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Coefficient of standardized total tract digestibility of phosphorus in oilseed meals and distillers dried grains in growing-finishing pigs

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Abstract

This study was conducted to determine the coefficient of total tract standardized digestibility (CTTSD) of phosphorus (P) in oilseed meals and distillers dried grains (DDG) fed to growing-finishing pigs. Twelve barrows (initial bodyweight (BW) ± standard deviation, 52.25 ± 2.57 kg) were allocated individually to metabolism cages. The experimental design was a 12 × 8 incomplete Latin square with 12 dietary treatments and eight replication periods. The diets were formulated individually with dehulled soybean meal produced in Korea (SBM-KD), soybean meal produced in India (SBM-I), soybean meal produced in Korea (SBM-K), corn high-protein distiller dried grains (HPDDGs), tapioca distillers dried grains (TDDG), canola meal (CAM), corn germ meal (CGM), copra meal (CM), palm kernel meal (PKM), sesame meal (SM), perilla meal (PM), and a P-free diet. Intake of P was highest in SM and PM. Excretion of P was reduced in y ascending order as HPDDG, TDDG and CGM; SBM-K; and SM and PM. The CTTAD of P was higher in CGM than SBM-K, TDDG, SM and PM. HPDDG and CGM showed greater CTTSD of P than SBM-K, CAM and PM. Digestible concentration of P on CTTSD (CTTSD-P) of P was greater in PM and CAM than the others except for SBM-KD. In summary, PM could be utilized as an alternative feedstuff to SBM, but its usage is regarded only as a source of P. In addition, the results of the current study would provide valuable information for formulating pig feed with precise P utilization in ingredients using mixed diets.

Key words: alternative feedstuffs, excretion, metabolism, phosphorus, swine
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Introduction

The growth of animals is closely related to the concentrations of dietary nutrients that are received under normal conditions. Farm animals, however, receive nutrients only from diets supplied by the farmer. These diets contain various feed ingredients, which show different concentrations and digestibility of nutrients (NRC, 2012). Among these nutrients, P is an essential element owing to its important functional roles in metabolism and bone formation (NRC, 2012). Shortage and excess of P supply both result in increased excretion of P. Digestibility of P is influenced by two factors: i) P-phytate complex in plant ingredients, which inhibits P digestibility owing to the inadequate secretion of digestive enzyme for phytate removal from the complex in pigs (Baidoo *et al*., 2003; Knowlton *et al*., 2004); and ii) basal endogenous loss (BEL) of P, which needs to be counted for P digestibility as standardized total tract digestibility (Almeida & Stein, 2010).

Soybean meal (SBM) is commonly used by the feed industry because of its palatability and high-quality protein (NRC, 2012). This high demand has resulted in an increase in price. Thus, other studies have investigated alternative ingredients to SBM. For example, although its use in pig feed is limited, CAM is the second most widely used protein ingredient after SBM. Because there is growing demand to replace oilseed meal with less expensive protein-rich ingredients, previous studies have identified certain candidate sources, including HPDDG, CGM, CM, PKM, SM and PM (Moon *et al*., 1994; Li *et al*., 2000; Kim *et al*., 2001; Babiker, 2012; NRC, 2012). However, these sources might be associated with growth inhibition or could interfere with the digestibility of other nutrients. In particular, the CTTSD of P, which is correlated with the BEL of P, has recently been adapted to the nutrient requirements of swine (NRC, 2012). Although studies have determined CTTSD of P in major feed ingredients (Almeida & Stein, 2010; Rojas *et al*., 2013; Almaguer *et al*., 2014; Jeong *et al*., 2015), information about minor ingredients is limited. The authors hypothesized that various

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feed ingredients affect the digestibility of P. Therefore, the purpose of the current study was to evaluate the CTTSD of P in eleven alternative feedstuffs, including nine oilseed meals and two DDG in growing-finishing pigs.

Materials and methods

A feeding trial, sample analysis and data processing were conducted in accordance with the authors' previous study (Jeong *et al.*, 2015). The experimental protocols describing the management and care of animals were reviewed and approved by the Animal Care and Use National Institute of Animal Science.

Twelve barrows (initial BW ± SD, 52.25 ± 2.57 kg) were housed in individual metabolism cages. The experimental design was a 12 × 8 incomplete Latin square, with twelve diets and eight periods. The experimental diets included sesame meal produced in Korea (SM), de-hulled soybean meal produced in Korea (SBM-KD), soybean meal produced in India (SBM-I), soybean meal produced in Korea (SBM-K), corn high-protein distillers dried grains produced in the USA (HPDDG), perilla meal produced in Korea (PM), canola meal produced in Indonesia (CAM), copra meal produced in Philippines (CM), corn germ meal from Korea (CGM), palm kernel meal produced in Malaysia (PKM), tapioca distillers dried grains produced in China (TDDG) and a P-free diet. The nutrient values of feed ingredients are shown in Table 1. The formulation and nutritional compositions of experimental diets are presented in Tables 2 and 3, respectively.

Table 1 Nutrient values of feed ingredients (g/kg, as-fed basis)

Composition[2]	Ingredients[1]										
	SBM-KD	SBM-I	SBM-K	HPDDG	TDDG	CAM	CGM	CM	PKM	SM	PM
DM	884.89	887.92	880.53	904.25	921.30	905.92	937.75	893.39	885.94	956.28	904.11
GE, MJ/kg	19.14	18.80	18.91	22.11	16.94	18.11	20.45	17.44	19.14	20.81	19.25
CP	471.20	396.00	466.80	382.50	178.40	367.70	218.50	217.30	157.00	486.30	444.70
EE	19.93	19.61	20.29	41.11	26.66	16.58	84.16	15.00	65.25	36.87	8.42
CF	59.50	54.00	51.30	98.40	261.30	97.00	103.20	254.00	255.70	43.20	211.40
Ash	60.25	65.48	65.66	13.84	154.61	99.25	23.06	65.75	46.20	58.42	90.06
NDF	103.55	113.80	86.97	396.44	586.88	223.75	492.75	540.90	561.28	228.41	432.94
ADF	56.99	53.17	45.37	120.95	360.22	140.98	122.77	354.40	361.44	117.93	246.65
Ca	3.91	6.08	5.62	0.24	7.49	10.68	1.23	2.12	3.85	3.38	13.85
P	6.31	5.42	5.68	2.42	2.26	9.93	5.32	5.56	5.39	6.32	12.85

[1]SBM-KD: dehulled soybean meal produced in Korea; SBM-I: soybean meal produced in India; SBM-K: soybean meal produced in Korea; HPDDG: high-protein distillers dried grains; TDDG: tapioca distillers dried grains; CAM: canola meal; CGM: corn germ meal; CM: copra meal; PKM: palm kernel meal; SM: sesame meal; PM: perilla meal
[2] DM: dry matter; GE: gross energy; CP: crude protein; EE: ether extract; CF: crude fibre; NDF: neutral detergent fibre; ADF: acid detergent fibre; Ca: calcium; P: phosphorus

The daily feed volume was calculated as 2.5 times the estimated requirement for maintenance energy (ME) (i.e., 106 kcal ME per $kg^{0.75}$) (NRC, 1998). Experimental diets were divided into two equal meals that were fed at 0900 and 1700 h. Animals were permitted ad libitum access to water during the experimental period. The adaptation period to the diets and metabolic cage consisted of four days. Faecal collection was conducted by the marker to marker approach (Adeola, 2001). Chromic oxide as a marker (colourings could be distinguished from faeces at d 5 and d 8) was incorporated in morning meals at 1 g/kg on d 5 and d 8.

Collected samples were dried at 60 °C in a forced-air drying oven and ground. Ingredients, diets and faeces were dried in a forced-air drying oven at 135 °C for 2 h for analysis of DM (method 930.15; AOAC, 2005) and nitrogen (N) (method 990.03; AOAC, 2005). The ingredients and experimental diets were analysed for gross energy (Model C2000, IKA, Germany), EE (method 920.39; AOAC, 2005), CF (method 978.10; AOAC, 2005), ash (method 942.05; AOAC, 2005), ADF (method 973.18; AOAC, 2005), and NDF (Holst, 1973). Concentration of calcium in feed ingredients, experimental diets and faeces were analysed with an atomic absorption spectrophotometer (method 978.02; AOAC, 2005; Perkin Elmer 3300, Perkin

Elmer, USA). The concentrations of P in feed ingredients, experimental diets and faeces were analysed with a spectrophotometer (method 946.06; AOAC, 2005; Optizen 2120UV, Mecasys, Republic of Korea).

Table 2 Formulation of feed ingredients in experimental diets (g/kg, as-fed basis)

	Diets[1]											
Ingredient[2]	SBM-KD	SBM-I	SBM-K	HPDDG	TDDG	CAM	CGM	CM	PKM	SM	PM	P-free[3]
Cornstarch	353	354	359	360	248	349	304	278	279	377	369	459
SBM-KD	400	-	-	-	-	-	-	-	-	-	-	-
SBM-I	-	400	-	-	-	-	-	-	-	-	-	-
SBM-K	-	-	400	-	-	-	-	-	-	-	-	-
HPDDG	-	-	-	400	-	-	-	-	-	-	-	-
TDDG	-	-	-	-	400	-	-	-	-	-	-	-
CAM	-	-	-	-	-	400	-	-	-	-	-	-
CGM	-	-	-	-	-	-	400		-	-	-	-
COM	-	-	-	-	-	-		400	-	-	-	-
PKM	-	-	-	-	-	-	-	-	400	-	-	-
SM	-	-	-	-	-	-	-	-	-	400	-	-
PM	-	-	-	-	-	-	-	-	-	-	400	-
Sucrose	200	200	200	200	200	200	200	200	200	200	200	200
Soybean oil	33	35	27	25	33	35	2	31	10	14	19	40
Gelatin	-	-	-	3	110	6	81	77	101	-	3	170
Cellulose	-	-	-	-	-	-	-	-	-	-	-	100
DL-Methionine	-	-	-	-	-	-	-	-	-	-	-	3
L-Threonine	-	-	-	-	-	-	-	-	-	-	-	1
L-Tryptophan	-	-	-	-	-	-	-	-	-	-	-	1
L-Histidine	-	-	-	-	-	-	-	-	-	-	-	1
L-Isoleucine	-	-	-	-	-	-	-	-	-	-	-	1
Limestone	5	2	5	4	-	1	4	5	1	-	-	10
Potassium carbonate	-	-	-	-	-	-	-	-	-	-	-	4
Magnesium oxide	-	-	-	-	-	-	-	-	-	-	-	1
Salt	4	4	4	4	4	4	4	4	4	4	4	4
Vit-min mix[3]	5	5	5	5	5	5	5	5	5	5	5	5

[1,2] SBM-KD: dehulled soybean meal produced in Korea; SBM-I: soybean meal produced in India; SBM-K: soybean meal produced in Korea; HPDDG: high-protein distillers dried grains; TDDG: tapioca distillers dried grains; CAM: canola meal; CGM: corn germ meal; CM: copra meal; PKM: palm kernel meal; SM: sesame meal; PM: perilla meal

[3] P-free: phosphorus-free diet

[3]The vitamin-mineral premix provided the following quantities of vitamins and minerals per kilogram of diets: vitamin A, 10,000 IU; vitamin D_3, 2,000 IU; vitamin E, 250 IU; vitamin K_3, 0.5 mg; vitamin B_1, 0.49 mg as mononitrate; thiamin, 0.49 mg as thiamin mononitrate; riboflavin, 1.50 mg; pyridoxine, 1 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.01 mg; niacin, 10 mg as nicotinic acid; pantothenic acid, 5 mg as calcium pantothenate; folic acid, 1 mg; biotin as d-biotin, 0.1 mg; choline, 125 mg as choline chloride; Mn, 60 mg as manganese sulfate; Zn, 75 mg as zinc sulfate; Fe, 20 mg as ferrous sulfate; Cu, 3 mg as cupric sulfate; I, 1.25 mg as calcium iodate; Co, 0.5 mg as cobaltous carbonate; and Mg, 10 mg as magnesium oxide

Table 3. Nutrient composition of experimental diets[1] (g/kg, as-fed basis)

	Diets											
Composition[2]	SBM-KD	SBM-I	SBM-K	HPDDG	TDDG	CAM	CGM	CM	PKM	SM	PM	P-free
DM	907.35	907.72	906.13	915.87	918.85	918.84	920.60	915.41	908.71	924.43	910.90	926
GE, MJ/kg	18.00	17.82	17.86	18.67	18.34	18.11	17.80	18.86	18.03	17.69	17.74	17.9
CP	197.70	157.10	188.40	147.30	179.90	166.70	160.90	161.10	160.50	181.40	177.30	29.9
EE	41.44	44.30	31.41	42.60	39.78	37.72	33.22	36.31	32.43	35.03	20.68	42.6
CF	25.40	24.20	22.50	35.30	40.30	40.90	45.50	90.90	79.90	37.60	77.50	91.6
Ash	32.88	33.17	33.36	13.85	92.83	45.25	18.96	34.20	23.86	40.87	40.59	12.7
NDF	49.33	47.00	45.15	147.90	73.20	92.55	193.80	229.57	226.20	82.10	161.74	195
ADF	26.57	20.18	22.24	32.65	18.60	58.74	60.70	128.99	138.80	39.23	91.16	140
Ca	4.00	3.71	4.22	2.31	3.87	5.31	3.09	3.42	2.89	8.30	6.66	1.13
P	2.69	2.38	2.69	1.03	1.01	4.00	2.37	2.24	2.34	4.88	4.97	0.09

[1] SBM-KD: dehulled soybean meal produced in Korea; SBM-I: soybean meal produced in India; SBM-K: soybean meal produced in Korea; HPDDG: high-protein distillers dried grains; TDDG: tapioca distillers dried grains; CAM: canola meal; CGM: corn germ meal; CM: copra meal; PKM: palm kernel meal; SM: sesame meal; PM: perilla meal; P-free: phosphorus-free diet

[2] DM: dry matter; GE: gross energy; CP: crude protein; EE: ether extract; CF: crude fibre; NDF: neutral detergent fibre; ADF: acid detergent fibre; Ca: calcium; P: phosphorus

The CTTSD or CTTAD of P and Ca, and the BEL of P in each experimental diet was calculated as described by Almeida & Stein (2010). Digestibility was calculated by this equation: CTTAD: (Pi – Pf)/Pi, where Pi is the total P intake (g) from 5 to 8 d and Pf is the total excreted P (g) in faeces from d 5 to d 8. The CTTAD of Ca was calculated from the following equation: (Cai – Caf)/Cai, where Cai is the total Ca intake (g) from 5 to 8d and Caf is the total Ca excretion from 5 to 8 d. The BEL of P was measured by the following equation: BEL of P (mg/kg DMI): ([Pf/Fi] x 1,000 x 1,000), where Fi is the total feed intake (g of DM) from d 5 to d 8. The daily BEL of P was determined by multiplying the calculated BEL of P of dry matter intake by dry matter intake. The CTTSD of P was calculated by this equation: STTD: [Pi – (Pf – BEL of P)/Pi]. Concentration of digestible P in CTTSD of P (designated CTTSD-P of P) was obtained by multiplying the STTD of P with the concentration of P in each ingredient (expressed as g/kg).

All data were analysed using the MIXED procedure (SAS Institute Inc., Cary, NC). Homogeneity of the variances among treatments was confirmed with the UNIVARIATE procedure. This procedure was also used to test for outliers, but none were identified. The model included diet as the fixed variable and animal and period as random variables. Least squares means were calculated and separated using the PDIFF option with Tukey's adjustment for multiple comparison to identify significant differences among treatments. The pig was the experimental unit for all analyses. An alpha level of 0.05 was used to assess significance among means.

Results

The digestibility of P in ingredients fed to pigs is shown in Table 4. No differences were observed in daily total intake and daily DM intake of feed among the feed ingredients. Intake of Ca ranged from 3.49 to 14.1 g/d. Level of Ca intake was greatest in SM and PM group and lowest in HPDDG (P <0.001). Intake of P was greater in pigs fed SM and PM (P <0.001) and lower in HPDDG and TDDG groups (P <0.001).

The level of total faeces excretion was reduced in the SBM group, including SBM-KD, SBM-1 and SBM-K, when compared with TDDG, CM, SM and PM (P <0.001). Similarly, the level of faecal DM was lower in SBM than TDDG, CM, PKM, SM and PM (P <0.001). Faeces Ca level was lower in HPDDG than SM and PM (P <0.001). The HPDDG, TDDG and CGM showed lower faecal P level than SM and PM groups (P <0.001).

The SBM group showed the greatest value of CTTAD of Ca, followed in descending order by HPDDG, TDDG, CGM, CM, SM, and PM (P <0.001). The CTTAD of P ranged from 0.510 to 0.752, and was higher in CGM than SBM-K, TDDG, SM and PM (P<0.001). Similarly, the CTTSD of P in HPDDG and CGM was greater when compared with SBM-K, CAM, SM and PM (P <0.001). However, the CTTSD-P of P was highest in PM, except for CAM (P <0.001).

Discussion

The CTTAD and CTTSD of P in SBM from the current study are greater than those reported in other studies (Bohlke *et al*., 2005; Dilger & Adeola, 2006; Akinmusire & Adeola, 2009; Almeida & Stein, 2010; NRC, 2012). The digestibility of P among sources of SBM used in this study showed no differences. These results are in agreement with a previous study which concluded that the area in which the ingredients are grown has no effect on the digestibility of P (Sotak-Peper *et al*., 2016). Thus, SBM from different origins need not be taken into account as sources of P when formulating pig diets.

The levels of CTTAD and CTTSD of P in CAM in the present study are almost two times greater than those reported by others (Fan & Sauer, 2002; Akinmusire & Adeola, 2009; NRC, 2012; Rodríguez *et al*., 2013). However, availability of P in CAM is lower than that of SBM (NRC, 2012; Rodríguez *et al*., 2013). The reason for this might stem from the high level of phytate in CAM compared to SBM (NRC, 2012; Rodríguez *et al*., 2013). Similarly, CTTSD-P of P of CAM was greater than that of SBM group in the current study. Degestibility of animal feed is based on the rate of intake and faecal output of dietary nutrients. Also, the dietary nutrient level influences the intake and excretion (Canh *et al*., 1998). Therefore, a greater proportion of total P, P intake, and faecal P output contributed to a higher CTTSD-P of P in CAM compared with the SBM group.

CTTAD and CTTSD of P in HPDDG in the current study were similar to those of the study of Almeida & Stein (2012), but greater than others (Widmer *et al*., 2007; NRC, 2012). Pigs fed CGM diet in the present study exhibited greater CTTAD and CTTSD of P values compared with previous reports (NRC, 2012; Rojas *et al*., 2013). This variation can be explained by different amounts of P in various types of corn (Almeida & Stein, 2012) and an addition of phytase during the process of ethanol extraction (Rojas *et al*., 2013).

Table 4 Coefficient of standardized total tract digestibility for phosphorus in oilseed meals and distiller dried grains fed to growing-finishing pigs[1,*] (g/d, as-fed basis)

	Diet[2]											SEM[4]	*P*-value
Items[3]	SBM-KD	SBM-I	SBM-K	HPDDG	TDDG	CAM	CGM	CM	PKM	SM	PM		
Bodyweight													
Initial (kg)	48.8	45.6	47	46.8	47.4	42.8	49.8	51.6	48.2	45.6	51.4	0.98	1.72
Final (kg)	55.6	55.8	56	56.4	56.2	52.0	59.0	61.4	54.4	48.0	56.2	0.85	2.08
Feed intake													
Total (kg/d)	1.68	1.64	1.69	1.54	1.61	1.65	1.80	1.71	1.63	1.68	1.66	0.08	0.237
DM (kg/d)	1.52	1.49	1.53	1.41	1.48	1.51	1.65	1.57	1.48	1.55	1.51	0.07	0.188
Ca	6.72^{de}	6.07^{def}	7.15^{d}	3.49^{g}	6.20^{de}	8.70^{c}	5.52^{ef}	5.89^{def}	4.74^{fg}	14.05^{a}	11.09^{b}	0.36	< 0.001
P	4.53^{c}	3.90^{c}	4.57^{c}	1.55^{d}	1.64^{d}	6.52^{b}	4.24^{c}	3.84^{c}	3.83^{c}	8.27^{a}	8.29^{a}	0.25	< 0.001
Output of faeces													
Total	46.14^{f}	64.96^{def}	63.13^{ef}	113.69^{cdef}	223.92^{a}	117.66^{bcde}	112.52^{cdef}	136.96^{bc}	135.16^{bcd}	185.70^{ab}	226^{a}	16.86	< 0.001
DM	42.24^{e}	60.20^{de}	57.71^{de}	107.03^{bcde}	211.962^{a}	108.51^{bcd}	105.71^{cde}	127.94^{bc}	126.49^{bc}	172.75^{ab}	211.46^{a}	15.70	< 0.001
Ca	1.68^{cd}	1.76^{cd}	2.16^{cd}	0.68^{d}	1.67^{cd}	3.05^{c}	1.29^{cd}	1.59^{cd}	1.61^{cd}	8.05^{a}	5.48^{b}	0.41	< 0.001
P	1.47^{def}	1.55^{de}	2.18^{cd}	0.41^{f}	0.69^{ef}	2.74^{bc}	1.03^{ef}	1.21^{def}	1.46^{def}	3.77^{ab}	4.05^{a}	0.26	< 0.001
Digestibility													
CTTAD of Ca	0.76^{a}	0.71^{a}	0.70^{a}	0.78^{a}	0.72^{a}	0.65^{ab}	0.76^{a}	0.74^{a}	0.67^{ab}	0.43^{c}	0.50^{bc}	0.04	< 0.001
CTTAD of P	0.69^{ab}	0.60^{ab}	0.52^{b}	0.69^{ab}	0.54^{b}	0.58^{ab}	0.75^{a}	0.69^{ab}	0.63^{ab}	0.55^{b}	0.51^{b}	0.05	< 0.001
CTTSD of P	0.75^{ab}	0.67^{abc}	0.59^{bc}	0.86^{a}	0.71^{abc}	0.62^{bc}	0.83^{a}	0.77^{ab}	0.71^{abc}	0.59^{bc}	0.55^{c}	0.05	< 0.001
CTTSD-P of P (g/kg)	4.72^{bc}	3.66^{c}	3.33^{cd}	2.12^{de}	1.63^{e}	6.14^{ab}	4.40^{c}	4.28^{c}	3.81^{c}	3.69^{c}	7.05^{a}	0.03	< 0.001

[a, b,c,d,e,f] Within a row, means without a common superscript letter differ (P <0.05)
[1] Each least squares mean represents eight observations
[2] SBM-KD: dehulled soybean meal produced in Korea; SBM-I: soybean meal produced in India; SBM-K: soybean meal produced in Korea; HPDDG: high-protein distillers dried grains; TDDG: tapioca distillers dried grains; CAM: canola meal; CGM: corn germ meal; CM: copra meal; PKM: palm kernel meal; SM: sesame meal; PM: perilla meal
[3] DM: dry matter; Ca: calcium; P: phosphorus; CTTAD: coefficient of total tract apparent digestibility; CTTSD: coefficient of total tract standardized digestibility
[3] Values for CTTSD were calculated by correcting CTTAD values for the basal endogenous loss of P. The basal endogenous loss of P was determined in pigs fed the P-free diet at 190 ± 91 mg/kg of dry matter intake
[3] The concentration of digestible phosphorus in coefficient of total tract standardized digestibility of P.
[4] Standard error means

Although digestibility of P varies, processed corn products generally show greater digestibility of P when compared with unprocessed corn (Almeida & Stein, 2012; NRC, 2012; Rojas *et al*., 2013).

Tapioca is a starch that is isolated from cassava root. It is known to be suitable for ethanol production because of its high carbohydrate content (Cooper & Weber, 2012). In 2010, a total of 1.3 million tons of dried cassava root were utilized for the biofuel industry (Licht, 2011). Production of TDDG will rise in future since there will be an increase in demand for biofuel (Jonker *et al*., 2015). To the best of the authors' knowledge, this is the first report to describe the digestibility of P in TDDG for pigs. It has shown that CTTSD-P of P value is lowest among feed ingredients tested in the current study. Therefore, TDDG might not be a good source of P in pig diet. This result warrants further investigation to optimize feed formulation and determine the digestibility of other nutrients by pigs. Levels of CTTAD and CTTSD of P in CM and PKM in the current study were greater than in the previous report (Almaguer *et al*., 2014). Digestibility and digestible P content in CM and PKM were similar to those in SBM group in the current study. However, CM and PKM should restrict the use for the pig diets, since CM and PKM showed an anti-nutritional effect when used as a SBM replacement (Kim *et al*., 2001; Sekoni *et al*., 2008). Thus, the CM and PKM could be partially utilized as sources of P.

Digestibility of P in SM and PM was lower than in other feed ingredients in the current study. This result may be owing to the high fibre content in SM and PM. According to other studies (Hooda *et al*., 2011; Hanson *et al*., 2012), high dietary fibre in pig diets can disturb the digestion process, resulting in increased faecal extraction of nutrients. Thus, increased fibre intake showed a negative influence on nutrient digestibility in pigs (Schulze *et al*., 1994; Hanson *et al*., 2012). Inclusion of PM in pig diets decreased growth performance and digestibility of protein (Moon *et al*., 1994). These results suggest that the amount of SM and PM should be carefully determined in pig diets although these ingredients showed greater CTTSD-P of P value in the current study.

All ingredient used in the current study showed a greater digestibility of P compared with those in previous studies (Dilger & Adeola, 2006; Akinmusire & Adeola, 2009; Almeida & Stein, 2010; Rojas *et al*., 2013). This might be due to differences in the BW of the pigs. Growing-finishing pigs were used in the current study, but weaners or growers were used in others. Heavier pigs exhibit greater P digestibility (Akinmusire & Adeola, 2009) with greater feed intake based on the equation of ME requirements per BW (NRC, 1998), and CTTAD than lighter ones (Kemme *et al*., 1997).

Conclusions

These results demonstrate the precise digestibility of P in six oilseed meals and two DDGs as alternatives to SBM. They show that the digestibility of P is not affected by the origin of the feed ingredients. PM and CAM could replace SBM as a good source of P. However, the level of use must be calculated carefully because of the inhibiting effect on growth performance. The data showed that digestibility of P varies among feed ingredients used in the current study. In summary, the data from precise evaluation of the nutritional value and P digestibility of various feed ingredients would help to reduce feed costs and P excretion.

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Authors' Contributions

SKP and ESC performed animal management and analysis of samples and results, and wrote the paper. YDJ participated as supervisor of all process for this manuscript. All authors read and approved the final manuscript.

Conflict of interest declaration

The authors have declared that there are no competing interests.

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