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ARTICLE

Quality of Frozen Pork from Pigs Fed Diets Containing Palm Kernel Meal as an Alternative to Corn Meal

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Abstract

The objective of this study was to evaluate the effect of different levels of palm kernel meal (PKM), an alternative to corn, on the quality of pork. A total of 72 crossbred pigs ([Yorkshire × Landrace] × Duroc) were assigned into four dietary treatments (PKM level of 0, 4, 8, or 12%). After 12 wk, one pig of median weight in each pen was selected and slaughtered to analyze meat quality. The color, free radical scavenging activity, lipid oxidation, texture, composition of fatty acids, and sensory qualities of pork loin were evaluated post slaughter. When the levels of PKM in the diet increased, the *L**-value of pork loin decreased, whereas *a**-value and total saturated fatty acids increased. 2-Thiobarbituric acid reactive substance (TBARS) values of pork loin were lower in groups treated with 8 and 12% PKM than in the control group at day 0; this difference, however, was not observed at day 3 and 7. The results of texture analysis showed that increasing the PKM ratio decreased hardness, chewiness, and springiness at day 7. The sensory test, however, indicated no differences between the control and treated groups. These findings show that finisher pigs could tolerate PKM as a replacement for corn; PKM did not negatively affect the quality of pork, indicating that it can be utilized as feed.

Keywords diet, meat quality, palm kernel meal, pork

Introduction

In recent years, the price of grains has increased worldwide. The cost of corn, which is a major component of animal feed, increased owing to the large demand for bio-ethanol and bio-fuel (De Gorter *et al*., 2013). Feed costs account for 65% to 75% of pig production expenses and significantly impact profitability of pork producers; therefore, producing alternative sources of feed is important (Choi *et al*., 2015).

Copra meal, a byproduct of oil extraction from dried coconut kernels (copra), has been investigated as an alternative to corn (Sulabo *et al*., 2013). Copra meal has high levels of arginine and residual oil composed of short chain saturated fatty acids. However, it is deficient in threonine, histidine, methionine, and lysine, which is a disadvantage. Therefore, effective alternatives are needed to replace corn in the feed industry.

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Palm kernel meal (PKM) is a by-product of palm oil production. As the amount of palm oil in the market has increased, production of PKM has also increased annually. Because of its competitive price, sufficient nutrient content, and wide availability, PKM is one of the most effective alternatives to wheat middlings in poultry diets (Perez *et al*., 2000). PKM has antioxidant potential, as well as anticancer effects and other important health benefits (Ofori-Boateng and Lee, 2013). Using PKM in pig diets is more cost efficient than employing diets containing maize, and feeding costs incurred per day are lower when pigs are fed 100% PKM compared with 50% PKM (Adesehinwa, 2007).

Despite the benefits of feeding PKM, its high content of indigestible fiber (a form of β-mannan) can decrease its digestibility in pigs (Sundu *et al*., 2006); this problem was solved by supplementing with 0.1% β-mannanase (Ao *et al*., 2011). Oluwafemi (2015) reported that with enzyme supplementation, finisher pigs could accept PKM at an inclusion level of up to 60% as replacement for maize without any negative effect on their growth performance.

However, limited studies are available on the effects of PKM on quality of pork. To adopt the feeding of PKM in the industry, swine growth performance and carcass characteristics, as well as quality of pork, should be evaluated. Thus, the objective of this study was to evaluate the quality of pork from pig fed a diet containing up to 12% PKM and to examine other factors, including increase in antioxidant potential of pork, in pigs fed this alternative source of energy.

Materials and Methods

Experimental design and diet

For the present experiment, a total of 72 crossbred pigs ([Yorkshire × Landrace] × Duroc), with an average body weight of 30.5±3.04 kg, were grown at a university experimental farm in Chonnam, Korea. There were 3 replicate pens per treatment, and the 6 pigs were grouped per pen using randomized complete block design. Treatments contained 0, 4, 8, or 12% of PKM with 0.1% β-mannanase added to each treatment to aid digestion (Ao *et al*., 2011). The main diet ingredients were corn and soybean meal. The amount of corn and soybean in the diets were adjusted with respect to the levels of PKM. Experimental diet was formulated for 4 phases: early growing (0-3 wk), late growing (4-6 wk), early finishing (7-9 wk), and late finishing period (10-12 wk). All phases were adjusted to the same metabolizable energy (ME) at 3295.0 kcal/kg. All levels of nutrients met or exceeded the requirements of the National Research Council issued at 1998. Pigs were raised in growing-finishing facilities for 12 weeks, and then one pig of median weight in each pen was selected. Therefore, totally 12 pigs (3 replicate for 4 treatments) were transported for 1 h to a commercial slaughter facility. The loading and unloading was conducted as parallel to the ground as possible. After being rested for approximately 12 h at the lairage facility, the pigs were slaughtered. The loin was removed from each carcass the next day, vacuum-packaged, and stored in a deep freezer at -70ºC until analysis. The frozen pork loins were thawed for 48 h in a refrigerator at 4ºC until analysis. The samples were analyzed for color, 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity, lipid oxidation, and texture analysis, and subjected to sensory evaluation.

Instrumental color measurement

Surface color values (International Commission on Illumination L^*, a^*, and b^* values representing lightness, redness, and yellowness, respectively) of the loin samples were measured using a colorimeter (CR-5, Minolta Camera Co., Japan). The colorimeter was calibrated using a standard black and white plate before analysis. The mean of three measurements taken at different locations was recorded for each sample.

DPPH radical scavenging activity

To assess free radical scavenging activity, loin samples (3 g) were homogenized with 15 mL of DW for 30 s and centrifuged at 2,149 g for 10 min. Then 800 μL of DW was added to the homogenates, followed by addition of 1 mL 0.2 mM DPPH in methanol. The mixture was shaken using a vortexer and incubated in the dark at 25ºC for 30 min. The absorbances of the homogenates and the blank were measured at 517 nm using a spectrophotometer (X-ma 3100, Human Co. Ltd., Korea). DPPH radical scavenging activity (%) was calculated using the following equation:

DPPH radical scavenging activity = [1-(absorbance of sample / absorbance of control)] × 100

Measurement of lipid oxidation

Lipid oxidation was determined by measuring 2-thio-

barbituric acid reactive substances (TBARS). Each pork loin (5 g) was homogenized with 15 mL DW and 50 μL butylated hydroxyl toluene in ethanol. The homogenates (2 mL) were transferred to 15 mL test tubes and mixed with 4 mL 2-thiobarbituric acid (TBA) and trichloroacetic acid (20 mM TBA in 15% trichloroacetic acid). The tubes were heated in a water bath at 90ºC for 30 min, cooled, and centrifuged (HM-150IV, Hanil Co. Ltd., Korea) at 2,149 g for 10 min. The absorbance of the supernatants was measured at 532 nm using a spectrophotometer (X-ma 3100). TBARS values were expressed as mg malondialdehyde/kg sample.

Fatty acid composition

Lipids in the loin samples (5 g) were extracted using 100 mL chloroform/methanol (2:1, v/v) according to the procedure used by Folch *et al*. (1957). After adding 0.88% NaCl, lipid samples were thoroughly mixed. After phase separation, the upper layer was removed and the remaining organic layer was dried under nitrogen flow. Extracted lipids were mixed with 2 mL of BF_3-methanol (14%, w/w) then heated in a water bath at 85°C for 10 min. After cooling, 2 mL hexane and 5 mL DW were added to the samples and centrifuged (Hanil Co. Ltd.) at 2,149 g for 10 min. Then, the top layer of hexane containing fatty acid methyl esters was transferred to vials and separated using a gas chromatograph (HP 7890, Agilent Technologies, USA). A split inlet (split ratio, 50:1) was used to inject the samples into a capillary column (SP^{TM} 2560 capillary column, Supelco, USA) at film thickness of 100 m × 0.25 mm × 0.20 μm and at ramped oven temperature (100°C for 5 min, increased to 240°C at 4°C/min, and maintained for 20 min). Inlet temperature was 225°C. N_2 was served as the carrier gas at a constant flow rate of 20 mL/min.

Texture profile analysis

Pork loin patties (4 cm in diameter, 2 cm in thickness, and 20 g in weight) were prepared separately, using samples of minced meat, and cooked in a water bath to an internal temperature of 75ºC. The centers of cooked loin samples were compressed twice to 75% of their original height using a texture analyzer (LLOYD, Ametek Lloyd Instruments Ltd., UK) attached to a round needle-type probe (75 mm of diameter) at test speed of 2.00 mm/s and trigger force of 1 N. The measured and recorded parameters were: hardness (N), adhesiveness (Nmm), chewiness (Nmm), and springiness (mm).

Sensory evaluation

Loin samples were cut into pieces of similar size (1 × 3 × 0.5 cm^3) in a raw state, and then cooked to an internal temperature of 75ºC using a pan. Ten panelists, having at least 1 year of experience in analyzing meat quality in sensory evaluations, evaluated the samples. Sensory parameters, including color, flavor, taste, tenderness, and overall acceptability, were evaluated using a 9-point Hedonic scale, where 9 indicates “extremely like” and 1 indicates “extremely dislike.” Off-odor was assessed as follows: 9, very strong; and 1, no off-odor.

Statistical analysis

All experiments were conducted in triplicate using a pen as experimental unit and pigs as observational units. Data analysis was performed by a one-way analysis of variance (ANOVA), and significant differences between mean values were determined by Duncan multiple-range test using SAS software (SAS, Release 9.4, SAS Institute Inc., USA) at a significance level of $p<0.05$. Data are presented as means±SEM; $p<0.05$ was considered statistically significant.

Results and Discussion

Color

The color of the meat is an important trait that primarily influences meat-purchasing decisions of the consumers; the state of meat color is often considered an indicator of freshness (Mancini and Hunt, 2005). The change in the color of pork from pigs fed diets containing different levels of PKM is shown in Table 1. The *L**-value of the control was higher than those of PKM-treated groups. The *a**-value of the control was lower than that of the group fed 12% PKM at storage day 0, and those of groups fed 8 and 12% PKM at storage day 3. However, there were no differences in *a**- and *b**-values between the control and treated groups regardless the storage day goes except for the group fed 4% PKM. Previously, Ao *et al*. (2011) reported that supplementing a diet containing 5% palm kernel meal with 0, 0.1 or 0.2% carbohydrase cocktail did not influence the color of pork (*L**-, *a**-, and *b**-values).

Barbut (1993) showed a significant negative correlation between *L**-value of the meat and pH of the muscle. In this study, the pH of the control sample was higher than those of PKM-treated groups for which the average value was 5.72 (data not shown). Increased pH influences water holding capacity (WHC) of meat and reduces available

Table 1. Color changes in pork from pigs fed diets containing palm kernel meal

Level of palm kernel meal (%)	Storage (d)			SEM[1)]
	0	3	7	
	*L**-value			
0	55.00^{ay}	55.53^{ay}	57.98^{ax}	0.379
4	51.66^{b}	52.14^{b}	52.62^{b}	0.858
8	50.84^{b}	52.11^{b}	53.45^{b}	0.856
12	51.30^{b}	51.56^{b}	52.72^{b}	0.994
SEM[2)]	0.675	0.557	1.089	
	*a**-value			
0	6.40^{b}	7.43^{b}	8.30	0.345
4	6.29^{by}	7.44^{bxy}	8.23^{x}	0.427
8	7.56^{ab}	9.11^{a}	8.19	0.843
12	9.68^{a}	9.03^{a}	8.71	0.319
SEM	0.844	0.454	0.372	
	*b**-value			
0	17.26	17.07	18.02	0.459
4	16.55	17.09	17.49	0.295
8	16.72	16.91	17.80	0.334
12	16.91	16.98	17.68	0.318
SEM	0.411	0.223	0.407	

[1)]Standard error of the means (n=9). [2)](n=12).
[a,b]Values with different letters within the same column differ significantly (p<0.05).
[x,y]Values with different letters within the same row differ significantly (p<0.05).

Table 2. 1, 1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity (%) of pork from pigs fed diets containing palm kernel meal

Level of palm kernel meal (%)	Storage (d)			SEM[1)]
	0	3	7	
0	25.13^{x}	24.35^{x}	22.16^{aby}	0.538
4	25.09^{x}	23.85^{y}	22.65^{az}	0.336
8	25.07^{x}	23.47^{y}	22.05^{abz}	0.271
12	25.09^{x}	23.77^{y}	21.40^{bz}	0.368
SEM[2)]	0.415	0.401	0.355	

[1)]Standard error of the means (n=9). [2)](n=12).
[a,b]Values with different letters within the same column differ significantly (p<0.05).
[x-z]Values with different letters within the same row differ significantly (p<0.05).

Table 3. 2-thiobarbituric acid reactive substances (TBARS) values (mg malondialdehyde/kg meat) of pork from pigs fed diets containing palm kernel meal

Level of palm kernel meal (%)	Storage (d)			SEM[1)]
	0	3	7	
0	0.33^{ay}	0.50^{x}	0.34^{y}	0.015
4	0.32^{aby}	0.49^{x}	0.37^{y}	0.024
8	0.30^{bz}	0.48^{x}	0.34^{y}	0.009
12	0.30^{bz}	0.48^{x}	0.32^{y}	0.008
SEM[2)]	0.012	0.016	0.017	

[1)]Standard error of the means (n=9). [2)](n=12).
[a,b]Values with different letters within the same column differ significantly (p<0.05).
[x-z]Values with different letters within the same row differ significantly (p<0.05).

water on the surface of the meat; therefore, light reflection and *L**-values may be decreased, as shown by the data indicating loin color.

Antioxidant supplementation increases *a**-value and extends color stability in raw meat (Higgins *et al*., 1998; McCarthy *et al*., 2001). Ofori-Boateng and Lee (2013) report that PKM has antioxidant potential. Therefore, the higher *a**-values in pork fed 12% PKM may be explained by antioxidant potential of PKM; however, because of the complexity of meat color, we were unable to conclude that diet supplemented with PKM was solely responsible for improved stability of meat color.

DPPH radical scavenging activity

DPPH is one of the most widely used methods to assess antioxidative potential. When DPPH and antioxidant are combined in solution, a hydrogen atom from the antioxidant forms a stable molecule of DPPH-H, causing a color change from violet to pale yellow (Molyneux, 2004). The DPPH radical-scavenging activities of pork from pigs fed diets containing different levels of PKM are shown in Table 2. There were no differences between the control and PKM-treated groups; however, DPPH radical-scavenging activity decreases during storage. We found that PKM level of 4% had higher DPPH-radical scavenging activity than did PKM level of 12% at day 7 of storage.

Polyphenols, carotenoids, sterols, and tocopherols are phytochemicals that are extracted from palm oil by-products. Palm kernel is rich in antioxidants (Zarei *et al*., 2012). According to Lau *et al.* (2008), extracts of palm wastes contain high amounts of tocopherols and carotene. Additionally, polyphenols extracted from palm oil byproducts have antioxidative potential (Neo *et al*., 2008). When the diet of broiler chickens was supplemented with α-lipoic acid and α-tocopherol acetate, DPPH-radical scavenging activity of the treated groups was stronger than that of control groups fed standard feed; this difference may be attributable to the amount of phenolic content (Yasin *et al*., 2012). Raw pork from pigs supplemented with antioxidants, such as vitamin E, showed a significantly higher DPPH scavenging activity than did that from the controls throughout storage (Rajauria *et al*., 2016). Therefore, we hypothesized that pork from pigs fed PKM will have

higher antioxidant activity. However, adding PKM to the diet did not influence radical scavenging activity of pork examined in this study.

TBARS value

Lipid oxidation is one of the main factors responsible for deterioration of meat because it changes the quality of meat, including color, and causes off-flavor and off-odor (Ladikos and Lougovois, 1990). As a secondary product of lipid oxidation, malondialdehyde is the main substance that reacts with TBA reagent. TBARS values of all samples were in a range of 0.28-0.50 (Table 3). At day 0, TBARS value of the control group was higher than those of groups fed PKM at 8 and 12%. However, this difference was not maintained during storage, resulting in no difference in TBARS values between control and treated groups at day 3 and 7. TBARS values of pork loin were highest at day 3 and decreased after storage day 7. Ao *et al*. (2011) showed that supplementing with 5% PKM, combined with a carbohydrase cocktail, did not affect TBARS values in pork loin.

Lipid oxidation affects sensory traits, especially odor and taste. TBARS values over 1 are a marker of sensory rancidity (Limbo *et al*., 2010). In this study, however, all TBARS values were below 1 during the 7 d of storage.

The decrease in TBARS values after 7 d might be partially caused by bacterial metabolism in pork. The decrease in TBARS values occurs when malondialdehyde and other TBARS react with amines produced by bacterial metabolism during storage (Branen, 1987). Similarly, Kim *et al.* (2004) presented that the TBARS losses may occur when the amines produced by bacterial metabolism directly react with malondialdehyde in raw ground pork during storage time.

Antioxidants influence lipid oxidation. Fresh pork, treated with antioxidative natural food and plant extracts, such as rosemary and ginseng, shows minimized lipid oxidation and increased redness (McCarthy *et al*., 2001). Similarly, pork from pigs supplemented with dl-α-tocopheryl-acetate, a recognized antioxidant, shows significantly higher oxidative stability than pork from pigs fed a basal diet (O'Sullivan *et al*., 1998). Lipid oxidation was decreased in raw pork from pigs fed a diet supplemented with olive leaves, which possess antioxidant activity and contain phenol, flavonoids, and α-tocopherol (Botsoglou *et al*., 2012). However, in this study, PKM did not play an antioxidative role despite its proven antioxidative potential (Ofori-Boateng and Lee, 2013).

Fatty acid composition

Total saturated fatty acids (ΣSFA) and palmitic acid (C16:0) were higher in loins from group fed 12% PKM compared with those from control and 4% PKM-treated groups. The levels of polyunsaturated fatty acids (ΣPUFA)

Table 4. Fatty acid composition (%) of pork from pigs fed diets containing palm kernel meal at day 0

	Level of palm kernel meal (%)				SEM[4)]
	0	4	8	12	
C14:0	1.83	2.17	1.87	1.82	0.155
C16:0	22.26^{x}	22.47^{y}	23.55^{xy}	24.08^{x}	0.422
C16:1	4.18	4.11	4.42	4.13	0.298
C18:0	11.48	11.47	11.25	11.51	0.369
C18:1n9c	38.26	38.14	38.02	38.58	0.517
C18:2n6c	12.66	12.41	12.27	11.69	0.492
C18:3n3	0.77	0.68	0.60	0.64	0.012
C18:3n6	0.36	0.35	0.31	0.35	0.039
C20:0	0.18	0.18	0.16	0.15	0.083
C20:1	0.83	0.86	0.74	0.66	0.057
C20:2	0.78	0.71	0.61	0.57	0.067
C20:3n6	1.12	1.14	0.96	0.98	0.087
C20:4n6	3.36	3.41	3.43	3.10	0.095
C22:0	0.82	0.80	0.81	0.78	0.230
C22:6n3	1.11	1.10	1.02	0.95	0.128
ΣSFA[1)]	36.58^{y}	37.09^{y}	37.63^{xy}	38.35^{x}	0.347
ΣMUFA[2)]	43.26	43.11	43.17	43.37	0.425
ΣPUFA[3)]	20.16^{x}	19.80^{xy}	19.20^{xy}	18.28^{y}	0.538

[1)]Saturated fatty acids. [2)]Monounsaturated fatty acids. [3)]Polyunsaturated fatty acids. [4)]Standard error of the means (n=12).
[x,y]Values with different letters within the same row differ significantly (p<0.05).

in pork loin were lower in group treated with 12% PKM compared with those from the control group (Table 4).

Dietary changes affect fatty acid composition in monogastric animals (Larick *et al*., 1992). PKM contains a high concentration of medium chain fatty acids, from C8:0 to C14:0 (Carrión *et al.*, 2011). Hence, the levels of saturated fatty acids in pork loin may be altered by the concentration of medium chain fatty acids in PKM. Ribeiro *et al*. (2011) reported that the concentration of C12:0 (lauric acid) and C14:0 (myristic acid) were increased by the addition of PKM in the muscle of lambs; additionally, there was a linear increase (p<0.05) in C16:0 when PKM levels were increased from 0 to 19.5%.

Dietary supplementation with PKM increases the levels of saturated fatty acids; there are, however, differences in the composition of fatty acids. Contrary to this study, Kim *et al*. (2001) reported that as the amount of PKM in the diet increased, the levels of C14:0 in pork increased, while those of C16:0, total saturated fatty acids, and polyunsaturated fatty acids did not. Pigs fed diets containing palm kernel oil showed high levels of C12:0, C14:0, and C18:0 (stearic acid). Palm oil has high concentrations of C16:0 and C16:1 (palmitoleic acid); therefore, the concentrations of C12:0 and C14:0 were increased in adipose tissue and muscle. However, concentrations of C16:0 and C18:0 in pork are rarely influenced by dietary changes (Teye *et al*., 2006). These results demonstrate that the concentrations of C16:0 and C18:0, internally synthesized in animal, were not affected by dietary supplementation. Conversely, C12:0 and C14:0 are mostly derived from diet and, thus, are affected by dietary changes (Wood *et al*., 2008).

Table 5. Texture-profile analysis of pork from pigs fed diets containing palm kernel meal

Level of palm kernel meal (%)	Storage (d)			SEM[1)]
	0	3	7	
	Hardness (N)			
0	34.19	34.09	36.79^{a}	1.096
4	37.14^{x}	33.15^{xy}	29.98^{by}	1.693
8	33.20	30.38	31.60^{b}	1.220
12	33.23	32.48	32.30^{b}	1.284
SEM[2)]	1.334	1.497	1.176	
	Adhesiveness (Nmm)			
0	0.77^{a}	0.71	0.71	0.057
4	0.60^{b}	0.59	0.64	0.028
8	0.67^{ab}	0.56	0.69	0.035
12	0.60^{b}	0.67	0.66	0.048
SEM	0.032	0.050	0.046	
	Chewiness (Nmm)			
0	11.26	12.09	10.40^{a}	1.605
4	12.65	11.85	8.85^{ab}	1.357
8	9.08^{xy}	10.42^{x}	7.61^{by}	0.636
12	10.05	10.55	7.94^{b}	1.459
SEM	1.481	1.604	0.669	
	Springiness (mm)			
0	0.58	0.45	0.36^{a}	0.118
4	0.45	0.42	0.35^{a}	0.030
8	0.41	0.37	0.33^{ab}	0.031
12	0.40	0.41	0.31^{b}	0.030
SEM	0.104	0.040	0.009	

[1)]Standard error of the means (n=9). [2)](n=12).
[a,b]Values with different letters within the same column differ significantly (p<0.05).
[x,y]Values with different letters within the same row differ significantly (p<0.05).

Texture profile analysis (TPA)

Tenderness of pork is one of the major traits valued by the consumer. In present study, hardness was not changed by diets containing different levels of PKM until storage day 3; however, the hardness of pork from pigs fed 4 and 8% PKM was decreased compared with that of pork from control pigs at day 7. The adhesiveness of pork from pigs fed 4 and 12% PKM was decreased compared with that of pork from control pigs at day 0. Chewiness also showed changes with respect to the level of PKM in the diet. Springiness of pork from pigs fed 12% PKM was decreased compared with that of pork from controls, as well as with that of pork from 4 and 8% PKM-fed pigs at day 7 (Table 5). Overall, pork from pigs fed PKM at over 8% was tenderer compared with that from control pigs at day 7.

Oluwafemi (2015) reported that pork from experimental animals fed different levels of PKM was judged very tender to slightly tender. Ribeiro *et al*. (2011) also showed that adding PKM to the diet leads to a quadratic relationship with tenderness in lamb meat (p<0.05). When broiler chickens were fed PKM fermented by *Paenibacillus polymyxa* ATCC 842, the results of shear force assessment indicated no significant difference in the tenderness of PKM fed broiler chickens compared with that of controls (Alshelmani *et al.,* 2016). Furthermore, adding PKM to the diet of Nellore bulls did not positively or negatively affect meat tenderness (Santana Filho *et al*., 2015). The use of PKM resulted in average weight gain in Nellore bulls; meat from these animals, slaughtered at a similar ages showed similar levels of tenderness.

Generally, when the ratio of saturated fatty acids is predominant, the hardness increases (Banskalieva *et al.*, 2000). Especially, the levels of C18:0 and C18:2 are strongly related to meat hardness (Żak *et al.*, 2001). When compar-

Table 6. Sensory scores of pork from pigs fed diets containing palm kernel meal at day 0

	Level of palm kernel meal (%)				SEM[1)]
	0	4	8	12	
Color	4.65	4.05	4.15	4.30	0.264
Flavor	4.55^{xy}	5.20^{x}	4.10^{y}	4.75^{xy}	0.269
Taste	5.05	5.25	4.55	4.55	0.230
Tenderness	5.45	4.90	5.05	5.40	0.288
Off-odor	2.45	2.75	1.95	2.55	0.370
Acceptability	4.95^{xy}	5.45^{x}	4.65^{y}	4.60^{y}	0.263

[1)]Standard error of the means (n=40).
[x,y]Values with different letters within the same row differ significantly (p<0.05).

ing the relation between fatty acids concentration with hardness of pork, there were no differences in hardness by the concentration of SFA at day 0 in the present study. Only the difference of hardness found at day 7. This means that not only fatty acid composition but other inherent factors, most probably proteins, may influence the texture of pork fed PKM. For example, it is known that a lower pH in meat causes the increase of drip loss. Then, the structure of meat becomes denser and the shear forces could increase (Morel *et al*., 2013; Tartrakoon *et al.*, 2016). In the present study, the pH of the control sample was higher than those of PKM-treated (data not shown).

Sensory evaluation

The sensorial parameters tested in this study showed no differences between control and PKM-treated pigs and were not affected by the levels of PKM at day 0 (Table 6). Pork from pigs fed 4% PKM showed a higher flavor score than that from pigs fed 8% PKM. However, there were no differences between control and PKM-treated groups in taste. Loins from pigs fed 4% PKM showed higher score in overall acceptability than those from pigs fed 8 and 12% PKM. There were no differences between control and PKM-treated groups in overall acceptability. Despite fluctuated differences in the results of sensory evaluation, adding PKM to pig diet appeared to have no adverse effect on the sensory quality of pork loin.

In pigs fed 60% PKM without Hemicell$^{(R)}$ enzyme supplementation, tenderness and flavor of the meat were decreased, whereas juiciness and overall acceptability were increased, compared with pork from pigs fed a basal diet (Oluwafemi, 2015). However, no significant differences in sensory characteristics were found in pork from pigs fed 60% PKM with the addition of the Hemicell$^{(R)}$ enzyme (Oluwafemi, 2015). Ao *et al*. (2011) reported that inclusion of 5% PKM had no effect on sensory qualities including color, marbling, and firmness. In evaluating the use of PKM in diets of sheep and Nellore bulls, Ribeiro *et al*. (2011) and Santana Filho *et al*. (2015) did not observe any effect on sensory traits of meat, respectively. These results agree with this study. Because including PKM in the diet had no impact on sensory qualities, it indicates that pork from PKM-fed pigs will receive the same consumer demand as that from pigs fed a basal diet.

Conclusion

Although the results showed fluctuated in different quality parameters of pork between control and groups fed PKM, there were no negative impacts when feeding up to 12% PKM in the quality of pork. Thus, using PKM with 0.1% β-mannanase as an energy source in swine diet may be an appropriate alternative for pork production because PKM is presently less expensive than corn.

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