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## Digestibility of phosphorous in cereals and co-products for animal feed

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### ABSTRACT

Feed ingredients used in swine diets contain various levels and availabilities of nutrients. Nutritional precision evaluation of each ingredient is necessary for formulating diets of pigs. Especially, phosphorous (P) is one of important nutrients for metabolism. However, current data of P digestibility were most apparent digestibility. Therefore, this study was aimed to estimate the coefficient of total tract standardized digestibility (CTTSD) of P in cereals and various co-products used in pig diet. Twelve barrows (initial BW  $\pm$  SD, 46.70  $\pm$  3.21 kg) were used in this experiment. The experimental design was a 12  $\times$  8 incomplete Latin square with 12 diets and 8 periods. Experimental diets were consisted of barley, wheat, lupine kernel (LK), soybean meal (SBM), almond meal (AM), corn gluten meal (CGM), corn gluten feed from China (CGF-C), corn gluten feed from Korea (CGF-K), wheat bran (WB), rice bran (RB), lupine hull (LH) and P-free diet. The CTTAD of Ca was higher in AM than RB and CGF-K. The LK and CGM showed greater CTTSD of P than RB and LH. In conclusion, our results indicated that the cereals and co-products as P sources were the ideally used as an ingredient in mixed diets of the growing-finishing pigs.

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## 1. Introduction

Among dietary nutrients, phosphorus (P) is closely involved in metabolic process (Jeong et al., 2015). As an enzyme co-factor, it helps formation of bone during a mineralization and production and is an energy currency stored in ATP or cAMP (NRC, 2005). Also, the P plays roles in maintenance of osmolality, acid-base balance, and in chemical reactions by activating or deactivating enzymes (Berner, 1997). Deficiency of P might cause rachitis (in young), osteomalacia (in old), or low appetite (NRC, 2005). Thus, the P is crucial element for health status in vertebrate animals. The P is presented in almost all food or feed sources because it is a structural component of living things. Especially, fish, meat, nuts and dairy products are rich sources of P (Institute of Medicine, 1997). However, plant-derived P existing as phytic acids show low

availability for human and pigs as they lack phytase (NRC, 2012; Calvo and Uribarri, 2013).

Animal diet has been formulated with various feed ingredients. Nutritional values (dry matter, crude protein, tryptophan, and tyrosine, respectively) of corn and soybean meals (SBM) are well assessed and used as major elements of swine diets since these ingredients contained high quality energy and protein with balanced amino acid contents (Akinmusire and Adeola, 2009; Bohlke et al., 2005; NRC, 2012). However, relatively limited data is available for other ingredients such as some cereal and cereal co-products according to NRC (2012).

Nutrient utilization of livestock depends on the constituents of the nutrients contained in the feed composed mainly of plant origin. Especially, pigs show very poor digestibility of P since they possess insufficient endogenous enzyme secretion for phytate-P complex derived from plants (NRC, 2012). We and others previously reported the major feed ingredients including corn and SBM (Akinmusire and Adeola, 2009; Bohlke et al., 2005; Jeong et al., 2015; NRC, 2012). In our earlier report we claimed that the amount of the phosphorous ranged from 2.0 to 2.9 g/kg for the studied nine corn food (Jeong et al., 2015). However, data on the CTTSD of P for minor feed ingredients are limited, when compared with major ones such as corn and SBM. Therefore, the objective of this study was to estimate the CTTSD of P in minor feed ingredients including lupine kernel (LK), lupine hull (LH), CGM, AM

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and two sources of CGF, and compare these with major ingredients, such as SBM, barley, wheat, WB and RB fed to growing-finishing pigs.

### 1.1. Experimental animals and design

Twelve barrows (Initial BW  $\pm$  SD, 46.70  $\pm$  3.21 kg) were randomly housed in individual metabolism cage. Experimental design was a 12  $\times$  8 incomplete Latin square design with twelve diet treatments and 8 periods. A total of 11 ingredients were selected that dehulled soybean meal from Korea (SBM), barley from China, wheat from USA, WB from Korea, RB from Korea, LK from Australia, LH from Australia, Corn gluten meal from Korea (CGM-K), corn gluten feed from China (CGF-C), corn gluten feed from Korea (CGF-K), and AM from unknown. Chemical analysis of each ingredient was shown in Table 1. The experimental diets were prepared that based on corn starch, sucrose and 40% of each test feed ingredient, and

the P free diet to determine the basal endogenous loss (BEL) of P (Table 2). Chemical composition in the experimental diets was presented in Table 3.

During experimental trial in this study, all procedure for managing and caring the experimental animals were approved and inspected by the Animal Care and Use from National Institute of Animal Science. The quantity of feed supplied to pigs was calculated as 2.5 times the estimated requirement for maintenance energy (i.e., 106 kcal ME per kg<sup>0.75</sup>; NRC, 1998). Daily feeding diets were bisected into 2 equal meals that were fed at am 0900 and pm 0500. Animals were accessed *ad libitum* to water during the experiment. The pigs were allowed to adapt the crate and diets during from d 0 to 4 of experimental period. According to marker to marker approach, chromic oxide (1 g/kg) was added in the each experimental diet as an indigestible marker, and the diets were fed at morning meal of d 5 and 8. Start and termination of feces collection were conducted, respectively, since observed the chromic oxide in

**Table 1**  
Nutrient values of feed ingredients<sup>1</sup> (g/kg, as-fed basis).

Items	SBM	Barley	Wheat	WB	RB	LK	LH	CGM	CGF-C	CGF-K	AM
Dry matter	875.54	877.31	896.7	871.43	879.81	889.49	887.13	889.24	894.44	877.86	877.14
Gross energy, MJ/kg	17.77	16	16.51	16.33	19.18	18.27	16.23	21.49	16.75	16.68	16.41
Crude protein	441.8	93.2	113.2	170.2	142.3	350.4	102	678.7	213.2	186.9	30.4
Ether extract	22.63	18.07	16.8	28.76	181.82	62.91	19.52	6.35	17.44	21.15	9.61
Crude fiber	39.05	41.94	21.21	84.46	59.85	38.5	394.37	0.3	95.46	72.65	447.51
Ash	63.86	23.98	17.52	50.85	78.18	30.71	23.87	12.41	60.44	67.68	55.55
Neutral detergent fiber	90.93	183.72	122.25	342.05	175.88	112.56	773.33	15.01	395.45	336.42	643.88
Acid detergent fiber	49.19	55.7	29.31	112.42	66.06	52.73	662.99	2.42	119.19	88.2	454.66
Calcium	4.77	0.7	0.7	1.89	0.65	2.04	5.54	0.24	2.04	0.4	2.9
Phosphorus	6.17	3.01	3.02	8.65	17.29	3.63	1.69	2.36	6.22	9.46	0.51

<sup>1</sup> SBM = soybean meal; WB = wheat bran; RB = rice bran; LK = lupine kernel; LH = lupine hull; CGM = corn gluten meal; CGF-C = corn gluten feed produced from China; CGF-K = corn gluten feed produced from Korea; AM = almond meal.

**Table 2**  
Formulation of feed ingredients in experimental diets<sup>1</sup> (g/kg, as-fed basis).

Items	SBM	Barley	Wheat	WB	RB	LK	LH	CGM	CGF-C	CGF-K	AM	P-free
Corn starch	348.50	280.80	236.00	245.00	255.00	376.30	218.00	361.00	275.00	260.50	371.00	458.90
SBM	400.00	-	-	-	-	-	-	-	-	-	-	-
Barley	-	400.00	-	-	-	-	-	-	-	-	-	-
Wheat	-	-	400.00	-	-	-	-	-	-	-	-	-
WB	-	-	-	400.00	-	-	-	-	-	-	-	-
RB	-	-	-	-	400.00	-	-	-	-	-	-	-
LK	-	-	-	-	-	400.00	-	-	-	-	-	-
LH	-	-	-	-	-	-	400.00	-	-	-	-	-
CGM	-	-	-	-	-	-	-	400.00	-	-	-	-
CGF-C	-	-	-	-	-	-	-	-	400.00	-	-	-
CGF-K	-	-	-	-	-	-	-	-	-	400.00	-	-
AM	-	-	-	-	-	-	-	-	-	-	400.00	-
Sucrose	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
Soybean oil	35.00	32.00	34.00	27.00	-	12.00	33.00	20.00	31.00	22.00	20.00	40.00
Gelatin	-	77.00	120.00	110.00	110.00	-	140.00	-	80.00	100.00	-	170.00
Cellulose	-	-	-	-	-	-	-	-	-	-	-	100.00
DL-Methionine	-	-	-	-	-	-	-	-	-	-	-	3.00
L-Threonine	-	-	-	-	-	-	-	-	-	-	-	1.00
L-Tryptophan	-	-	-	-	-	-	-	-	-	-	-	1.10
L-Histidine	-	-	-	-	-	-	-	-	-	-	-	1.00
L-Isoleucine	-	-	-	-	-	-	-	-	-	-	-	1.00
Limestone	7.50	1.20	1.00	9.00	26.00	2.70	-	10.00	5.00	8.50	-	10.00
Potassium carbonate	-	-	-	-	-	-	-	-	-	-	-	4.00
Magnesium oxide	-	-	-	-	-	-	-	-	-	-	-	1.00
Salt	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Vit-Min premix <sup>2</sup>	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

<sup>1</sup> SBM = soybean meal; WB = wheat bran; RB = rice bran; LK = lupine kernel; LH = lupine hull; CGM = corn gluten meal; CGF-C = corn gluten feed produced from China; CGF-K = corn gluten feed produced from Korea; AM = almond meal; P-free = phosphorus-free diet.

<sup>2</sup> The vitamin-mineral premix provided the following quantities of vitamins and minerals per kilogram of diets: vitamin A, 10,000 IU; vitamin B<sub>1</sub>, 0.49 mg as mononitrate; vitamin B<sub>2</sub>, 0.01 mg; niacin, 10 mg as nicotinic acid; vitamin D<sub>3</sub>, 2000 IU; vitamin E, 250 IU; vitamin K<sub>3</sub>, 0.5 mg; thiamine, 0.49 mg as thiamin mononitrate; riboflavin, 1.50 mg; pyridoxine, 1 mg as pyridoxine hydrochloride; pantothenic acid, 5 mg as calcium pantothenate; folic acid, 1 mg; biotin as d-biotin, 0.1 mg; choline, 125 mg as choline chloride; Co, 0.5 mg as cobaltous carbonate; Cu, 3 mg as cupric sulfate; Fe, 20 mg as ferrous sulfate; I, 1.25 mg as calcium iodate; Mg, 10 mg as magnesium oxide; Mn, 60 mg as manganese sulfate; Zn, 75 mg as zinc sulfate.

**Table 3**  
Nutrient composition of experimental diets<sup>1</sup> (g/kg, as-fed basis).

Items	SBM	Barley	Wheat	WB	RB	LK	LH	CGM	CGF-C	CGF-K	AM	P-Free
Dry matter	914.31	910.51	916.10	907.50	908.03	914.32	913.75	919.29	921.19	916.70	907.58	914.40
Gross energy, MJ/kg	16.93	17.14	17.43	17.13	17.05	17.16	17.57	18.44	17.28	16.78	16.38	17.07
Crude protein	180.10	112.90	165.00	179.60	164.10	120.60	179.40	247.20	162.80	157.90	13.40	171.50
Ether extract	32.94	32.98	32.23	33.43	67.22	31.20	34.30	22.57	34.92	31.45	17.83	28.81
Crude fiber	18.20	14.93	4.95	36.03	23.04	18.43	161.75	1.14	38.43	29.62	169.75	25.41
Ash	38.75	15.52	13.38	32.34	61.74	19.35	15.98	17.58	32.02	34.84	29.64	12.20
Neutral detergent fiber	42.87	81.64	52.32	145.59	71.44	224.19	228.02	11.39	161.15	140.03	242.45	61.34
Acid detergent fiber	22.33	24.07	17.76	48.99	29.95	191.58	183.69	3.86	47.14	34.78	179.77	41.60
Calcium	4.94	1.49	1.48	4.56	9.17	2.09	3.44	3.84	2.80	3.34	2.04	1.36
Phosphorus	4.03	1.55	1.41	5.48	12.36	2.04	0.74	3.68	3.33	5.30	0.32	0.21

<sup>1</sup> SBM = soybean meal; WB = wheat bran; RB = rice bran; LK = lupine kernel; LH = lupine hull; CGM = corn gluten meal; CGF-C = corn gluten feed produced from China; CGF-K = corn gluten feed produced from Korea; AM = almond meal.

feces after fed the meals at d 5 and 8, respectively. Collected fecal samples were stored at  $-20^{\circ}\text{C}$  for chemical analysis.

### 1.2. Sample analysis

Analysis of samples was in accordance with methods of AOAC (2005). Feces samples were pre-dried at  $60^{\circ}\text{C}$  of a drying oven and ground. Collected all samples as test ingredients, experimental diets and feces were analyzed to determine dry matter (DM; 930.15), crude protein (990.03). In the all samples, calcium (Ca) was identified by using an atomic absorption spectrophotometer (978.02; Perkin Elmer 3300, Perkin Elmer, USA). Content of P in the feed ingredients, experimental diets, and feces was evaluated by using a spectrophotometer (946.06; Optizen 2120 UV, Mecasys, Republic of Korea). The feed ingredients and experimental diets were assessed to analyze gross energy using bomb calorimeter (Model C2000, IKA, Germany), ether extract (920.39), crude fiber (978.10), ash (942.05), acid detergent fiber (973.18), and NDF (neutral detergent fiber; Holst, 1973).

### 1.3. Digestibility calculation

Digestibility of P were calculated as previous our study (Park et al., 2017). The digestibility was calculated by equation as following:  $\text{CTTAD} = (\text{Pi} - \text{Pf})/\text{Pi}$ , where Pi is the total P intake (g) and Pf is the total fecal P (g) during from d 5 to 8, respectively. The BEL of P

was measured by following equation as following:  $\text{BEL of P (mg/kg DMI)} = [(\text{Pf}/\text{Fi}) \times 1000 \times 1000]$ , where Fi is the total feed intake (g of DM) from d 5 to 8. The daily BEL of P in pigs fed the experimental diets was determined by multiplying the calculated BEL of P on DM intake by dry matter intake. The CTTSD of P was calculated by equation as following:  $\text{CTTSD} = [\text{Pi} - (\text{Pf} - \text{BEL of P})]/\text{Pi}$ . The CTTAD of Ca was obtained based on formula of CTTAD.

### 1.4. Statistical analysis

Every statistical analysis was executed with SAS package (SAS Inst. Inc., Cary, NC). Basic statistics for each treatment was worked out with UNIVARIATE procedure. ANOVA test was conducted with MIXED procedure using the model considered with the fixed (diet) and random (animal and period) effects. Pairwise comparison among the groups' means was carried out with the Tukey's adjustment using PDIFF option.

## 2. Results

Table 4 showed the CTTAD or CTTSD of P in cereals and co-products. The Ca intake was higher ( $P < 0.001$ ) in RB, SBM, CGM, CGF-C, CGF-K, WB and LH than those of barley, wheat, LK and AM. The fecal Ca was reduced ( $P < 0.001$ ) in barley, wheat, LK and AM compared with SBM, CGM, WB and RB. The CTTAD of Ca

**Table 4**  
Digestibility of phosphorus in cereals and various co-products fed to growing-finishing pigs<sup>1,2</sup> (g/d, as-fed basis).

Items <sup>3</sup>	SBM	Barley	Wheat	WB	RB	LK	LH	CGM	CGF-C	CGF-K	AM	SEM <sup>4</sup>	P value
<i>Feed intake</i>													
Total intake, kg/d	1.59 <sup>cd</sup>	1.73 <sup>abcd</sup>	1.56 <sup>cd</sup>	1.89 <sup>a</sup>	1.83 <sup>ab</sup>	1.61 <sup>bcd</sup>	1.75 <sup>abc</sup>	1.60 <sup>cd</sup>	1.50 <sup>d</sup>	1.63 <sup>bcd</sup>	1.63 <sup>bcd</sup>	0.07	<0.001
Intake of dry matter, kg/d	1.46 <sup>bc</sup>	1.57 <sup>abc</sup>	1.43 <sup>c</sup>	1.72 <sup>a</sup>	1.67 <sup>ab</sup>	1.47 <sup>bc</sup>	1.60 <sup>abc</sup>	1.47 <sup>bc</sup>	1.38 <sup>c</sup>	1.49 <sup>bc</sup>	1.48 <sup>bc</sup>	0.06	<0.001
Intake of calcium	7.98 <sup>b</sup>	2.62 <sup>ef</sup>	2.35 <sup>f</sup>	8.74 <sup>b</sup>	16.97 <sup>a</sup>	3.39 <sup>e</sup>	6.10 <sup>e</sup>	6.22 <sup>c</sup>	4.29 <sup>d</sup>	5.40 <sup>e</sup>	3.36 <sup>e</sup>	0.23	<0.001
Intake of phosphorus	6.47 <sup>d</sup>	2.76 <sup>fg</sup>	2.21 <sup>gh</sup>	10.50 <sup>b</sup>	22.83 <sup>a</sup>	3.35 <sup>f</sup>	1.25 <sup>hi</sup>	5.98 <sup>de</sup>	5.05 <sup>e</sup>	8.48 <sup>c</sup>	0.59 <sup>i</sup>	0.26	<0.001
<i>Excretion of feces</i>													
Total output	60.1 <sup>d</sup>	108.1 <sup>cd</sup>	67.4 <sup>d</sup>	216.6 <sup>b</sup>	197.8 <sup>b</sup>	61.1 <sup>d</sup>	225.8 <sup>b</sup>	50.5 <sup>d</sup>	164.2 <sup>bc</sup>	180.3 <sup>b</sup>	365.2 <sup>a</sup>	16.3	<0.001
Output of dry matter	56.2 <sup>d</sup>	103.3 <sup>cd</sup>	63.4 <sup>d</sup>	206.9 <sup>b</sup>	184.1 <sup>b</sup>	57.6 <sup>d</sup>	216.3 <sup>b</sup>	48.0 <sup>d</sup>	156.8 <sup>bc</sup>	170.8 <sup>bc</sup>	349.6 <sup>a</sup>	15.3	<0.001
Output of calcium	2.24 <sup>bc</sup>	1.04 <sup>de</sup>	0.88 <sup>e</sup>	2.52 <sup>b</sup>	7.89 <sup>a</sup>	0.93 <sup>de</sup>	1.62 <sup>bcd</sup>	2.28 <sup>bc</sup>	1.34 <sup>cde</sup>	2.10 <sup>bcd</sup>	0.83 <sup>e</sup>	0.26	<0.001
Output of phosphorus	2.43 <sup>cd</sup>	1.31 <sup>efg</sup>	1.05 <sup>efg</sup>	3.48 <sup>b</sup>	10.86 <sup>a</sup>	1.11 <sup>efg</sup>	0.88 <sup>fg</sup>	1.92 <sup>de</sup>	1.84 <sup>def</sup>	3.30 <sup>bc</sup>	0.41 <sup>g</sup>	0.25	<0.001
<i>Digestibility</i>													
CTTAD of calcium	0.72 <sup>ab</sup>	0.62 <sup>abc</sup>	0.65 <sup>abc</sup>	0.71 <sup>ab</sup>	0.53 <sup>c</sup>	0.72 <sup>ab</sup>	0.75 <sup>ab</sup>	0.65 <sup>abc</sup>	0.70 <sup>ab</sup>	0.61 <sup>bc</sup>	0.76 <sup>a</sup>	0.03	<0.001
CTTAD of phosphorus	0.63 <sup>a</sup>	0.53 <sup>ab</sup>	0.55 <sup>a</sup>	0.67 <sup>a</sup>	0.52 <sup>ab</sup>	0.67 <sup>a</sup>	0.35 <sup>bc</sup>	0.69 <sup>a</sup>	0.64 <sup>a</sup>	0.61 <sup>a</sup>	0.25 <sup>c</sup>	0.04	<0.001
CTTSD of phosphorus	0.66 <sup>ab</sup>	0.60 <sup>ab</sup>	0.64 <sup>ab</sup>	0.69 <sup>ab</sup>	0.53 <sup>b</sup>	0.72 <sup>a</sup>	0.52 <sup>b</sup>	0.72 <sup>a</sup>	0.68 <sup>ab</sup>	0.63 <sup>ab</sup>	0.62 <sup>ab</sup>	0.04	0.004

a,b,c,d,e,f,g,h,i Means within a row without a common superscript letter differ ( $P < 0.05$ ).

<sup>1</sup>SBM = soybean meal; WB = wheat bran; RB = rice bran; LK = lupine kernel; LH = lupine hull; CGM = corn gluten meal; CGF-C = corn gluten feed produced from China; CGF-K = corn gluten feed produced from Korea; AM = almond meal.

<sup>2</sup>Each least squares mean represents 8 observations except CGM (n = 9).

<sup>3</sup>CTTAD = coefficient of total tract apparent digestibility; CTTSD = coefficient of total tract standardized digestibility.

<sup>4</sup>Values for CTTSD were calculated by correcting values of CTTAD for the basal endogenous loss (BEL) of P. The BEL of P was determined in pigs fed the P-free diet at  $131 \pm 28$  mg/kg of dry matter intake (DMI).

<sup>5</sup>SEM = standard error of the means.

was lower ( $P < 0.001$ ) in RB than those of LK, SBM, AM, CGF-C, WB and LH.

The intake of P was higher ( $P < 0.001$ ) in SBM, WB, RB and CGF-K than the other ingredients except CGM. The pigs fed RB presented highest ( $P < 0.001$ ) fecal P level than the other ingredients. The CTTAD of P was higher ( $P < 0.001$ ) in SBM, wheat, WB, LK, CGM, CGF-C, CGF-K than those of LH and AM. The LK and CGM showed higher ( $P < 0.01$ ) CTTSD of P than RB and LH.

### 3. Discussion

In this study, values for CTTAD and CTTSD of P in SBM, barley, wheat, WB and RB tended to be greater than those reported by others (Bohlke et al., 2005; Fandrewski et al., 1997; NRC, 2012; Nyachoti et al., 2005; Thacker et al., 2003). In digestibility analysis, the amount of diet fed to pigs is generally calculated by following formula; 106 Kcal ME per  $\text{kg}^{0.75}$  (NRC, 1998). According to this equation, the heavier pigs have more P intake by increasing diet volume than lighter pigs. Ajakaiye et al. (2003) reported that digestibility of P is improved by increasing intake of P in growing pigs. Son et al. (2013) showed that the BEL is increased by gaining BW of growing-finishing pigs. Thus, greater level of CTTAD and CTTSD of P might be due to the greater BW of pigs used in our study when compared with others (47 vs. 13–40 kg).

Values for CTTAD and CTTSD of P of CGM, CGF-K and CGF-C from the current study were greater than those published by NRC (2012), but lower than Rojas et al. (2013)'s data. Nutrient contents in corn co-product including CGM and CGF vary depending on the manufacturing processes of starch, corn oil, or ethanol extraction (Bothast and Schlicher, 2005; Rojas et al., 2013). Compare to unprocessed corn, these processed corn co-products have higher levels of gross energy, protein, amino acids, Ca, and P, but they showed relatively high inhibition factors for P absorption (Rojas et al., 2013). Furthermore, reinforcement levels of nutrient by processing methods also vary depending on the source or origin of grain (Jeong et al., 2015). Thus, these results may explain the discrepancies of P digestibility between the current and other studies.

Lupine is a good ingredient for pig diet because of its relatively high protein and energy content. However, it contains several anti-nutritional factors such as alkaloids, saponins, and raffinose that could negatively affect growth performance by decreasing both feed intake and ileal amino acid digestion (Ferguson et al., 2003; Yang et al., 2007). The LH, which contains more anti-nutritional factors than kernel, showed a lower digestibility of P compare to LK (Ferguson et al., 2003). Anti-nutritional factors can also be reduced by expanding and flaking process (Yang et al., 2007). Therefore, it is desirable to select appropriate processing method to optimize the P availability of lupine.

The CTTAD and CTTSD of P in AM were 25 and 62%, respectively, in our current study, however CTTSD of AM was not statistically different from other feed ingredients. This result suggest that AM might act as a P source, but showed the lowest P intake among feed ingredients in growing-finishing pigs. These results agreed with the previous study showing a significant positive relationship between intake and apparent fecal digestible intake of P, but a negative correlation between endogenous P loss and P intake (Ajakaiye et al., 2003). In other words, CTTAD of P is decreased when P intake is low, whereas CTTSD of P is increased when endogenous P loss is high. Therefore, AM is not to be considered as a P source due to its low availability in pigs.

The Ca is an essential element for animal growth and reproduction (González-Vega and Stein, 2014; NRC, 2012). In most cases, pigs absorb Ca from an inorganic form because Ca in plant-derived feed ingredients is poorly digested in pigs and Ca content is very low in plant (Lee et al., 2017; González-Vega and Stein,

2014). In swine feed industry, inorganic forms of Ca such as limestone and Ca-phosphate are well analyzed and commonly used as Ca supplements, but data of organic form of Ca is relatively limited (González-Vega and Stein, 2014). Results of CTTAD of Ca in cereal and various co-products from our current study might be useful in aspect of basic data for Ca availability.

### 4. Conclusions

In our current study, the AM showed greater CTTAD of Ca than RB and CGF-K. The CTTAD of P, however, was lower in AM compare to other ingredients and CTTSD of P of AM was similar to other ingredients. These results suggest that minor ingredients including LK, SBM, CGM, CFG, WB, RB, LH can be used as feed ingredients but AM is not suitable infeed ingredient for growing-finishing pigs. The CTTAD of Ca was higher in AM than RB and CGF-K. The LK and CGM showed greater CTTSD of P than RB and LH. In conclusion, our results indicated that the cereals and co-products as P sources were the ideally used as a source for the feed additives in the growing-finishing pigs. Results from this study can be used to determine the precise P level in pig feed formulation.

### Declaration conflict of interest

Not applicable.

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