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Effect of inclusion level and adaptation duration on digestible energy and nutrient digestibility in palm kernel meal fed to growing-finishing pigs

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Objective: An experiment was conducted to evaluate effects of inclusion level of palm kernel meal (PKM) and adaptation duration on the digestible energy (DE) and apparent total tract digestibility (ATTD) of chemical constituents in diets fed to growing-finishing pigs.
Methods: Thirty crossbred barrows (Duroc×Landrace×Large White) with an average initial body weight of 85.0±2.1 kg were fed 5 diets in a completely randomized design. The diets included a corn-soybean meal basal diet and 4 additional diets in which corn and soybean meal were partly replaced by 10%, 20%, 30%, or 40% PKM. After 7 d of adaptation to the experimental diets, feces were collected from d 8 to 12, d 15 to 19, d 22 to 26, and d 29 to 33, respectively.
Results: The DE and ATTD of gross energy (GE), dry matter (DM), ash, organic matter (OM), neutral detergent fiber (NDF), acid detergent fiber (ADF), and crude protein (CP) in diets decreased linearly as the dietary PKM increased within each adaptation duration ($p<0.01$). Diet containing 19.5% PKM had less DE value and ATTD of all detected items compared with other diets when fed to pigs for 14 days ($p<0.05$). The ATTD of CP in PKM calculated by 19.5% and 39.0% linearly increased as adaptation duration prolonged from 7 to 28 days ($p<0 .01$).
Conclusion: Inclusion level of PKM and adaptation duration had an interactive effect on DE and the ATTD of GE, DM, OM, and CP ($p<0.01$ or 0.05) but ash, NDF, and ADF in diet ($p>0.05$). Considering a stable determination, 21 days of adaptation to a diet containing 19.5% PKM is needed in pigs and a longer adaptation time is recommended as dietary PKM increases.

Keywords: Adaptation Duration; Digestibility; Digestible Energy; Growing-finishing Pig; Inclusion Level; Palm Kernel Meal

INTRODUCTION

Palm kernel meal (PKM) is a by-product after solvent extraction of the oil from the oil palm nut kernels [1]. Compared to conventional feedstuffs, PKM is cost effectiveness and mostly used in broiler and pig's feeds, especial in the tropical regions of the world: Asia, Pacific, South America, and Africa [2]. Some nutritive evaluation studies for PKM have been done on chickens [3,4]. The digestible energy (DE) and metabolizable energy (ME) of PKM on pigs were previously reported by several studies [1,5,6]. However, most of those studies focused on only one substitution rate of PKM in experimental diet. The main limitation for optimum utilization of PKM in non-ruminant animal's feed is the high fiber content in it. The higher substitution rate of evaluated feedstuff, the more accuracy of DE or ME can be get in it according to the difference method [7]. However, the higher level of dietary fiberous ingredient, the higher fiber content and which can affect energy and the other nutrient digestibility in diets when fed to pigs [8-10]. In addition, the adaptation duration of a new diet especial in high fiber also can affect the evaluation values of experimental diets and their nutrients digestibility [11-13]. Accurate assessment of the nutritive value of PKM is important for it's optimum utilization in non-ruminant livestocks. There were no studies on investigating the interaction effect of inclusion level of PKM and the adaptation duration on the energy and other nutrient digestibility in diet. Therefore, the objective of the current experiment was carried out to test the hypothesis that there is a combination effect of graded increasing inclusion level of PKM and different adaptation duration of diets on the energy and nutrient digestibility in diet and PKM fed to growing-finishing pigs.

MATERIALS AND METHODS

The protocol for all animal procedures were approved by the Institutional Animal Care and Use Committee at China Agricultural University, Beijing, China.

Animals and housing

Thirty crossbred barrows (Duroc×Landrace×Large white) with an initial body weight (BW) of 85.0±2.1 kg were used. During experiments, pigs were housed individually in stainless-steel metabolism crates (1.7×0.9×0.7 m^2). The crates had adjustable sides to accommodate animal welfare and were located in rooms with temperature controlled at 22°C±2.5°C. Humidity varied from 35% to 59% during the trial and the light and dark time was controlled at 12 h vs 12 h automatically. An adjustable tray that was used for total feces collection was placed under each cage, which permitted collection of feces. All pigs had *ad libitum* access to water via a drinking nipple.

Experimental diets

Thirty pigs were allotted to 5 diets in a completely randomized design according to their initial BW and with 6 pigs fed each diet. Diets included a corn-soybean meal basal diet containing 76.6% corn, 21.0% soybean meal (SBM), 1.0% limestone, 0.6% dicalcium phosphate, 0.3% salt, and 0.5% vitamin-mineral premix and 4 additional diets were formulated by including 10%, 20%, 30%, and 40% PKM at the expense of corn and SBM, and therefore, 9.8%, 19.5%, 29.3%, and 39.0% PKM in final experimental diets, respectively (Tables 1, 2). Vitamins and minerals were supplemented in all diets to meet or exceed nutrient requirements of pigs according to NRC [14]. The composition of PKM in the experiment was also analyzed (Table 1).

Experimental design and sample collection

All pigs were acclimation to the new environment for 7 d and fed a standard corn-soybean meal diet before the start of the experiment. Pigs were weighed at the beginning of the experiment. Experimental feeds were fed in a meal form and offered to pigs at a level of 3% of individually initial BW of pig and were fed in 2 equal daily meals at 0730 and 1630 h, respectively [15]. Feed refusals were collected and weighed daily.

There were 4 different adaptation duration of 7, 14, 21, and 28 d were set in the current study. After 7 days of adaptation to experimental diets fed to pigs, feces were collected from d 8 to 12, d 15 to 19, d 22 to 26, and d 29 to 33, respectively. Each feces collection day was 24 h of full collection and no any marker was used. One stainless feces collection tray was put under the metabolism cage at 4 pm on day 7, so the first whole collection day was end till 4 pm on day 8. The first five collection days were end at 4 pm on day 12. Same method for the other

Table 1. Analyzed chemical composition of palm kernel meal (%, as-fed basis)[1)]

Item	Palm kernel meal
Dry matter	91.7
Crude protein	14.7
Ash	5.7
Organic matter	86.0
Neutral detergent fiber	48.7
Acid detergent fiber	26.8
Gross energy (MJ/kg)	17.76

[1)] All data are the results of a chemical analysis conducted in duplicate.

Table 2. Ingredients and analyzed chemical composition of experimental diets (as-fed basis, %)[1)]

Items	Basal diet	Level of palm kernel meal in diet (%)			
		9.8	19.5	29.3	39.0
Ingredients					
Corn	76.6	68.9	61.3	53.6	46.0
Soybean meal (dehulled), 48%	21.0	18.9	16.8	14.7	12.6
Palm kernel meal	-	9.8	19.5	29.3	39.0
Limestone	1	1	1	1	1
Dicalcium phosphate	0.6	0.6	0.6	0.6	0.6
Salt	0.3	0.3	0.3	0.3	0.3
Vit-Min premix, 0.5%[2)]	0.5	0.5	0.5	0.5	0.5
Analyzed chemical composition					
Dry matter	88.4	88.1	88.6	89.0	88.9
Crude protein	16.8	16.2	16.0	15.8	15.6
Ash	4.0	4.4	4.7	5.0	5.3
Organic matter	84.4	83.6	83.9	84.0	83.6
Neutral detergent fiber	10.1	19.2	22.0	26.5	26.2
Acid detergent fiber	3.5	7.7	9.6	13.9	13.1
Gross energy (MJ/kg)	16.2	16.3	16.5	16.7	16.8

[1)] All data are the results of a chemical analysis conducted in duplicate.
[2)] Provided the following quantities per kg of complete diet: Mn, 50 mg (MnO); Fe, 125 mg ($FeSO_4 \cdot H_2O$); Zn, 125 mg (ZnO); Cu, 150 mg ($CuSO_4 \cdot 5H_2O$); I, 50 mg (CaI_2); Se, 0.30 mg (Na_2SeO_3); retinyl acetate, 4,500 IU; cholecalciferol, 1,350 IU; DL-α-tocopheryl acetate, 13.5 mg; menadione sodium bisulphite complex, 2.7 mg; niacin, 18 mg; vitamin B_{12}, 27.6 μg; thiamine, 0.6 mg; pyridoxine, 0.9 mg; riboflavin, 1.8 mg; D-Ca-pantothenate, 10.8 mg; nicotinic acid, 30.3 mg.

three collection periods. Each pig was fed the same diet through the whole experiment and with *ad libitum* tab water intake. Fresh feces were stored at –18°C immediately after collected. At the end of each collection duration, the collected feces of 5 d from each pig were weighed, dissolved, and then homogenized thoroughly. A 600 gram sub-sample was dried in a forced-air oven at 65°C for 72 h. Dried feces were ground through a 1-mm screen for chemical analysis.

Sample analysis and calculations

Samples were analyzed for gross energy (GE) via an adiabatic oxygen bomb calorimeter (Parr Instruments, Moline, IL, USA), dry matter (DM) (AOAC procedure 4.1.06; 2000), crude protein (CP) by Kjeldahl N method [16], ash (AOAC International method, 942.05, 2005). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined using fiber bags and fiber analyzer equipment (Fiber Analyzer, Ankom Technology, Macedon, NY, USA) following a modification of the procedure [17].

The DE and ATTD of chemical components in diets and PKM were calculated according to the difference method described by Adeola [7]. In which method, it was supposed that the digestibility of the basal diet was same in different experimental diet and the DE and ME of tested ingredient were calculated by subtracting the DE and ME in the basal diet from corresponding items in test feed according to the contribution of tested ingredient. Organic matter (OM) was calculated as the difference between DM % and ash %.

Statistical analysis

Normality was verified and outliers were identified using the UNIVARIATE procedure (SAS Inst. Inc., Cary, NC, USA). An observation was considered an outlier if the value was more than 3 standard deviations away from the grand mean. Data were analyzed by analysis of variance using the PROC MIXED of SAS in a randomized complete block design with the pig as the experimental unit. The statistical model included inclusion level, adaptation duration, and their interaction as fixed effect and pig as random effect. Treatment means were separated by using the LSMEANS statement and the PDIFF option of PROC MIXED if the interaction between inclusion level and adaptation duration was significant. Contrast statements were conducted to test linear and quadratic effects of inclusion level and adaptation duration. Statistical significance and tendency were considered at $p<0.05$ and $0.05\le p<0.10$, respectively.

RESULTS

Energy and chemical composition of palm kernel meal and experimental diets

On an as-fed basis, PKM detected in the current trial contained 91.7% DM, 14.7% CP, 5.7% ash, 86.0% OM, 48.7% NDF, and 26.8% ADF (Table 1). The concentration of GE in PKM was 17.76 MJ/kg (as-fed basis) and the analyzed chemical composition of diets were showed in Table 2.

Effect of inclusion level of palm kernel meal on energy and nutrient digestibility in diet

Significantly interaction effects between the inclusion level of PKM and adaptation duration of diets on DE and the ATTD of GE in diet were observed ($p<0.01$, Table 3). Significantly interaction effects were also observed between the inclusion level of PKM and the adaptation duration of diets on the ATTD of DM, OM, and CP in diets ($p<0.05$). No interaction effects were observed between the inclusion level of PKM and adaptation duration of diets on the ATTD of ash, NDF, and ADF in diets ($p>0.05$). Therefore, the effect of inclusion level and adaptation duration on the ATTD of ash, NDF, and ADF were showed in Table 4 and 5, respectively.

A linearly decreased were observed in DE and the ATTD of GE, DM, ash, OM, NDF, ADF, and CP in diets as dietary PKM increasing from 9.8% to 39.0% within each adaptation duration ($p<0.01$). The greatest ($p<0.05$) concentration of DE and the ATTD of GE, DM, ash, OM, NDF, ADF, and CP was observed in diet containing 9.8% PKM, and the diet containing 39.0% PKM had the least DE and the ATTD of all detected items ($p<0.05$). For 7 days of adaptation, no differences were observed in DE value and the ATTD of all detected items between diets containing 19.5% and 9.8% PKM ($p>0.05$). However, after 14 days of adaptation, diet containing 19.5% PKM had a less DE and ATTD of all detected items compared with 9.8% PKM diet ($p<0.05$). The ATTD of GE and OM in diet containing 29.3% PKM was greater than that in diet containing 39.0% PKM ($p<0.05$), but less compared with diet included with 19.5% PKM ($p<0.05$) within each adaptation duration. The ATTD of CP in diet containing 29.3% and 39.0% PKM was less than that in diet containing 9.8% and 19.5% PKM, respectively within each adaptation duration ($p<0.05$).

The ATTD of ash, NDF and ADF in diets linearly decreased as the dietary PKM increasing from 9.8% to 39.0% ($p<0.01$, Table 4), regardless of adaptation duration effect. Diet containing 29.3% PKM had a greater ATTD of NDF and ADF than that in 39.0% PKM diet ($p<0.05$), but no differences compared with diet containing 19.5% PKM within each adaptation duration ($p>0.05$).

Effect of adaptation duration on energy and nutrient digestibility in diet

The adaptation duration had no effect on DE and the ATTD of all detected items in diets contaning 9.8%, 29.3%, or 39.0% PKM ($p>0.05$), respectively. As for diet containing 19.5% PKM, it's DE and ATTD of GE, DM, OM, and CP was less when fed to pigs for 14 days compared with 7, 21, or 28 days of diet adaptation, respectively ($p<0.05$).

Table 3. Effect of inclusion levels of palm kernel meal and the adaptation duration on the digestible energy (DE, as fed-basis) content and the apparent total tract digestibility (ATTD, %) of chemical composition in diets fed to growing-finishing pigs[1)]

Item	DM	OM	CP	ADF	NDF	Ash	GE	DE (MJ/kg)
Adaptation duration, 7 days								
0%	92.3^{a}	93.8^{a}	93.1^{a}	61.2^{bcde}	68.5^{defg}	60.6^{a}	92.3^{a}	14.93^{a}
9.8%	88.3^{c}	90.2^{c}	89.3^{c}	68.5^{a}	75.4^{a}	53.7^{bc}	88.2^{c}	14.37^{c}
19.5%	86.8^{d}	88.7^{de}	87.6^{def}	62.0^{abcde}	73.7^{abc}	53.0^{bcd}	86.5^{d}	14.25^{c}
29.3%	83.4^{ef}	85.6^{g}	83.8^{gh}	64.2^{abcde}	70.9^{abcdef}	46.6^{efg}	83.4^{ef}	13.94^{d}
39.0%	80.5^{hi}	83.1^{i}	80.2^{j}	50.4^{f}	65.0^{ghi}	40.0^{hi}	80.6^{ij}	13.57^{fg}
SEM	2.03	1.85	2.24	2.99	1.85	3.50	2.01	0.23
Adaptation duration, 14 days								
0%	91.3^{ab}	92.9^{ab}	92.1^{ab}	68.5^{a}	68.9^{defg}	56.1^{ab}	91.4^{ab}	14.78^{ab}
9.8%	88.3^{c}	90.3^{c}	89.2^{cd}	67.2^{ab}	75.4^{a}	51.6^{bcde}	88.3^{c}	14.38^{c}
19.5%	84.6^{e}	86.8^{f}	85.3^{g}	58.4^{e}	70.5^{bcdef}	44.8^{fgh}	84.4^{e}	13.91^{de}
29.3%	82.5^{fg}	84.8^{gh}	83.7^{gh}	60.4^{cde}	67.9^{efgh}	42.7^{fghi}	82.7^{fg}	13.82^{de}
39.0%	79.5^{ij}	82.1^{j}	80.4^{j}	47.5^{f}	62.3^{ij}	38.4^{ij}	79.5^{j}	13.40^{g}
SEM	1.76	1.61	2.05	3.76	2.11	3.17	1.75	0.24
Adaptation duration, 21 days								
0%	90.6^{b}	92.4^{b}	91.5^{b}	66.7^{abc}	66.4^{fghi}	52.0^{bcde}	90.7^{b}	14.67^{b}
9.8%	87.8^{cd}	89.7^{cd}	88.7^{cde}	64.8^{abcde}	73.7^{abc}	50.7^{bcde}	87.9^{cd}	14.31^{c}
19.5%	86.4^{d}	88.4^{e}	87.2^{ef}	67.9^{a}	72.4^{abcde}	51.6^{bcde}	86.5^{d}	14.25^{c}
29.3%	82.9^{fg}	85.3^{gh}	83.8^{gh}	63.9^{abcde}	69.7^{cdefg}	42.7^{fghi}	83.0^{efg}	13.87^{de}
39.0%	80.7^{h}	83.2^{i}	81.8^{i}	48.9^{f}	63.5^{hij}	40.9^{ghi}	81.2^{hi}	13.67^{ef}
SEM	1.76	1.63	1.73	3.45	1.88	2.39	1.71	0.18
Adaptation duration, 28 days								
0%	90.8^{b}	92.6^{b}	91.9^{ab}	66.8^{abc}	67.2^{fgh}	52.3^{bcde}	90.8^{b}	14.69^{b}
9.8%	87.3^{cd}	89.4^{cde}	88.7^{cde}	65.8^{abcd}	73.3^{abcd}	48.5^{def}	87.4^{cd}	14.24^{c}
19.5%	86.4^{d}	88.4^{e}	86.9^{f}	63.2^{abcde}	74.5^{ab}	49.9^{cde}	86.6^{d}	14.26^{c}
29.3%	81.9^{gh}	84.4^{hi}	83.5^{hi}	59.9^{de}	68.5^{defj}	39.2^{hij}	82.2^{gh}	13.74^{ef}
39.0%	78.9^{j}	81.7^{j}	80.3^{j}	45.6^{f}	60.5^{j}	34.5^{j}	79.5^{j}	13.40^{g}
SEM	2.10	1.92	2.02	3.85	2.48	3.42	1.99	0.22
p-values								
Inclusion level	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Adaptation duration	< 0.01	< 0.01	0.12	0.34	0.18	< 0.01	< 0.01	< 0.01
Inclusion level × Adaptation duration	< 0.05	< 0.05	< 0.05	0.06	0.68	0.06	< 0.01	< 0.01
Inclusion level								
Linear	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Quadratic	0.78	0.93	0.74	< 0.01	< 0.01	0.28	0.92	0.86
Adaptation duration								
Linear	< 0.01	< 0.01	0.22	0.81	0.07	< 0.01	0.01	0.01
Quadratic	0.24	0.23	0.54	0.50	0.32	0.36	0.26	0.27

ATTD, apparent total tract digestibility; DM, dry matter; OM, organic matter; CP, crude protein; ADF, acid detergent fibre; NDF, neutral detergent fibre; GE, gross energy; DE, digestible energy; SEM, pooled standard error of the mean.

[1)] Data are least square means of 6 observations for all treatments.

[a-j] Values within a column lacking a common superscript letter are different ($p < 0.05$).

A linearly decreased in the ATTD of ash in diet was observed as the adaptation increasing from 7 to 28 days ($p<0.01$, Table 5), regardless of inclusion level effect. The ATTD of ADF in diet containing 19.5% PKM was greater when fed to pigs for 21 days than for 14 days ($p<0.05$), but no differences compared with 7 or 28 days of adaptation ($p>0.05$, Table 3). The adaptation duration had no effect on the ATTD of NDF in diet containing 19.5% PKM ($p>0.05$).

Effect of inclusion level of palm kernel meal on digestible energy and the apparent total tract digestibility of gross energy and crude protein in palm kernel meal

Significant interaction effect was observed between the inclusion level of PKM and adaptation duration on DE and the ATTD of GE and CP in PKM ($p<0.05$ or $p<0.01$, Table 6). After fed to pigs for 7, 21, or 28 days, the DE content and ATTD of GE in PKM calculated by 19.5% was greater ($p<0.05$) than that calculated by 9.8%, but no differences compared with

Table 4. Effects of inclusion levels of palm kernel meal on the apparent total tract digestibility (ATTD, %) of ash, neutral detergent fiber (NDF), and acid detergent fiber (ADF) in diet, regardless of the effect of adaptation duration[1),2)]

Item	Inclusion levels of palm kernel meal in diet (%)					SEM	p-value		
	0	9.8	19.5	29.3	39.0		ANOVA	Linear	Quadratic
Ash	55.3[a]	51.1[ab]	49.8[b]	42.8[c]	38.4[d]	1.50	< 0.01	< 0.01	0.28
Neutral detergent fiber	67.7[b]	74.4[a]	72.8[a]	69.2[b]	62.8[c]	1.10	< 0.01	< 0.01	< 0.01
Acid detergent fiber	65.8[ab]	66.6[a]	62.9[ab]	62.1[b]	48.1[c]	1.48	< 0.01	< 0.01	< 0.01

SEM, pooled standard error of the mean; ANOVA, analysis of variance.
1) Data are the means of 6 replicates.
2) The ATTD of ash, NDF, and ADF were calculated by using the difference method described by Adeola [7].
a,b,c,d Means with the same row without common superscripts differ significantly ($p < 0.05$).

Table 5. Effects of adaptation duration on the apparent total tract digestibility (ATTD, %) of ash, neutral detergent fiber (NDF), and acid detergent fiber (ADF) in diet, regardless of the effect of inclusion level of palm kernel meal[1), 2)]

Item	Adaptation duration, days				SEM	p-value		
	7	14	21	28		ANOVA	Linear	Quadratic
Ash	50.8[a]	46.7[bc]	47.6[b]	44.9[c]	0.94	< 0.01	< 0.01	0.36
Neutral detergent fiber	70.7	69.0	69.1	68.8	0.77	< 0.01	0.07	0.32
Acid detergent fiber	61.3	60.4	62.4	60.3	1.05	< 0.01	0.81	0.50

SEM, pooled standard error of the mean; ANOVA, analysis of variance.
1) Data are the means of 6 replicates.
2) The ATTD of ash, NDF, and ADF were calculated by using the difference method described by Adeola [7].
a,b,c Means with the same row without common superscripts differ significantly ($p < 0.05$).

that calculated by 29.3% or 39.0%, respectively (p>0.05). After fed to pigs for 7 days, the ATTD of CP in PKM with inclusion rate of 19.5% in diet was greater than that in PKM calculated by 9.8% but no differences compared with that calculated by 29.3% or 39.0%, respectively (p>0.05). A linearly reduction in the ATTD of CP was observed in PKM as its inclusion rate increased in diet when fed to pigs for 14, 21, or 28 days (p<0.01).

Effect of adaptation duration on digestible energy and the apparent total tract digestibility of gross energy and crude protein in palm kernel meal

Palm kernel meal with 9.8% inclusion rate in diet had a greater DE value and ATTD of GE and CP when fed to pigs for 14 days than that in PKM after fed to pigs for 7 days (p<0.05), but no differences compared with that in PKM as adapted to pigs for 21 or 28 days, respectively (p>0.05). The DE and ATTD of GE and CP in PKM calculated with 19.5% was greater when fed to pigs for 21 days compared with 14 days of adaptation (p<0.05), but no differences compared with an adaptation of 28 days (p>0.05). A greater ATTD of CP in PKM calculated with 29.3% was observed when fed to pigs for 14 days compared with 7 days (p<0.05), but no differences compared with that in PKM after adaptation for 21 or 28 days (p>0.05), respectively. However, as for PKM with 39.0% inclusion rate in diet, the ATTD of CP in which was greater when fed to pigs for 21 days compared with 7 days (p<0.05), but no differences compared with that in PKM after adaptated to pigs for 14 or 28 days (p>0.05), respectively.

DISCUSSION

Energy and chemical composition of palm kernel meal

The GE in PKM was in agreement with the values previously reported [2,18]. The CP content in PKM was within the range of values reported by Stein et al [19], but greater than the those previously values [2,20]. A greater concentration of ash but less NDF and ADF were observed in PKM than those previously values [6,14,20]. The above differences were possibly due to the different species of palm nut, method of oil extraction, and the residual shell in the meal after oil extraction [21].

Effect of inclusion level of palm kernel meal on energy and nutrient digestibility in diet

The linearly decreased in DE and the ATTD of energy in diets as the dietary PKM increasing was in agreement with that increasing the fiber content in the diet negatively affected the fecal digestibility of energy [22,23]. The reason for the reduction maybe due to the high insoluble dietary fiber in PKM as: most of the total carbohydrates in PKM are in the form of non-starch polysaccharides (NSP), and β-(1,4)-D-mannans are the main form of the NSP [24] and the high amount of lignin in PKM [25]. Different effects of dietary PKM on DE and the ATTD of detected items between diets within each single adaptation duration may be mainly due to the interaction effect between the inclusion level of PKM and adaptation duration of diets especial between the inclusion level of 19.5% and 14 days of adaptation. Furthere more, 21 days of adaptation

Table 6. Effects of inclusion levels of palm kernel meal (%) and adaptation duration (days) on its concentration of digestible energy (DE, as fed-basis) and the apparent total tract digestibility (ATTD, %) of gross energy (GE) and crude protein (CP) fed to growing pigs[1), 2)]

Item	GE	CP	DE (MJ/kg)
Adaptation duration, 7 days			
9.8%	54.3[f]	57.1[h]	9.64[f]
19.5%	66.7[bce]	67.0[efg]	11.84[bce]
29.3%	67.2[abcd]	63.5[fh]	11.93[abcd]
39.0%	66.6[abcde]	62.2[gh]	11.83[abcde]
SEM	3.40	3.86	0.60
Adaptation duration, 14 days			
9.8%	62.8[cde]	85.0[a]	11.15[cde]
19.5%	60.1[df]	68.7[efg]	10.68[df]
29.3%	66.9[abcd]	71.0[deg]	11.88[abcd]
39.0%	65.4[abcde]	67.8[efg]	11.61[abcde]
SEM	2.34	3.30	0.41
Adaptation duration, 21 days			
9.8%	64.4[cde]	85.5[a]	11.44[cde]
19.5%	72.7[a]	80.7[abc]	12.92[a]
29.3%	69.3[abc]	72.6[bcde]	12.31[abc]
39.0%	70.3[abc]	72.2[cdef]	12.48[abc]
SEM	3.10	3.67	0.55
Adaptation duration, 28 days			
9.8%	59.1[ef]	81.6[ab]	10.49[ef]
19.5%	72.4[ab]	77.8[abcd]	12.86[ab]
29.3%	66.4[abcde]	70.7[deg]	11.79[abcde]
39.0%	66.1[abcde]	67.9[efg]	11.74[abcde]
SEM	1.79	2.06	0.32
p-values			
Inclusion level	>0.05	<0.05	<0.05
Adaptation duration	<0.01	<0.01	<0.01
Inclusion level × Adaptation duration	<0.01	<0.05	<0.05
Inclusion level			
Linear	<0.01	<0.05	<0.05
Quadratic	0.73	0.05	>0.05
Adaptation duration			
Linear	<0.01	0.11	<0.05
Quadratic	0.25	0.37	0.19

SEM, pooled standard error of the mean.

1) Data are least squares means of 6 observations for all treatments.

2) DE and the ATTD of GE and CP were calculated by using the difference method described by Adeola [7].

a-g Values within a column lacking a common superscript letter are different ($p<0.05$).

can stable the digestibility of energy and other macronutrients in diets containing high fiber ingredient. Those observations indicated that the interaction effect of inclusion level and adaptation duration had a similar effect on those detected items. The decreased ATTD of CP in diet as deitary PKM increasing was in agreement with several previously studies reporting that dietary fiber's increasing has negative effect on protein digestibility [9,23,26]. The negative effect of dietary fiber on CP digestibility maybe firstly due to increasing endogenous excretion of N [27]. Increasing passage rate of digesta through the entire gastrointestinal tract [28,29]. Not mainly but as partly reason was that the excretion of NDF-binding N increased in upper gastrointestinal tract as dietary NDF increased [9,27]. In addition, the decreased ratio of urinary to fecal nitrogen excretion induced by high dietary fiber may be also contributed to the decreased ATTD of CP in diet [26,30].

The decreased ATTD of NDF and ADF as dietary PKM increasing was in agreement with previously studies [9,23]. This can be easly explained by that the NDF and ADF had a lower digestibility than the other macronutrients and the higher level, the less digestibility [12]. The decreased ATTD of ash can be explained by the increasing excretion of ash in fecals caused by increased dietary fiber [22]. The decreased effect of inclusion level on the ATTD of DM in diet was in agreement with previously studies [8,26].

Effect of adaptation duration on energy and nutrient digestibility in diet

The adaptation duration had no effect on DE and the ATTD of all detected items in all but diet contaning 19.5% PKM indicated that an interaction effect between the adaptation duration and inclusion level of 22.0% NDF took place. The quadratic effect of the adaptation duration on DE and the ATTD of GE in diet containing 19.5% PKM showed that the DE value and ATTD of energy firstly decreased when fed to pigs for 14 days and then increased to the same level as 7 days of adaptation after fed to pigs for 21 days and 28 days. This was inagreement with that at least of 23 days was needed to detected the greater ATTD of OM, CP, and starch between diets containing corn digestible starch and resistant starch [31]. The currently results indicated that at least of 21 days of adaptation on diets with 19.5% PKM (22.0% NDF in diet, as fed) are necessary for stability of measurements of the digestibility of fiber and most of macronutrients. This implication is conflict with that of adaptation duration of 7 and 26 days had no effect on the ATTD of NDF [32]. Decreased ATTD of ash and CP in diet when fed to pigs for 14 days may be mainly due to the increased endogenous counterparts before the ileum of pigs caused by the high dietary fiber [22].

Effect of inclusion level of palm kernel meal on digestible energy and the apparent total tract digestibility of gross energy and crude protein in palm kernel meal

The DE concentration in PKM was in agreement with the reported value [18], but less compared with those previously reported values [2,6]. When fed to pigs for 7 days, the less DE and ATTD of GE in PKM with 9.8 inclusion rate in diet may be mainly due to the big error caused by the low inclusion level since the more inclusion level of ingredient, the more calculation accuracy according to the difference method [7]. As time prolonged to 14 and 21 days, the differeces diminished. This may be mainly due to the interaction effect between inclusion level and adaptation duration. However, the DE and ATTD of GE in PKM with 9.8% inclusion rate in diet still less than that in PKM with 19.5% or 29.3% inclusion rate in diet, but no significantly difference compared with that in PKM with 39.0% inclusion rate in diet. This difference firstly may be due to the interaction effect between inclusion level and adaptation duration and another reason may be the higher calculation error caused by the lower nutrient contributions from only 9.8% PKM in diet according to the difference method [7,9]. The linearly decreased ATTD of CP in PKM within each single adaptation duration was may be first due to the decreased ATTD of CP in diet according to the calculation method [7]. Another important reason may be due to the increasing excretion of less digestible NDF-binding N in fecals [9].

Effect of adaptation duration on digestible energy and the apparent total tract digestibility of gross energy and crude protein in palm kernel meal

Adaptation duration had no effect on DE and the ATTD of GE and CP in PKM calculated by 9.8% indicated that 7 days of adaptation to a new diet with low fiber may be enough for stable digestibility of N and energy [11,32]. Significantly increased in DE and ATTD of GE and CP in PKM with 19.5% inclusion rate in diet when fed to pigs for 21 days compared with 14 days maybe due to the interaction effect between inclusion level and adaptation duration. Also, adaptation duration had no effect on DE and ATTD of GE in PKM calculated either by inclusion of 29.3% or 39.0% indicated that longer time is needed for stable digestibility of energy, may be especial for high fiber digestibility. This difference was in consistent with previous reported and in which 35 days of adaptation to a high fiber diet to pig was suggested [11]. Castillo et al [32] reported that time of adaptation of microbiota was shown by xylanase and cellulase activities that were not detected until day 7 and 42 days and could be even up to 6 weeks. This maybe the main resson for that 28 days of adaptation in the current study is not enough to detect the adaptation effect on digestibility of fiber and so for DE and ATTD of energy in PKM since at least 5 weeks of adaptation of growing pigs was required to reflect the whole-tract digestibility of purine and short-chain fatty acid [33].

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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REFERENCES

1. Jaworski NW, Shoulders J, González-Vega JC, Stein HH. Effects of using copra meal, palm kernel expellers, or palm kernel meal in diets for weanling pigs. Prof Anim Sci 2014;30:243-51.
2. Sulabo RC, Ju WS, Stein HH. Amino acid digestibility and concentration of digestible and metabolizable energy in copra meal, palm kernel expellers, and palm kernel meal fed to growing pigs. J Anim Sci 2013;91:1391-9.
3. Perez JF, Gernat AG, Murillo JG. The effect of different levels of palm kernel meal in layer diets. Poult Sci 2000;79:77-9.
4. Jang YD, Kim YY. Energy values and apparent total tract digestibility coefficients of copra meal and palm kernel meal fed to growing pigs. Can J Anim Sci 2013;93:517-21.
5. Agunbiade JA, Wiseman J, Cole DJA. Energy and nutrient use of palm kernels, palm kernel meal and palm kernel oil in diets for growing pigs. Anim feed Sci Technol 1999;80:165-81.
6. Son AR, Ji SY, Kim BG. Digestible and metabolizable energy concentrations in copra meal, palm kernel meal, and cassava root fed to growing pigs. J Anim Sci 2012;90:140-2.
7. Adeola O. Digestion and balance techniques in pigs. In: Lewis DJ, Southern LL, editor. Swine nutrition, 2nd ed. New York, USA: CRC Press; 2001. pp. 903-16.
8. Moeser AJ, Van Kempen TAGT. Dietary fibre level and enzyme inclusion affect nutrient digestibility and excreta characteristics in grower pigs. J Sci Food Agric 2002;82:1606-13.
9. Dégen L, Halas V, Tossenberger J, Szabó C, Babinszky L. The impact of dietary fiber and fat levels on total tract digestibility of energy and nutrients in growing-finishing pigs and its consequence for diet formulation. Acta Agric Scand Sect A Anim Sci 2009;59:150-60.
10. Chen L, Gao L, Zhang H. Effect of graded levels of fiber from alfalfa meal on nutrient digestibility and flow of fattening pigs. J Integr Agric 2014;13:1746-52.
11. Longland AC, Low AG, Quelch DB, Bray SP. Adaptation to the digestion of non-starch polysaccharide in growing-finishing pigs fed on cereal or semi-purified basal diets. Br J Nutr 1993;70:557-66.
12. Noblet J, Goff GL. Effect of dietary on the energy value of feeds for pigs. Anim Feed Sci Technol 2001;90:35-52.
13. Urriola PE, Stein HH. Effects of distillers dried grains with solubles on amino acid, energy, and fibre digestibility and on hindgut fermentation of dietary fibre in a corn-soybean meal diet fed to growing pigs. J Anim Sci 2010;88:1454-62.
14. NRC. Nutrient requirements of swine, 11th rev ed. Washington, DC, USA: National Academy Press; 2012.
15. Kerr BJ, Dozier WA, Shurson GC. Effects of reduced-oil corn distillers dried grains with solubles composition on digestible and metabolizable energy value and prediction in growing pigs. J Anim Sci 2013;91:3231-43.
16. Thiex NJ, Manson H, Anderson S, Persson JA. Determination of crude protein in animal feed, forage, grain, and oilseeds by

using block digestion with copper catalyst and steam distillation into boric acid: collaborative study. J AOAC Int 2002;85:309-17.

17. Van Soest PJ, Robertson JB, Lewis BA. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J Dairy Sci 1991;74:3583-97.
18. Stein HH, Casas GA, Abelilla JJ, Liu Y, Sulabo RC. Nutritional value of high fiber co-products from the copra, palm kernel, and rice industries in diets fed to pigs. J Anim Feed Sci Technol 2015;6:56.
19. Stein HH, Lagos LV, Casas GA. Nutritional value of feed ingredients of plant origin fed to pigs. Anim Feed Sci Technol 2015; 218:33-69.
20. Almaguer BL, Sulabo RC, Liu Y, Stein HH. Standardized total tract digestibility of phosphorus in copra meal, palm kernel expellers, palm kernel meal, and soybean meal fed to growing pigs. J Anim Sci 2014;92:2473-80.
21. O'Mara FP, Muligan FJ, Cronin EJ, Rath M, Caffrey PJ. The nutritive value of palm kernel meal measured *in vivo* and using rumen fluid and enzymatic techniques. Livest Prod Sci 1999; 60:305-16.
22. Wilfart A, Montagne L, Simmins PH, Van Milgen J, Noblet J. Sites of nutrient digestion in growing pigs: Effect of dietary fiber. J Anim Sci 2007;85:976-83.
23. Huang Q, Su YB, Liu L, Piao XS, Li DF. Effects of inclusion levels of wheat bran and body weight on ileal and fecal digestibility in growing pigs. Asian-Australas J Anim Sci 2015;28: 847-54.
24. Bach Knudsen KE. Carbohydrate and lignin contents of plant materials used in animal feeding. Anim Feed Sci Technol 1997; 67:319-38.
25. Mok CH, Lee JH, Kim BG. Effects of exogenous phytase and beta-mannanase on ileal and total tract digestibility of energy and nutrient in palm kernel expeller-containing diets fed to growing pigs. Anim Feed Sci Technol 2013;86:209-13.
26. Zhang WJ, Li DF, Liu L, et al. The effects of dietary fiber level on nutrient digestibility in growing pigs. J Anim Sci Biotechnol 2013;4:17.
27. Schulze H, Van Leeuwen P, Verstegen MWA, et al. Effect of level of dietary neutral detergent fiber on ileal apparent digestibility and ileal nitrogen losses in pigs. J Anim Sci 1994;72: 2362-8.
28. Le Goff G, Van Milgen J, Noblet J. Influence of dietary fibre on digestive utilization and rate of passage in growing pigs, finishing pigs and adult sows. Anim Sci 2002;74:503-15.
29. Chesson A. Dietary fiber. In: Alistair AM, Philips GO, Williams PA, editors. Food polysaccharides and their applications. 2nd ed. Boca Raton, FL, USA: CRC Press; 2006. pp. 629-63.
30. Chaheauti E, Noblet J, Carré B. Digestion of plant cell walls from four different sources in growing pigs. Anim Feed Sci Technol 1991;32:207-13.
31. Castillo M, Martín-Orúe SM, Anguita M, Pérez JF, Gasa J. Adaptation of gut microbiota to corn physical structure and different types of dietary fibre. Livest Sci 2007;109:149-52.
32. Fan Y, Guo P, Yang Y, et al. Effects of particle size and adaptation duration on the digestible and metabolizable energy contents and digestibility of various chemical constituents in wheat for finishing pigs determined by the direct or indirect method. Asian-Australas J Anim Sci 2017;30:554-61.
33. Martinez-Puig D, Pérez JF, Castillo M, et al. Consumption of raw potato starch increases colon length and fecal excretion of purine bases in growing pigs. J Nutr 2003;133:134-9.