquatic animals, and the supplementation of enzyme could further make an improvement, yet further studies have to be carried out to evaluate the maximum inclusion of PKC in aqua feed together with optimum level of enzymes needed to counter the poor nutrient digestibility of PKC.

Apart from using commercial and specific enzymes, the use of cellulase, xylanase and mannanase-producing microbes

such as fungi and bacteria could also be applied to improve the quality of PKC as animal feed. For instance, using fibrolytic microbes as an agent to improve the PKC quality has two advantages. Firstly, these microbes will use PKC as growth substrate and subsequently will degrade the fibrous materials and secondly, the growth of these microbes eventually will increase the CP content of PKC, thus improving its nutritive values (Wong *et al.*, 2010).

Many studies have been conducted to improve nutrient values of PKC through solid-state fermentation (SSF) either by using fungi such as *Aspergillus niger* (Iluyemi *et al.*, 2006; Lawal *et al.*, 2010 and Ramin *et al.*, 2010), *Sclerotium rolfsii*, *Trichoderma harzianum* (Ramin *et al.*, 2010), *Trichoderma longibrachiatum* and *Trichoderma koningii* (Iluyemi *et al.*, 2006), *Rhizopus* spp. (Rahim *et al.*, 2007; Lawal *et al.*, 2010; Ramin *et al.*, 2010), *Trichoderma varidae* and *Mucor mucedo* (Lawal *et al.*, 2010) and bacteria such as *Bacillus 7DY7* (Wong *et al.*, 2010). The fermented feed ingredients under SSF conditions have been found to be more suitable for low technology application, and there is hardly any waste disposal at the end because the whole product may be used directly in the animal feeds (Iluyemi *et al.*, 2006). Apart from that, the SSF of PKC produces a product that

contains high protein content and low hemicellulose and cellulose concentration. The levels of unsaturated fatty acids increase while saturated fatty acids decrease as a result of SSF of PKC using fungi as culturing agents (Iluyemi *et al.*, 2006). The unsaturated fatty acids are more nutritionally valuable compared to the saturated fatty acids. This is because all of the essential fatty acids are unsaturated and must be provided from feed (Murano, 2003; Iluyemi *et al.*, 2006).

The use of different types of fungi or bacteria as an agent in SSF by several researchers has showed different results on the nutrient contents of PKC. In a study conducted by Ramin *et al.* (2010) using three different fungi species: *Aspergillus niger*, *Trichoderma harzianum* and *Rhizopus oryzae* in SSF of PKC, they reported that *A. niger* or *R. oryzae* were two potentially effective fungal species which could improve the nutrient content of PKC, but the other two fungi did not. The treatment improved the concentration of CP and reduced the NDF and ADF values. The result appeared to be in line with observations by Ng *et al.* (2002), where they reported *Trichoderma koningii* almost doubled the protein content of PKC. The nutrient analysis of raw PKC and fermented PKC from different fungal strains is shown in Table 5.

Table 5. Proximate analysis of raw PKC and fermented PKC of different fungal strains

Nutrient	PKC <sup>1</sup>	*FPKC <sup>1</sup>	PKC <sup>2</sup>	FPKC <i>Rhizopus</i> sp. <sup>2</sup>	PKC <sup>3</sup>	FPKC <i>A.</i> <i>niger</i> <sup>3</sup>	FPKC <i>T.</i> <i>viridae</i> <sup>3</sup>	FPKC <i>M.</i> <i>mucedo</i> <sup>3</sup>
DM (%)	91.8	91.8	-	-	88.4	90.0	88.8	88.9
CP (%)	20.0	23.4	16.	18.9	12.0	21.2	19.6	20.7
EE (%)	8.6	3.8	2.0	1.3	3.9	3.9	4.2	4.0
CF (%)	15.4	12.4	21.9	18.6	20.2	12.4	11.8	11.3
ASH (%)	7.5	8.3	-	-	13.9	19.6	19.8	18.9
ME (MJ/Kg)	11.6	11.1	1750.0	2739.0	2129.0	2273.4	2286.0	2280.7

\*FPKC: Fermented PKC

<sup>1</sup>Dairo and Fasuyi (2007); <sup>2</sup>Rahim *et al.*, (2007); <sup>3</sup>Lawal *et al.*, (2010)

Besides using PKC as a partial replacement for SBM, it could also be used to substitute certain amount of corn in poultry feed as it contains moderate amount of energy together with protein. As the PKC comprises mainly of cell wall, through biological treatment of SSF could improve the digestibility and vitamin content, protein efficiency ratio and amino acid availability through the destruction of anti-nutritional factors of PKC achieved through to the occurrence of related enzymes (Marini *et al.*, 2005). Selective enrichment technique was carried out to isolate PKC degrading microorganisms, such as *Aspergillus niger* and *A. fumigatus* from rotting PKC and the environment to ferment PKC through SSF (Marini *et al.*, 2005). In their study, there was a reduction in NDF and ADF of fermented PKC with *A. niger* by about 30.39% and 14.58%, and SSF with *A. fumigatus* the reduction of NDF and ADF were 30.33% and 13.36%, respectively. Even though SSF of PKC using *A. fumigatus* observed in the reduction of NDF and ADF this culture could not be used as inoculum because it was reported to be pathogenic to animals and humans (Marini *et al.*, 2005).

In contrast to ruminants, the microbial upgrading of high fiber feed materials is not commonly practiced for non-ruminant feeds. However, fungal protein enriched agricultural by-products preferably SSF can be the preferred method for the improvement of nutrients of agricultural residues since it simulates the natural environment of most microorganisms, especially fungi and be utilized by simple stomach animals such as poultry (Dairo and Fasuyi, 2008; Wong *et al.*, 2010) and fish (Ng and Chen, 2002).

In a feeding trial conducted by Lawal *et al.* (2010) it was shown that the apparent digestibility of nutrients of broilers receiving the fermented PKC was improved compared to unbiodegraded PKC and commercial enzyme (Roxazyme G2G) supplemented

PKC. Besides improvement in terms of performance of the birds on fermented PKC was also improved significantly. Results from this study reveal that multi-enzymes produce through the fermentation of PKC can be used to ferment the PKC based diet, thus improving the nutrient content and availability to poultry.

In the previous study conducted by Dairo and Fasuyi, (2008), it was found that the fermentation of PKC increased the CP content from 20.04 to 23.42% and decreased the CF from 15.47 to 12.44%. The fermented PKC was formulated in the layer hen diets, substituting SBM at a rate of 25, 50 and 75%. Overall the growth performance of laying hens was significantly improved, where feed intake and body weight gain of laying hens fed 75% PKC was the highest.

The profit margin of lower-value fish enterprises such as catfish, tilapia and carps, depends mostly on the feed prices, especially the rising trend in the cost of imported ingredients such as fish meal, SBM, corn and wheat flour which makes these aqua enterprises becoming no longer profitable (Ng, 2004). The incorporation of agricultural by-product such PKC could overcome this problem; but the enhancement of nutrient availability of PKC for aqua animals should be made. Besides using exogenous enzymes, SSF of PKC gradually becomes popular for improving the nutrient availability of PKC for aquatic animals (Ng, 2004; Iluyemi *et al.*, 2006).

The use of fermented PKC in fresh water aquaculture has been documented by Ng (2004). In his work, the microorganisms used to ferment PKC were isolated and obtained from oil samples of which *Trichoderma koningii* was chosen to be the potential microorganism. The protein content of fermented PKC was doubled from 17 to 32% meanwhile the reducing sugar content was also increased. However, when the fermented PKC was included into tilapia

diets, a noticeable reduction in their growth was observed. Despite the improvement in fermented PKC nutrient especially protein, the growth of fish was poor which could be due to the mycotoxins released by the microbes used during the fermentation process (Ng, 2004).

Comparison between fungi enzyme treated SSF of PKC with enzyme supplemented PKC was carried out by Ng (2004) and Lawal *et al.* (2010). Cellulose and hemicellulose components were significantly reduced in fungi enzyme treated SSF of PKC (biodegraded) compared with PKC

supplemented with commercial enzyme, Roxazyme G2G (Table 6). A significant increase in CP, phosphorus and energy of biodegraded PKC was observed compared to that treated with Roxazyme G2G PKC. The enzyme complexes (enzyme produced through SSF of PKC with four different fungi, namely *Aspergillus niger*, *Trichoderma viride*, *Rhizopus stolonifer* and *Mucor mucedo*) produced were more efficacious in breaking down the cellulose and hemicellulose compared to Roxazyme G2G, an enzyme product specific for cereal-based diets (Lawal *et al.*, 2010).

Table 6. Proximate composition (% dry matter) of raw and treated PKC

Ingredient	Proximate composition					
	Moisture	Crude protein	Crude fat	Crude fiber	Ash	Nitrogen free extract
PKC	11.43	16.86	6.82	15.12	6.58	54.62
Enzyme-treated PKC	10.15	17.11	5.15	14.59	5.40	57.75
Fermented PKC	6.67	31.27	3.36	14.51	11.34	39.52

Source: Ng, 2004

Ng (2002) had conducted a feeding trial to compare whether pre-treatment of PKC with commercial feed enzyme (Allzyme VegproTM) or SSF of PKC with *T. koningii* (Oudemans) could improve the nutritive value of raw PKC in the diets of red hybrid tilapia, *Oreochromis* sp. The growth performance and FCR of tilapia fed 20% enzyme treated PKC was observed to be not different from the diet without PKC while tilapia fed fermented PKC had poorest growth which could be due to the presence of anti-nutrients in the fungal biomass (Ng, 2002).

#### Combination of Treatments

Several studies have been conducted to study the effect of combining chemical and biological treatments on the nutrient contents of PKC (Mirnawati *et al.*, 2010; A'dilah and Alimon, 2011). A'dilah and Alimon (2011)

worked on the application of chemical pre-treatment of PKC using ammonium hydroxide, formic acid and acetic acid individually before carrying out the solid state culture of the pre-treated PKC with two different fungal strains (*R. oligosporus* and *T. harzianum*) incubated for seven days. On the other hand, Mirnawati *et al.*, (2010) mixed the PKC with humic acid at different dosages (0, 100 and 200 ppm) together with *A. niger* in fermenting the PKC for a 7-day incubation period. The pre-treatment of PKC either by acid or alkaline solution improved the nutrient content of PKC by reducing ADF, NDF and ADL contents, and a similar trend was also observed after the solid state culture of pre-treated PKC was carried out (A'dilah and Alimon, 2010). The chemical treatment using humic acid combined with SSF on PKC (Mirnawati *et al.*, 2010) did improve the nutrient content particularly CP and

reduce the CF content. The data demonstrated the interaction between humic acid dosage and SSF affected the CP and CF content of PKC. A mixture of 100 ppm of humic acid with PKC and then fermented for 7 days with *A. niger* was recorded to result in higher content of CP and CF of 23.20 and 10.59%, respectively (Mirnawati *et al.*, 2010). The combined methods of chemical pre-treatment and SSF seem to improve the nutritive value of PKC and chicken could tolerate fermented PKC.

### Conclusion

Conclusively, despite having the abundance of PKC production especially in tropical countries such as Malaysia and Indonesia, the PKC potential in poultry feeding is very poor. Undoubtedly, more work should be done and focused on improvement of the nutrient contents of PKC before it could be offered to poultry as feed. Such work must emphasize more on reducing the CF and NSPs contents of PKC because poultry lack enzymes and cellulolytic bacteria in their gastrointestinal tract that could help to degrade these two components. Finally, the most important part in selecting the best method to alleviate the nutrient contents of PKC must include the followings: the cost of conducting the treatment should be kept low (Abonyi and Uchendu, 2005), the treated PKC should be easily handled and can be kept for a long period of time (Adesehinwa, 2007), the product should be palatable and accepted by the poultry (Ahmad Borhan *et al.*, 2005) and it should be easily digested and absorbed by the poultry (Alimon, 2004) so that, it will eventually improve their growth performance and production.

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### References

- A'dilah, M.M. and Alimon, A.R. 2011. Improving the nutritive value of palm kernel cake (PKC) through chemical pre-treatment and fungal fermentation. Paper presented at the 32<sup>nd</sup> Annual Conference Malaysian Society of Animal Production (MSAP) Kuantan, Pahang, Malaysia. pp 39.
- Abonyi, F.D. and Uchendu, C.N. 2005. Effect of graded levels of palm kernel cake in broiler finisher performance. Paper presented at the 30<sup>th</sup> Annual Conference Nigerian Society Animal Production, Nsukka, Nigeria. pp. 204-206.
- Adesehinwa, A.O.K. 2007. Utilization of palm kernel cake as a replacement for maize in diets of growing pigs: Effects on performance, serum metabolites, nutrient digestibility and cost of feed conversion. *Bulgarian. J. Agri. Sci.* 13: 593-600.
- Aghazu, B.U.C., Meissner, H.P., Ngoui, C.I. and Tannenbaum, S.R. 1979. Protein-rich flours from palm kernels. *J. Feed Technol.* 14: 1-8.
- Ahmad Borhan, A.N., Venugopal, R., Amiruddin, N. and Simeh, M.A. 2005. Palm kernel cake marketing: constraints and prospects. *Oil Palm Industry Econ. J.* 5(2): 37-46.
- Alimon, A.R. 2004. The nutritive value of palm kernel cake for animal feed. *Palm Oil Developments.* 40:12-16.
- Aneato, M., Chioma, G.O. and Omeshi, D.J. 2009. Palm kernel cake as substitute for maize in broiler finisher diet. *Int. J. Poult. Sci.* 8(12): 1206-1208.

- Ao, X., Zhou, T.X., Meng, Q.W., Lee, J.H., Jang, H.D., Cho, J.H., Kim, I.H. 2011. Effects of a carbohydrase cocktail supplementation on the growth performance, nutrient digestibility, blood profiles and meat quality in finishing pigs fed palm kernel meal. *Livestock Sci.* 137: 238–243.
- Armas, A.E. and Chicco, C.F. 1977. Use of palm kernel meal of the oil palm (*Elaeis guineensis* Jacq) in broiler chickens diets. *Venezuela Agron. Trop.* 27: 339-343.
- Cheng Hai, T. 2011. The Palm Oil Industry in Malaysia; from seed to frying pan. Prepared for WWF Switzerland by TEOH Cheng Hai, Hon. Advisor, Plantation Agriculture, WWF.
- Chenost, M. and Kayouli, C. 1997. Roughage utilization in warm climates. *FAO Animal Production and Health Paper 135*, FAO, Rome. pp. 226
- Chin, F.Y. 2008. Palm kernel cake (PKC) as a supplement for fattening and dairy cattle in Malaysia. 7<sup>th</sup> Meeting of the Regional Working Group on Grazing and Feed Resources. Forage Development in Southeast Asia; Strategies and Impact.
- Choct, M. and Anisson, G. 1992. Anti-nutritive effect of wheat pentosans in broiler chickens: roles of viscosity and gut microflora. *Br. Poult. Sci.* 33: 821-834.
- Choct, M.R., Hughes, R.J. and Bedford, M.R. 1999. Effects of a xylanase on individual bird variation, starch digestion throughout the intestine, ileal and cecal volatile fatty acid production in chickens fed wheat. *Br. Poult. Sci.* 40: 419-422.
- Chong, C.H., Zulkifli, I. and Blair, R. 2008. Effects of Dietary Inclusion of palm kernel Cake and palm oil, and enzyme supplementation on performance of laying hens. *Asian-Aust. J. Anim. Sci.* 21 (7): 1053-1058.
- Dairo, F.A.S. and Fasuyi, A.O. 2007. Evaluation of fermented palm kernel meal and fermented copra meal proteins as substitute for soybean meal protein in laying hens diets. *J. Cent. Eur. Agr.* 9: 33-47.
- Daud, M.J. and Jarvis, M.C. 1992. Mannan of oil palm kernel. *Phytochemistry.* 31(2): 463-464.
- Daud, M., Samad, J.N. and Rasool, S. 1997. Specific commercial enzymes for nutritive value improvement of palm kernel cake of poultry diets. In *Proceedings of the 19<sup>th</sup> Malaysian Society of Animal Production (MSAP)*, Johore Baharu, Johore, Malaysia.cpp. 137-138.
- Dusterhoft, E.M. and Voragen, A.G.J. 1991. Non-starch polysaccharides from sunflower (*Helianthus annuus*) and palm kernel (*Elaeis guineensis*) meal preparation of cell wall material and extraction of polysaccharides fractions. *J. Sci. Food Agri.* 55: 411-422.
- Ezieshi, E.V. and Olumu, J.M. 2007. Nutritional evaluation of palm kernel meal types: 1. Proximate composition and metabolizable energy values. *African J. Biotechnol.* 6 (21): 2484-2486.
- Ezieshi, E.V. and Olumu, J.M. 2008. Nutritional evaluation of palm kernel meal types: 2. Effects on live performance and nutrition retention in broiler chicks diets. *Afr. J. Biotechnol.* 7: 1171-1175.

- Fernandez, M.J., Roche, E., Pou, J., Garrido, F and Garrido D. 1989. Enzyme production by solid-state cultures of aerobic fungi on lignocelluloses substrates. In Coughan M. P. C (Editor), *Enzyme Systems for Lignocellulose*. Elsevier Applied Sci Pub, London. 177-191.
- Hair-Bejo, M. and Alimon, A.R. 1995. The protective role of zinc in palm kernel cake (PKC) toxicity in sheep. *Mal. J. Nut.* 1: 75-82.
- Hishamuddin, M.A. 2002. Malaysian palm kernel cake as animal feed. *Malaysian Palm Oil Board. Palm Oil Developments.* 34: 4-6. [http://bepi.mpob.gov.my/images/area/2013/Area\\_summary.pdf](http://bepi.mpob.gov.my/images/area/2013/Area_summary.pdf)  
<http://www.etawau.com/OilPalm/Elaeisguineens.htm>
- Iluyemi, F.B., Hanafi, M.M., Radziah, O. and Kamarudin, M.S. 2006. Fungal solid state culture of palm kernel cake. *Bioresc. Technol.* 97: 477- 482.
- James, E.C. Jr. and Wheeler, R.S. 1949. Relation of dietary protein content to water intake elimination and amount of cloacal excrete produced by chickens. *Poult. Sci.* 28: 456-467.
- Józefiak, D., Rutkowski, A. and Martin, S.A. 2004. Carbohydrate fermentation in the avian ceaca. *Anim. Feed Sci. Technol.* 113:1-15.
- Kim, B.G., Lee, J.H., Jung, H.J., Han, Y.K., Park, K.M., Han, I.K., 2001. Effects of partial replacement of soybean meal with palm kernel meal and copra meal on growth performance, nutrient digestibility and carcass characteristics of finishing pigs. *Asian-Aust. J. Anim. Sci.* 14: 821–830.
- Kperegbe, J.I and Ikperite, S.E. 2011. The effectiveness of replacing maize with palm kernel cake in broilers' starter diets. *J. Env. Issues and Agri. In Dev. Count.* 3 (1): 145-149.
- Kushairi, A., Rajanaidu, N., Jalani, B.S. and Zakri, A.H. 1999. Agronomic Performance and Genetic Variability of Dura X Pisifera Progenies. *J. Oil Palm. Res.* 2: 24
- Lawal, T.E., Iyayi, E.A., Adeniyi, B.A. and Adaromoye, O.A. 2010. Biodegradation of Palm Kernel Cake with Multienzymes Complexes from Fungi and its Feeding Value for Broilers. *Int. J. Poult Sci.* 9(7): 695-701.
- Lui, J.X., Ørskov. and Chen, X.B. 1999. Optimization of steam treatment as a method of upgrading rice straw as feed. *Anim. Feed Sci. Technol.* 76: 345-357.
- Marini A.M., Daud, M.J., Noraini, S., Jame'ah, H. and Engku Azahan, E.A. 2005. Performance of locally isolated microorganism in degrading palm kernel cake (PKC) fibre and improving the nutritional value of fermented PKC. *J. Trop. Agric. Food. Sci.* 33(2): 311–319.
- Mirawati, Rizal, Y., Marlida, Y. and Kompiang, P. 2010. The Role of humic acid in palm kernel cake fermented by *Aspergillus niger* for poultry ration. *Pak. J. Nut.* 9 (2): 182-185.
- MPOB, 2011. Overview of the Malaysian oil palm industry. Kuala Lumpur: Malaysian Palm Oil Board.
- Murano, P.S. 2003. Understanding food science and technology. Wadsworth, Thomson Learning. Belmont, CA, USA. pp. 71.
- Ng, W.K. 2004. Researching the use of palm kernel cake in aquaculture feeds. *Palm Oil Developments.* 41: 19-21.
- Ng, W.K. and Chen, M.L. 2002. Replacement of soybean meal with palm kernel meal in practical diets for hybrid Asian-African catfish, *Clarias macrocephalus* x *C. gariepinus*. *J. Appl. Aquacult.* 12 (4): 67-76.

- Ng, W.K. and Chong, K.K. 2002. The nutritive value of palm kernel meal and the effect of enzyme supplementation in practical diets for red hybrid tilapia (*Oreochromis* sp.). *Asian Fisheries Sci.* 15:167-176
- Ng, W.K., Lim, H.K., Lim, S.W. and Ibrahim, O. 2002. Nutritive value of palm kernel meal pretreated with enzyme or fermented with *Trichoderma koningii* (Oudemans) as a dietary ingredient for red hybrid tilapia (*Oreochromis* sp.). *Aqua Resc.* 33: 1119-1207.
- Nuzul Amri, I. 2013. Characteristics of Malaysian palm kernel and its products. *J. Oil Palm. Res.* 25 (2): 245-252.
- Oluwafemi, R.A. and Akpodiete, O.J. 2010. Carcass characteristics and meat quality of weaner pigs fed palm kernel cake based ration. *Electro. J. Env. Agri. Food Chem.* 9(1): 123-128.
- Onuh, S.O., Ortserga, D.D. and Okoh, J.J. 2010. Response of broilers chickens to palm kernel cake and maize offal mixed in different ratios. *Pakistan J. Nut.* 9(6): 516-519.
- Onuora J.O. and King, R.D. 1985. Technical note preliminary study of Enzymic Solubilization of Nitrogenous Constituents of Palm Kernel Cake. *Food Chemistry* 17: 297-302.
- Onuwudike, O.C. 1986. Palm Kernel as feed a feed poultry. 2. Diets containing palm-kernel meal for starter and grower pullets. *Anim. Feed Sci. Tech.* 16: 187-194.
- Onuwudike, O.C. 1996. Oil palm (*Elaeis guineensis* Jacq.). In: Nwokolo, E., Smartt, J. (Eds), *Legume and Oilseeds in Nutrition*. Chapman and Hall Publishers, England. 318-330.
- Rahim, F., Sabrina, Rusmawati and Syibli, F. 2007. Broiler small intestine villi response to feed containing palm kernel cake which fermented with *Rhizopus*. *J. Indon. Trop. Anim. Agri.* 32(4): 251-256.
- Ramin, M., Alimon, A.R. and Ivan, M. 2010. Effects of fungal treatment on the *in vitro* digestion of palm kernel cake. *Livestock Research for Rural Development. Volume 22, Article #82*. Retrieved April 17, 2014, from <http://www.lrrd.org/lrrd22/4/rami22082.htm>
- Rhule, S.W.A. 1996. Growth rate and carcass characteristics of pigs fed on diets containing palm kernel cake. *Anim. Feed Sci. Technol.* 61: 167-172.
- Saenphoom, P., Liang, J.B., Ho, Y.W., Loh, T.C. and Rosfarizan, M. 2011. Effect of enzyme treatment on chemical composition and production of reducing sugars in palm (*Elaeis guineensis*) kernel expeller. *Afr. J. of .Biotechnol.* 10(68): 15372-15377.
- Saenphoom, P., Liang, J.B., Ho, Y.W., Loh, T.C. and Rosfarizan, M. 2013. Effects of Enzyme Treated Palm Kernel Expeller on Metabolizable Energy, Growth Performance, Villus Height and Digesta Viscosity in Broiler Chickens. *Asian-Aust. J. Anim. Sci.* 26(4): 537-544.
- Saw, H.Y., Janaun, J, Kumaresan, S. and Chu, C.M. 2012. Characterization of the physical properties of palm kernel cake. *Int. J. Food Properties.* 15: 536-548.
- Sekoni, A.A., Omage, J.J., Bawa, G.S. and Esuga, P.M. 2008. Evaluation of enzyme (Maxigrain®) treatment of graded levels of Palm Kernel Meal (PKM) on nutrient retention. *Pak. J. Nut.* 7(4): 614-619.

- Setthapakdee, C., Jalaludin, S. and Mahyuddin, M. 1991. Effect of supplementing grass and urea on the performance and carcass characteristics of lambs fed palm kernel cake-based diet. Proceeding of the 3<sup>rd</sup> International Symposium on the Nutrition of Herbivores, pp.100.
- Shaen, M. 2011. Malaysia: Obstacles may reduce future palm oil production growth. Retrieved from <http://www.pecad.fas.usda.gov/highlights/2011/06/Malaysia/>
- Soltan, M.A. 2009: Growth performance, immune response and carcass traits of broiler chicks fed on graded levels of palm kernel cake without or with enzyme supplementation. *Livestock Research for Rural Development. Volume 21, Article #37*. Retrieved April 17, 2014, from <http://www.lrrd.org/lrrd21/3/solt21037.htm>
- Sundu, B., Kumar, A. and Dingle, G. 2006. Palm kernel meal in broiler diets: effect on chicken performance and health. *World's Poult. Sci. J.* 62: 316-325
- Sundu, B., Kumar, A. and Dingle, J. 2005. Response of birds fed increasing levels palm kernel meal supplemented with enzymes. *Austr. Poult. Sci. Symp.* 12: 63-75.
- Tang, T.S. and Teoh, P.K. 1985. Palm oil extraction-The Malaysian experience. *JAOCS.* 62: 254-258.
- Tang, T.S. 2001. Quality and characteristics of Malaysian palm kernel cake/expeller. *Palm Oil Developments.* 34: 1-3.
- Wan Zahari, M. and Alimon, A.R. 2004. Use of palm kernel cake and oil palm by-products in feed compounds. *Palm Oil Developments.* 40: 5-9.
- Wong, C.M.V.L., Lau, S.Y.L., Abdullah, N. and Elaine, R.D.T. 2010. Bioconversion of palm kernel cake (PKC) to value added feed using fibrolytic bacteria and fungi. Paper presented at the National Biotechnology Seminar, Putra World Trade Centre, Kuala Lumpur.
- Yeong, S.W. 1983. Amino acid availability of palm kernel cake, palm oil sludge and sludge fermented product (Prolima) in studies with chickens. *MARDI. Res. Bull.* 11: 84-88.
- Yeong, S.W., Mukherjee, T.K. 1983. The effect of palm oil supplementation in palm kernel cake-based diets on the performance of broiler chicken. *MARDI Res. Bull.* 11(3): 378-384.
- Yusof, B. and Chan, K.K. 2004. The oil palm and its sustainability. *J. Oil Palm. Res.* 16(1): 1-10.
- Zanu, H.K., Abangiba, J., Arthur-Badoor, W., Akparibo, A.D. and Sam, R. 2012. Laying chickens' response to various levels of palm kernel cake in diets. *Int. J. Livest Product.* 3(1): 12-16.