EFFECTS OF PROCESSING METHODS ON COMPOSITION, ANTINUTRIENTS, AND PHYSICOCHEMICAL PROPERTIES OF PALM KERNEL CAKE

by

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LIST OF ABBREVIATIONS

BDH	Rochelle salt
BSA	Bis (Trimethylsilyl) Acetamide
CGTase	Cyclodextrin glycosyltransferase
CT	Condensed tannin
DF	Dietary fiber
EDTA	Ethylenediaminetetraacetic acid
EGTA	Ethyleneglycoltetraacetic acid
FAME	Fatty acid methyl ester
GC-FID	Gas chromatography-Flame ionization detector
HCN	Hydrogen cyanide
HDL	High density lipoprotein
HT	Hydrolysable tannin
ICP-OES	Inductively coupled plasma-Optical emission spectrometry
IDF	Insoluble dietary fiber
IP6	1,2,3,4,5,6-hexakisphosphate
K_a	Disassociation constant
LC-APCI-MS	Liquid chromatography-Atomic pressure chemical ionization-Mass spectrometry
LC-ESI-MS	Liquid chromatography-Electrospray ionization-Mass spectrometry
LDL	Low-density lipoprotein
Mr	Relative molecular mass
NFE	Nitrogen free extract
NSP	Non-starch polysaccharide
OHC	Oil holding capacity
PA	Phytic acid
PKC	Palm kernel cake
SDF	Soluble dietary fiber

SNP	Soluble non-starch polysaccharide
TAN	Tropical ataxic neuropathy
TDF	Total dietary fiber
WHC	Water holding capacity

KESAN KAEDAH PEMPROSESAN TERHADAP KOMPOSISI, ANTINUTRIEN DAN SIFAT FIZIKOKIMIA KERNEL KEK SAWIT

ABSTRAK

Kernel kek sawit (BIS) merupakan bahan sampingan pemprosesan minyak kernel sawit. BIS digunakan sebagai bahan makanan ruminan kerana kos yang rendah dan bahan ini boleh diperolehi dengan mudah jika dibandingkan dengan bahan yang lain. Walaubagaimanapun, penggunaan BIS terhad dalam diet haiwan bukan ruminan akibat kandungan serat yang tinggi dan kehadiran antinutrien. Faktor nutrisi dan antinutrisi BIS telah dikaji. Komposisi proksimat BIS turut dianalisa. Vitamin B_2 (1.55 ± 0.03 mg/g), B_5 (13.70 ± 0.02 mg/g), B_6 (0.50 ± 0.003 mg/g) and E (3.98 ± 0.05 mg/g) telah dikesan dalam BIS. Asid laurik (2.91 mg/g), asid lignoserik (1.86 mg/g) dan asid sterik (1.17 mg/g) merupakan asid-asid lemak utama dalam BIS. sulfur (28.59 g/kg), fosforus (14.44 g/kg), kalsium (9.63 g/kg) dan magnesium (2.55 g/kg) merupakan mineral utama yang ditemui dalam BIS. Asid fitik (4.16 ± 0.007 mg/g), tanin (0.30 ± 0.06 mg/g), saponin (0.27 ± 0.002 mg/g), kandungan oksalat keseluruhan (7.38 ± 0.04 mg/g) dan terlarut(0.48 ± 0.01 mg/g), aktiviti perencatan α-amilase (98%), hydrogen sianida (0.40 ± 0.14 mg/g) dan polisakarida bukan-kanji (45.79 ± 2.07%) turut diuji untuk antinutrien. Kandungan serat yang tinggi dan kehadiran antinutrien dalam BIS mengurangkan potensi BIS sebagai sumber serat makanan. Pelbagai kaedah fizikokimia dan enzimatiktelah dijalankan untuk menyingkirkan faktor-faktor ini. Keberkesanan rawatan fizikokimia berbeza berdasarkan jenis antinutrien. Hidrogen peroksida (H_2O_2) telah mengurangkan kandungan saponin, tanin dan aktiviti perencatan α-amilase dengan lebih baik berbanding rawatan fizikokimia yang lain. Kandungan oksalat keseluruhan dan

tidak-larut berkurang melalui penggunaan asid hidroklorik. Pendidihan telah mengurangkan kandungan oksalat tidak-larut dengan lebih baik berbanding kaedah yang lain. HCl dan H_2O_2 telah menghilangkan kandungan hidrogen sianida. Tidak ada kaedah yang menunjukkan kesan yang signifikan terhadap kandungan asid fitik. Sampel yang dirawat dengan H_2O_2 menunjukkan penurunan tertinggi dalam kandungan serat makanan tidak larut (SMT). Kombinasi H_2O_2 dan enzim selulase menghasilkan pengurangan maksimum dalam kandungan SMT berbanding kombinasi lain. Kandungan serat makanan terlarut (SML) adalah tertinggi untuk rawatan dengan H_2O_2 berbanding rawatan lain. Kombinasi H_2O_2 4.5% dan enzim hemiselulase menunjukkan kandungan SML yang tertinggi di antara semua kombinasi. Kandungan liginin dalam BIS berkurang sebanyak 60% apabila dirawat dengan H_2O_2 4.5%. Nisbah optimum SML:SMT (1:2) diperoleh apabila sampel BIS dirawat dengan hemiselulase selepas pra-rawatan dengan hydrogen peroksida. Semua aktiviti enzim dipertingkatkan melalui pra-rawatan. Kegiatan enzim xilanase menunjukkan peningkatan yang tertinggi apabila melalui pra-rawatan berbanding enzim-enzim yang lain. Rawatan dengan 4.5% H_2O_2 meningkatkan kegiatan hemiselulase dan selulase manakala pendidihan selama 60 minit paling meningkatkan aktiviti xilanase. Rawatan dengan H_2O_2 bermanfaat dalam menghilangkan antinutrien, memperbaiki nisbah SML:SMT dan sebagai kaedah pra-rawatan untuk enzim. SIfat berfungsi BIS turut ditingkatkan secara siginifikan melalui rawatan fizikokimia. Rawatan dengan H_2O_2 meningkatkan WHC dan OHC, sekaligus mengoptimumkan nisbah SML:SMT. Walaubagaimanapun WHC BIS yang rendah selapas rawtan H_2O_2 menjadikannya sumber yang kurang sesuai untuk diterapkan sebagai bahan menghentikan sineresis dalam makanan manakala BIS yang dirawat dengan H_2O_2 (4.5%) boleh digunakan dengan jayanya sebagai bahan

penstabil makanan dengan peratusan lemak dan emulsi yang tinggi. Secara kesimpulannya, kajian ini melaporkan kandungan antinutrien BIS buat pertama kalinya dan kaedah kimia dan fizikal untuk mengurangkan antinutrien. Di samping itu, BIS telah diperbaiki sebagai makanan haiwan bukan ruminan kerana kandungan polisakarida bukan-kanji tidak larut yang rendah dan kandungan polisakarida bukan-kanji larut yang lebih tinggi. Peningkatan SML dan nisbah SML: SMT untuk BIS yang dirawat menjadi sumber serat makanan baru yang diperlukan dalam kajian haiwan dan keselamatan.

EFFECTS OF PROCESSING METHODS ON COMPOSITION, ANTINUTRIENTS, AND PHYSICOCHEMICAL PROPERTIES OF PALM KERNEL CAKE

ABSTRACT

Palm kernel cake (PKC) is a by-product of palm kernel oil milling process. It has been used as a feed ingredient for ruminants due to its relatively low cost and availability. However, PKC application is impeded in non-ruminant diets due to its high fiber contents and the presence of antinutrients. The nutritional and antinutritional factors of PKC were determined in this study. The proximate composition of PKC was analyzed. PKC was treated with physical (Removal of fat, boiling, and autoclaving), chemical (HCl and H_2O_2), and enzymatic (cellulase, hemicellulase, and xylanase) treatments. The effectiveness of the physicochemical treatment as a pre-treatment for the enzymes is also studied. The moisture content, crude protein content, crude fiber content, crude fat content, and ash content are 9.60 ± 0.05%, 12.72 ± 0.53%, 24.11 ± 2.61%, 11.10 ± 0.73%, and 8.18 ± 0.58%, respectively. Vitamin B_2 (1.55 ± 0.03 mg/g), B_5 (13.70 ± 0.02 mg/g), B_6 (0.50 ± 0.003 mg/g), and E (3.98 ± 0.05 mg/g) are detected in PKC. Lauric acid (2.91 mg/g), lignocereic acid (1.86 mg/g), and stearic acid (1.17 mg/g) are the main fatty acids found in PKC. Sulfur (28.59 g/kg), phosphorus (14.44 g/kg), calcium (9.63 g/kg), and magnesium (2.55 g/kg) are the major minerals detected in PKC. Phytic acid (4.16 ± 0.007 mg/g), tannin (0.30 ± 0.06 mg/g), saponin (0.27 ± 0.002 mg/g), total oxalate (7.38 ± 0.04 mg/g) and soluble oxalate (0.48 ± 0.01 mg/g), α-amylase inhibitory activity (98%), hydrogen cyanide (0.40 ± 0.14 mg/g), and non-starch polysaccharide (45.79 ± 2.07%) were tested for antinutrients. A high amount of fibers and antinutrient contents present in PKC reduced its potential as a dietary fiber source. The effectiveness of the physicochemical treatments was different according to the type of antinutrient. Saponin, tannin contents and α-amylase inhibitory activity were reduced by hydrogen peroxide (H_2O_2) treatments better than the other physicochemical treatments. Total and insoluble oxalate contents were reduced under the HCl treatments. Boiling treatments reduced the insoluble oxalate contents over the other treatments. HCl and H_2O_2 treatments eliminated the hydrogen cyanide (HCN) contents. No treatment showed a significant effect on phytic acid contents. Among the physicochemical treatments, the highest reduction in insoluble dietary fiber contents was achieved for the sample treated with H_2O_2. The combine treatment of H_2O_2 and cellulase enzyme denoted the maximum reduction in insoluble dietary fiber (IDF) contents compared to the all treatment combinations. Soluble dietary fiber (SDF) contents were highest for the H_2O_2 treated PKC. The combination of 4.5% H_2O_2 and hemicellulase enzyme treatment exhibited the highest soluble dietary fiber contents. Lignin contents were reduced by 60% in PKC, treated with 4.5% H_2O_2. The optimum SDF: IDF ratio (1: 2) exhibited for the hydrogen peroxide pre-treated and hemicellulase treated PKC samples. All the enzyme activities were enhanced by the pre-treatments. Among the enzymes employed, xylanase denoted the highest enhancement in activity due to the pre-treatments. The treatment of 4.5% H_2O_2 enhanced the activities of hemicellulase and cellulase whereas boiling for 60 min enhanced xylanase activity, the most. H_2O_2 treatments were beneficial in removing antinutrients, improving SDF: IDF and as a pre-treatment method for enzymes. The functional properties of PKC were improved significantly after the physicochemical treatments. H_2O_2 treatment increased the WHC and OHC, simultaneously optimized the SDF: IDF ratio. But, low WHC of H_2O_2 treated PKC

makes it a poor source to be applied as an ingredient to stop syneresis in food whereas H_2O_2 treated (4.5%) PKC can be a successful candidate after in-vivo and in-vitro studies to stabilize food with a high percentage of fat and emulsion. As a summary, the study reported antinutrient content for the first time for PKC and the means of chemical and physical methods to reduce it. Further, the treated PKC is improved as a non-ruminant feed due to its lower insoluble non-starch polysaccharides and higher soluble non-starch polysaccharides. With increased amount of SDF and SDF: IDF, treated PKC become a possible new candidate for a dietary fiber source which needs an animal and safety study.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Oil palm is a leading commercial, perennial crop in Malaysia, providing a large proportion for the revenue of the country. Palm oil, palm kernel oil, oleochemicals, bio-fuel and palm kernel cake are the major derivatives of oil palm industry.

Palm kernel cake (PKC) is a by-product of palm kernel oil extraction process. Palm kernel expeller and palm kernel meal are synonyms for PKC. Palm kernel oil extraction is done by either mechanical pressing or solvent extraction method, which produces mechanical pressed PKC or solvent extracted PKC. Thus, the solvent extraction method is less popular in the industry due to its high cost in the production of the oil (Sue and Teoh, 1985; Awaludin, 2001; Alimon, 2004).

Most of PKC (70%) in the world is produced by Malaysia and Indonesia (Sundu and Dingle, 2005) and the production has increased by 15% in the last two decade. In 2008 and 2009 Malaysia produced 2.3 million tonnes of PKC, where, 2.2 million was exported in 2008 and 2.3 million was exported in 2009 (MPOB, 2009). The exported PKC was used as a component in animal feed.

1.2 Rationale of the Research

PKC has become a popular feed source in an animal husbandry due to its higher availability (Babatunde et al., 1975) and low price (Babatunde et al., 1975; Jaafar and Hamali, 1989; Orunmuyi et al., 2006). Other frequently used feed sources, such as soybean, groundnut, cottonseed (Ojewola and Ozuo, 2006), and maize (Rhule, 1996) are seasonal and their availability is insufficient during off-seasons, which increases the price of animal feed. In many developing countries, the rising price of livestock feed and the growing scarcity of fish meal and soy meal have forced animal nutritionists to seek alternatives (Babatunde et al., 1975). This quest directed scientist towards the use of fibrous by-products such as PKC as an animal feed.

The use of PKC in animal feed was first reported in 1915 for cattle (Anonymous, 1915). Ever since, it has been using as a ruminant and non-ruminant feed, although the feed cannot be used solely for non-ruminants own to high fiber contents, antinutrient contents and the putrid odor (butyric odor) of PKC. Studies performed using PKC as a non-ruminant feed (poultry and fish) showed unsatisfactory outcomes in all contexts. The growth rate of animals was compromised. However, for ruminants, there were no such incidences observed.

Non-ruminant health was impaired with PKC application in their diet due to high fiber contents. Humans are also considered as non-ruminants. Therefore, high contents of fiber in PKC are a major hurdle in the application of PKC for human food. High fiber diets are known in the prevention and treatment of some diseases such as constipation, diverticular disease, colonic cancer, coronary heart disease and diabetes (Grigelmo-Miguel et al, 1999). These indigestible portions in fiber by human enzymes are referred as dietary fiber (DF).

Dietary fiber is categorized as insoluble and soluble according to the solubility in water. The insoluble part of DF is related to water absorption and intestinal regulation. The soluble fraction is associate with the reduction of cholesterol in blood and the diminution in the intestinal absorption of glucose. In the terms of health benefits, the both kinds of fiber complement each other and a 50 - 70% insoluble and 30 - 50% soluble DF considers a well-balanced proportion (Grigelmo-Miguel et al, 1999), although, PKC contains less soluble dietary fiber. The reduction of insoluble dietary fiber and increment in soluble dietary fiber will enhance the application and properties of PKC on human food.

Antinutrients hinder mineral absorption (phytic acid, tannin, and oxalate), digestive enzyme systems (phytic acid and tannin), bind protein and reduce the absorption (phytic acid, tannin) and denote hemolytic activities (saponin). Few studies have been reported on the analysis of antinutrient contents and the ways to reduce antinutrients contents in PKC. The health condition and simultaneously the nutritive value of PKC are affected by the action of antinutrients in a diet. Therefore, data on antinutrient contents in PKC will be useful when it is tested for both human and animal applications.

1.3 Hypothesis of the Research

To overcome the mentioned antinutritive compounds and unsatisfactory IDF and SDF contents, PKC was treated with physical (boiled, autoclaved, and defatted), chemical (H_2O_2, HCl), and enzymatic (cellulase, hemicellulase, and xylanase) treatments.

1.4 Objectives

The general objective of the research was to evaluate the potential for the applicability of PKC to human foods. Screening the nutritional and antinutritional compounds in PKC is vital in applying it to human foods. The knowledge on chemical constituents is beneficial on selecting the proper treatment for PKC to make it more suitable for non-ruminant feed applications. Furthermore, this information would contribute to the development of a low cost dietary fiber source for human food application and improve the applicability of PKC as an animal feed. To achieve the main objective and address the above factors, specific objectives were formulated,

1. To determine the nutritional composition of PKC.
2. To determine and reduce the antinutrient contents in PKC by physical and chemical treatments.
3. To determine water holding capacity, oil holding capacity, and color of PKC and improve the properties through physicochemical treatments.
4. To determine the effect of physicochemical and enzymatic treatments of PKC on the insoluble and soluble dietary fibre content.

CHAPTER 2

LITERATURE REVIEW

2.1 Palm Kernel Cake (PKC)

2.1.1 The Production Process of PKC

The oil palm (*Elaeis guineensis* Jacq) is an important oil crop that can be found in four tropical regions of the world (Sundu and Dingle, 2005): Africa, Southeast Asia, Latin America and the South Pacific. Palm oil and palm kernel oil are the major products of the oil palm industry.

Palm kernel cake (PKC) is a by-product of palm kernel oil processing, and is generated after the oil has been extracted from palm kernels. PKC is also known as palm kernel meal and palm kernel expeller. However, Okeudo et al. (2005) defined PKC as the by-product of mechanical expression of palm kernel oil while palm kernel meal is the solvent-extracted by-product. The mechanical expeller method and the solvent (hexane) extraction method are the most commonly used procedures in the palm oil industry to extract oil, though solvent extraction process is elusive, owing to a high cost of production (Sue and Teoh, 1985; Awaludin, 2001; Alimon, 2004). Henceforth, PKC is defined as the by-product generated after oil has been extracted by the mechanical expeller method from palm kernels.

2.1.2 PKC as an Animal Feed

PKC has been used as a feed for ruminants (cattle, sheep) and non-ruminants (pigs, poultry, fish). The incorporation level is different for ruminants and non-ruminants (Table 2.1). The use of PKC in animal feed was first reported in 1915 for the cattle feed (Anonymous, 1915). Since then, many studies have been conducted to test the incorporation of PKC for ruminants and non-ruminants. An understanding of the composition and chemical nature of PKC is vital for enhancing the inclusion level of PKC in the diet of ruminants and non-ruminants. Hence, a considerable amount of researches have been conducted to examine the properties of PKC. The analyzed nutritional and antinutritional properties described by various authors are reviewed in the next section.

2.1.3 The Composition of PKC

2.1.3.1 Proximate Composition

Studies on the proximate composition of PKC are summarized in table 2.2. It is evident that the variability of the data from different sources is high. The chemical constituents and quality of PKC vary widely according to the degree of oil extracted from palm kernels (Sundu and Dingle, 2005), the nature of the raw materials (Akpanabiatu et al., 2001), storage conditions and the amount of shell materials removed.

PKC has been reported to contain a mediocre amount of protein (8 - 20%) compared to other common feed sources (Balogun, 1982; Düsterhöft and Voragen, 1991; Chin, 2001)

Table 2.1: Inclusion levels of PKC in ruminants and non-ruminants feed

Animal	Inclusion level	Authors
Ruminants		
Cattle	60%	Umunna et al., 1980
Feedlot cattle	100%	Zahari and Alimon, 2004
Dairy cattle	30% - 50%	Zahari and Alimon, 2004
Sheep	30%	Zahari and Alimon, 2004
Goat	50%	Zahari and Alimon, 2004
Non-ruminants		
Pig	20 - 25%	Saad et al., 1997; Ng and Chong, 2002; Zahari and Alimon, 2004
	20% - 30%	Siew, 1989
	30%	Adesehinwa, 2007
	34.5%	Okai et al., 2006
Poultry	5%	Ojewola and Ozuo, 2006
	20%	Saad et al., 1997; Ng and Chong, 2002; Zahari and Alimon, 2004
Layers	25%	Zahari and Alimon, 2004
Rabbit	30%	Orunmuyi et al., 2006
Duck	30%	Zahari and Alimon, 2004
Red hybrid tilapia	20%	Ng et al., 2002; Zahari and Alimon, 2004
O. mossambicus	30%	Lim et al., 2001
Cat fish	30%	Zahari and Alimon, 2004
Fish	30%	Saad et al., 1997; Ng and Chong, 2002

It is not as rich in protein as fish meal. Further, hexane-extracted PKC has a higher protein concentration than PKC derived via the mechanical method (Akpanabiatu et al., 2001). However, Chin (2001) mentioned that there was no significant difference in the crude protein contents of solvent-extracted PKC and the mechanically expeller-pressed PKC. Nevertheless, the fat and ash percentages are lower in solvent-extracted PKC than in the mechanically expeller-pressed PKC, as the solvent extraction method removes more oil from palm kernel, thus comparatively concentrating the other available nutrients (Ezieshi and Olomu, 2007).

Although the quality of PKC is expressed in terms of crude protein, the actual nutritive value of the protein should determined by comparing the amino acid contents in PKC with the essential amino acid profile required by a consumer. If the tested amino acid profile is proximate to the essential amino acid contents, then the feed is considered to be a good protein source. Further, crude protein usually includes non-protein nitrogen which is contributed by nucleic acid components without any nutritive value (Iluyemi et al., 2006). Therefore, for a better understanding of protein quality, the individual amino acid contents must express instead of crude protein contents.

PKC contains a negligible amount (1 g/kg) of starch (Düsterhöft and Voragen, 1991). Crude fiber contents in PKC have been reported to be in the range of 12% to 18% which is relatively high compared to other oil cakes (Awaludin, 2001). Crude fiber refers to the cellulose and lignin contents of a measured commodity (Joslyn, 1970). The amount of crude fiber represents only a part of indigestible matter in PKC. Ezieshi and Olomu (2007) claimed that crude fiber contents are higher in mechanically expeller-pressed PKC (17.96%) than in solvent-extracted PKC.

Table 2.2: A summary on proximate composition and chemical compounds of PKC

Components	Value (%)	Authors
Moisture	9.00 - 58.92	Onuora & King, 1985; Sue & Teoh, 1985; Rhule, 1996; Akpanabiatu et al., 2001; Lim et al., 2001; Ng, 2004; Kolade et al., 2005; Adesehinwa, 2007; Ezieshi & Olomu, 2007
Dry matter	87.50 - 94.50	Babatunde et al., 1975; Kuan et al., 1982; Jaafar & Hamali, 1989; Siew, 1989; Mustaffa et al., 1991; Agunbiade et al., 1999; O'Mara et al., 1999; Perez et al., 1999; Awaludin, 2001; Chin, 2001; Alimon, 2004; Orunmuyi et al., 2006; Gill & Hill, 2008
Carbohydrate	41.20 - 62.00	Onuora & King, 1985; Sue & Teoh, 1985; Gill & Hill, 2008
Crude fiber	6.02 - 24.90	Babatunde et al., 1975; Umunna et al., 1980; Balogun, 1982; Kuan et al., 1982; Onuora & King, 1985; Sue & Teoh, 1985; Jaafar & Hamali, 1989; Siew, 1989; Mustaffa et al., 1991; Rhule, 1996; Agunbiade et al., 1999; O'Mara et al., 1999; Perez et al., 1999; Akpanabiatu et al., 2001; Awaludin, 2001; Chin, 2001; Lim et al., 2001; Alimon, 2004; Ng, 2004; Marini et al., 2005; Orunmuyi et al., 2006; Adesehinwa, 2007; Ezieshi & Olomu, 2007; Gill & Hill, 2008
Crude fat	6.39 - 13.42	Balogun, 1982; Sue & Teoh, 1985; Lim et al., 2001; Ng, 2004; Ezieshi & Olomu, 2007; Gill & Hill, 2008
Ash	2.90 - 12.00	Umunna et al., 1980; Kuan et al., 1982; Balogun, 1982; Onuora & King, 1985; Sue & Teoh, 1985; Jaafar & Hamali, 1989; Siew, 1989; Mustaffa et al., 1991; Rhule, 1996; Agunbiade et al., 1999; O'Mara et al., 1999; Perez et al., 1999; Akpanabiatu et al., 2001; Awaludin, 2001; Chin, 2001; Lim et al., 2001; Alimon, 2004; Ng, 2004; Orunmuyi et al., 2006; Adesehinwa, 2007; Ezieshi & Olomu, 2007
Crude protein	7.70 - 20.30	Lyman et al., 1956, 1958; Babatunde et al., 1975; Umunna et al., 1980; Balogun, 1982; Kuan et al., 1982; Onuora & King, 1985; Sue & Teoh, 1985; Jaafar & Hamali, 1989; Siew, 1989; Mustaffa et al., 1991; Düsterhöft et al., 1992; Rhule, 1996; Agunbiade et al., 1999; O'Mara et al., 1999; Perez et al., 1999; Akpanabiatu et al., 2001; Awaludin, 2001; Chin, 2001; Lim et al., 2001; Omoregie, 2001; Alimon, 2004; Atil, 2004; Ng, 2004; Marini et al., 2005; Illuyemi et al., 2006; Orunmuyi et al., 2006; Adesehinwa, 2007; Ezieshi & Olomu, 2007; Gill & Hill, 2008; Sekoni et al., 2008
Nitrogen Free Extract	46.70 - 63.50	Balogun, 1982; Kuan et al., 1982; Jaafar & Hamali, 1989; Siew, 1989; Awaludin, 2001; Chin, 2001; Lim et al., 2001; Alimon, 2004; Ng, 2004; Orunmuyi et al., 2006; Ezieshi & Olomu, 2007
Reducing Sugars	0.29	Ng et al., 2002
NSP	46.60 - 50.00	Düsterhöft & Voragen, 1991; Knudsen, 1997
Ether extract	0.80 - 19.50	Babatunde et al., 1975; Umunna et al., 1980; Kuan et al., 1982; Onuora & King, 1985; Jaafar & Hamali, 1989; Siew, 1989; Mustaffa et al., 1991; Rhule, 1996; Agunbiade et al., 1999; O'Mara et al., 1999; Perez et al., 1999; Awaludin, 2001; Chin, 2001; Alimon, 2004; Orunmuyi et al., 2006; Adesehinwa, 2007

Nitrogen-free extract (NFE) represents the soluble carbohydrate in a diet (Sekoni et al., 2008). According to table 2.2, the total carbohydrate contents, the NFE portion and the non-starch polysaccharide (NSP) amount fluctuates around 50%; hence, the proximate analysis of PKC is not giving the actual valuation of the distribution of carbohydrate, NSP, and NFE.

Although PKC is considered as a good source of protein for ruminants and non-ruminants, the availability of protein and digestibility of the feed plays a vital role. As discussed in the preceding section, substitution of PKC in non-ruminant feed is generally limited to 30%, beyond which there will be a growth reduction (Ng et al., 2002; Zahari and Alimon, 2004). Ruminants can digest PKC via their gut microflora, but non-ruminants are not capable of such a process. Siew (1989) mentioned that the difficulties in digestion for non-ruminant may be due to the fiber contents and grittiness of PKC. Hence, to improve the amount of PKC inclusion and nutrients availability, the indigestible matter must be converted to a digestible form. The indigestible portion mainly consists of NSP, or fiber. NSPs in PKC consist mostly of hemicellulose (mannan and xylan) and cellulose. Lignin contents also play a vital role in digestion. Therefore a detailed analysis, rather than a mere measurement of the crude fiber amount is necessary for an understanding of the fiber contents of PKC which will be a critical factor for the improvement of PKC as a feed and food ingredient.

2.1.3.2 Dietary Fiber Contents

The term "dietary fiber" encompasses many polymers such as cellulose, hemicellulose, pectin, and lignin that are not digestible by human digestive system (Sundu and Dingle, 2005). Hemicellulose portion is constituted mainly of mannan and xylan. The dietary fiber content of PKC is summarized in table 2.3.

Table 2.3: A summary of fiber contents in PKC

Hemicellulose (%)		Cellulose (%)	Lignin (%)	Authors
Mannan	Xylan			
57.80	3.70	11.60	-	Ong et al., 2004
37.03		27.86	-	Iluyemi et al., 2006
-	-	7.30	13.60	Knudsen, 1997
34.80	2.40	7.20	-	Daud and Jarvis, 1992
-	-	-	18.09	O'Mara et al., 1999
39.00	1.50	6.00	12.00	Düsterhöft et al., 1992

Some authors have analyzed the acid and neutral detergent fiber contents which were 31.00 - 54.33% and 66.40 - 80.11%, respectively (Agunbiade et al., 1999; O'Mara et al., 1999; Chin, 2001; Alimon, 2004; Marini et al., 2005); these values are important for animal nutrition. Joslyn (1970) performed a detailed sugar contents analysis for the insoluble and soluble NSP (Table 2.4). According to the study, the most of NSP in PKC are insoluble and represent almost 50% of the total weight of PKC [Alimon (2004), Palm kernel cell walls are made up of cellulose, hemicellulose, lignin and pectin substances].

Table 2.4: Sugar contents of soluble and insoluble NSP in PKC

Sugar	Insoluble NSP (%)	Soluble NSP (%)
Arabinose	0.9	0.3
Galactose	1.2	0.3
Glucose	0.4	0.3
Mannose	29.3	1.6
Uronic acid	1.2	0.7
Xylose	3.1	-

Source: (Knudsen, 1997)

As mentioned earlier, the inclusion levels of PKC in animal feed were impaired mainly by the fiber contents or fibrous nature of the feed. PKC is not a good feed source for weaners due to its fibrous nature and low digestibility (Babatunde et al., 1975). The limits of incorporation of PKC into fish diets were also low due to its low protein contents and the presence of a high level of NSP in PKC cell wall materials (Ng et al., 2002). Agunbiade et al. (1999) mentioned, the limitation of PKC is a consequence of its fibrous nature and the decrease in digestibility may be due to a high fiber level of palm kernel products. Moreover, a high dietary fiber, grittiness (Sekoni et al., 2008) and low digestibility of protein (Balogun, 1982) have precluded the inclusion of PKC in broiler diets. Sekoni et al. (2008) claimed that PKC is inferior in quality compared to concentrated conophor seed meal, soybean meal, and groundnut cake.

It is patently clear from the above-mentioned studies that NSP contents can be considered as the limiting factor for PKC inclusion in non-ruminant diets. NSPs are known to impair the digestion and utilization of nutrients present in PKC by increasing the viscosity of the intestinal contents, thus reducing the rate of hydrolysis and the absorption of nutrients (Ng et al., 2002). On the contrary, galactomannan or mannan in PKC has a low water absorption capacity and thus may not greatly contribute to the viscosity (Sundu and Dingle, 2005). Further, Perez et al. (1999) indicated that high dietary fiber contents can provoke slogging of intestinal epithelial cells, causing an increase in mucosal secretion into the intestine which leads to a loss of endogenous amino acids. The indigestible property of dietary fiber originates from the β-glucosidase linkage that makes up 90% of the linkages in dietary fiber (Sundu and Dingle, 2005). Ruminants are able to cleave this linkage, but monogastric animals or non-ruminants are incapable of that. Therefore, NSP must be broken down to small fragments to ease the digestion for non-ruminants.

PKC galactomannan is a hard, crystalline, and has a high mannose: galactose ratio (Sundu and Dingle, 2005). It is possible to increase the linkage between galactomannan and cellulose with decreased galactose contents (Whitney et al., 1998). Therefore, PKC galactomannan also has a considerable amount of linkage with cellulose. This property of galactomannan may be the reason that the commercially available enzyme can only hydrolyze a limited amount of mannan in PKC (Zahari and Alimon, 2004).

Solid-state fermentation of raw PKC with *Aspergillus flavus* increases the crude protein contents of the final product to 22.3% from the initial protein contents of 16.5% (Lim et al., 2001). This suggests that a nexus exists between protein and lignocellulosic fiber in PKC, and when the links are degraded, protein content is increased.

As stated earlier, NSP contents in PKC is an antinutritional factor that hinders the digestibility and palatability of the feed. To reduce the antinutritional effect of the NSP, degradation of these components would be desirable. Extensive studies on the degradation of NSP into oligomers have been carried out with enzymes such as mannase, cellulase and xylanase. The digestibility of NSP can be further improved using several degrading enzymes simultaneously (Sundu and Dingle, 2005). Therefore, a thorough understanding of the chemical composition of the NSP contents in PKC is necessary to allow selection of an appropriate combination of enzymes that can cleave PKC mannan or galactomannan efficiently. The stereochemistry and molecular structure of the polymers must be explored to allow for its enzymatic degradation, which would make PKC a highly desirable component of animal feed as well as human food.

2.1.3.3 Protein and Amino Acid Contents

PKC contains 19% protein which classifies it as a medium-protein feed (Balogun, 1982). Studies on the amino acid contents of PKC have been carried out by some authors with contradictory results. Amino acid availabilities in PKC have been reported as 85% (Nwokolo et al., 1976), 74.4% (Rhule, 1996), 67.85% (Yeong et al., 1983), and 65% (Mustafa et al., 2004). A similar variation was also observed for the composition of amino acids. Lysine appears to be the first limiting amino acid for animals, followed by the sulfur-contain amino acids (methionine and cysteine) and tryptophan (Agunbiade et al., 1999; Alimon, 2004). PKC has been reported to be lacking in methionine and lysine (Siew, 1989; Rhule, 1996; Ng, 2004; Sundu and Dingle, 2005), deficient in lysine and threonine (Carvalho et al., 2006) and deficient in lysine, leucine, threonine and phenylalanine compared to the other protein concentrates used in feed for farm animals (Babatunde et al., 1975). In contrast, other studies have stated that PKC is a rich source of protein with methionine (Lyman et al., 1956; Agunbiade et al., 1999; Carvalho et al., 2006). A summary of the studies on the amino acid contents of PKC is presented in table 2.5. Researches on PKC have been mainly focused on animal feeds, and included analysis and amino acid contents as related to animal nutrition. Various studies on the addition of PKC to feed for ruminants and non-ruminants have produced belie findings. One study concluded that PKC is not a good feed source for pigs (Babatunde et al., 1975). Relatively low levels of essential amino acids (lysine and methionine), high dietary fiber and grittiness in PKC have reduced its level of inclusion in broiler diets (Sekoni et al., 2008). It has also been suggested that PKC is not a good protein source in compound feed for ruminants and non-ruminants (Adesehinwa, 2007). Another study noted that higher inclusion levels of PKC showed a decreasing trend in lysine contents (Rhule, 1996; Adesehinwa, 2007). It has been proposed that the addition of sulfur-contain amino acids and lysine would enhance the nutritive value of PKC used for poultry feed, compensating for its lack of essential amino acids and a high amount of arginine (Sundu and Dingle, 2005).

Table 2.5: A summary of amino acid contents in PKC (mg/g protein)

Amino acid	Contents	Authors
Alanine	35.55 - 42.26	Babatunde et al., 1975; Cheah et al., 1989; Perez et al., 1999; Alimon, 2004; Illuyemi et al., 2006
Aspartic acid	36.30 - 102.29	
Glutamic acid	157.73 - 218.20	
Proline	26.25 - 37.80	
Valine	28.44 - 54.00	Lyman et al., 1956, 1958; Babatunde et al., 1975; Cheah et al., 1989; Siew, 1989; Sreedhara and Kurup, 1998; Perez et al., 1999; Alimon, 2004; Illuyemi et al., 2006
Threonine	21.33 - 37.88	
Histidine	4.37 - 23.40	
Isoleucine	32.20 - 50.87	
Leucine	60.70 - 125.82	
Lysine	9.84 - 37.11	
Methionine	16.95 - 21.39	
Phenylalanine	26.80 - 43.00	
Arginine	48.68 - 149.00	
Serine	35.05 - 53.10	Babatunde et al., 1975; Siew, 1989; Perez et al., 1999; Alimon, 2004; Illuyemi et al., 2006
Glycine	38.84 - 50.31	
Tyrosine	18.59 - 29.80	
Tryptophan	7.21 - 12.42	Lyman et al., 1956, 1958; Babatunde et al., 1975; Siew, 1989; Sreedhara and Kurup, 1998; Perez et al., 1999
Cysteine	7.65 - 17.39	Babatunde et al., 1975; Cheah et al., 1989; Siew, 1989; Perez et al., 1999; Alimon, 2004; Illuyemi et al., 2006

In contrast to the above findings, Nwokolo et al. (1976) reported that all the essential amino acids are present in PKC; they also indicated that amino acid availability is higher than 85%, except for valine which is available at 68.4%. Nevertheless, PKC has been named as a high-energy diet due to its high quality protein contents and high fiber contents (Siew, 1989). A few authors have also suggested that PKC contains high quality amino acids (Cornelius, 1966; Umunna, et al., 1980; Omoregie, 2001; Atill, 2004), and is also a good source of protein (Alimon, 2004).

The availability of amino acid contents is affected by the palm kernel oil extraction process and the antagonistic effect of some amino acids. The availability of protein is reduced due to the heat that generates from the processing of palm kernel oil (Sundu and Dingle, 2005). Further, browning (which can be caused by the heat generated in the screw press) in commercial PKC can seriously affect its nutritional value, particularly with regard to amino acids such as lysine, cysteine, and methionine (Cornelius, 1966). Browning may be the result of a Maillard reaction that takes place when the sugar and amino acids interact at high temperatures and at relatively low water activity.

Antagonistic effects are mainly seen between arginine and lysine (Sundu and Dingle, 2005), especially when low levels (0.5 - 2.0%) of lysine are present (James et al., 1967). When the arginine contents are high in a feed, lysine has to be supplied to keep the correct ratio between arginine and lysine, or the availability of lysine will be reduced. The authors (James et al., 1967) also mentioned that PKC has a high amount of arginine; as a result the lysine in PKC may be affected by the arginine contents. Therefore, to make PKC a high quality protein feed or food, browning and antagonistic effects should be minimized.

2.1.3.4 Mineral Contents

PKC contains 0.6 - 28.9 mg/kg of copper (Table 2.6). The excess usage (90%) of PKC in sheep feed causes copper toxicity because the dietary requirement of copper for sheep is only 4 - 6 mg/kg (Hair-Bejo and Alimon, 1995). The authors speculated that high contents of copper in PKC are probably due to the contamination that occurred during the oil extraction process. The most probable step for contamination will be at the pressing of palm kernel where a screw press is used.

Table 2.6: A summary of mineral contents in PKC

Mineral	Quantity (mg/kg)	Authors
Ca	2000 - 3400	Babatunde et al., 1975; Jaafar and Hamali, 1989; Siew, 1989; Mustaffa et al., 1991; Akpanabiatu et al., 2001; Awaludin, 2001; Chin, 2001; Alimon, 2004
Cu	0.60 - 28.90	Jaafar and Hamali, 1989; Siew, 1989; Hair-Bejo and Alimon, 1995; Akpanabiatu et al., 2001; Chin, 2001; Alimon, 2004; Akpan et al., 2005; Gill and Hill, 2008
Fe	4.05 - 6130	Siew, 1989; Akpanabiatu et al., 2001; Alimon, 2004
K	1900 - 9300	Akpanabiatu et al., 2001; Alimon, 2004; Kolade et al., 2005
Mg	100 - 5000	Jaafar and Hamali, 1989; Siew, 1989; Akpanabiatu et al., 2001; Alimon, 2004; Gill and Hill, 2008
Mn	17.10 - 520	Jaafar and Hamali, 1989; Siew, 1989; Akpanabiatu et al., 2001; Alimon, 2004
Mo	7000 - 7900	Alimon, 2004
Na	1200	Akpanabiatu et al., 2001
P	4100 - 7900	Babatunde et al., 1975; Jaafar and Hamali, 1989; Siew, 1989; Mustaffa et al., 1991; Akpanabiatu et al., 2001; Awaludin, 2001; Chin, 2001; Alimon, 2004; Kolade et al., 2005
S	1900 - 2300	Akpanabiatu et al., 2001; Alimon, 2004
Se	0.23 - 0.30	Alimon, 2004; Gill and Hill, 2008
Zn	3.70 - 340	Jaafar and Hamali, 1989; Siew, 1989; Akpanabiatu et al., 2001; Alimon, 2004; Akpan et al., 2005; Gill and Hill, 2008

Another important mineral-related parameter in PKC is the Ca: P ratio. The Ca: P ratio in PKC is adequate for beef cattle fattening, but not enough for high-producing dairy cattle. Therefore, the use of PKC as a whole feed requires a supplementation with minerals (Awaludin, 2001). Further, special attention needs to be given to