Effects of extrusion and microbial phytase on the apparent and standardized total tract digestibility of phosphorus in hemp hulls fed to growing pigs

J. W. Kim,* B. Koo,* I. H. Kim,[†] and C. M. Nyachoti*¹

*Department of Animal Science, University of Manitoba, Winnipeg, MB R3T 2N2, Canada; [†]Department of Animal Resource and Science, Dankook University, Cheonan, Chungnam 330-714, South Korea

ABSTRACT: An experiment was carried out to determine the apparent total tract digestibility (ATTD) and the standardized total tract digestibility (STTD) of P and the effects of extrusion and microbial phytase on ATTD and STTD of P in hemp hulls (HH). Thirty-six pigs (30.3 ± 2.7 kg) were randomly allotted to 1 of 6 experimental diets in a complete randomized design with 6 replicates per diet. A corn-soybean meal (SBM)-based basal diet was formulated. Two additional diets were formulated by replacing 40% of corn and SBM (on a 100% of total diet basis) with HH or extruded HH (EHH). The test ingredients, corn, and SBM were the only sources of P in the diets. Three additional diets were also prepared by supplementing 500 unit/kg of microbial phytase to the initial 3 diets (the corn-SBM basal diet and diets containing test ingredients). Pigs were fed experimental diets at 3 times the maintenance energy requirement ($197 \text{ kcal ME/kg BW}^{0.60}$). Results indicated that fecal P concentration and daily P output were reduced ($P < 0.05$) from pigs fed diets with dietary phytase compared with pigs fed diets without dietary phytase. The ATTD and STTD of P in experimental diets were

not different. However, the ATTD and STTD of P in experimental diets supplemented with dietary phytase were increased ($P < 0.05$) compared with the diets without phytase. The ATTD and STTD of P in HH were 18.8% and 22.0%, respectively, whereas respective values for EHH were 22.5% and 26.3%. Extrusion had no effects on ATTD and STTD of P in HH. However, the ATTD and STTD of P in HH and EHH increased ($P < 0.05$) when dietary phytase was added to the diets. The concentration of Ca in feces and daily Ca output were reduced ($P < 0.05$) as a result of phytase supplementation. Addition of dietary phytase increased ($P < 0.05$) the ATTD of Ca in all experimental diets. In conclusion, the ATTD and STTD of P in HH fed to growing pigs were 18.8% and 22.0%, respectively. Respective values for EHH were 22.5% and 26.3%. Extrusion did not affect the ATTD and STTD of P in HH. However, the addition of microbial phytase to experimental diets increased the ATTD and STTD of P in diets and test ingredients and decreased fecal P output from pigs fed experimental diets. There was no interaction between extrusion and dietary phytase supplementation.

Key words: extrusion, hemp hulls, phosphorus digestibility, phytase, pig

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INTRODUCTION

Hemp (*Cannabis sativa* L.) is an annual herbaceous plant belonging to the Cannabinaceae

family, traditionally planted for seed and fiber production (Turner et al., 1979). The hemp hulls (HH), a coproduct of dehulled hemp seed, has received great attention as a potential alternative to conventional feed ingredients due to its high nutritive values (high fat and protein) and availability in North America (Kim and Nyachoti, 2017). However, information on the nutritive value of HH for swine

¹Corresponding author: Martin.Nyachoti@umanitoba.ca

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is scarce and in particular, no study has determined the digestibility of P in HH for swine. To accurately formulate swine diets with respect to dietary P supply, the use of standardized total tract digestibility (STTD) values determined for individual feed ingredients is recommended (NRC, 2012).

Most P in feed ingredients of plant origin is bound to phytate (Bedford, 2000), which is poorly digested by pigs and results in low digestibility of P. Dietary microbial phytase supplementation has been shown repeatedly to improve the digestibility of P in pig feed and feed ingredients (Casas and Stein, 2015; Adhikari et al., 2016b; Kim et al., 2017). Also, extrusion, a thermal and mechanical processing technique, which combines high pressure with high temperatures, has been reported to improve the nutritive value of pig feed ingredients (Golian et al., 2007; Kiarie and Nyachoti, 2007; Ayoade et al., 2012). The extrusion procedure appears to improve the digestibility of P in feed ingredients of plant origin by reducing the phytate content (Alonso et al., 2001; Singh et al., 2007). Therefore, it was hypothesized that dietary phytase supplementation and extrusion would improve the digestibility of P in HH.

Thus, the objectives of this study were to determine the apparent total tract digestibility (ATTD) and STTD of P in HH and extruded HH (EHH) and to test the hypothesis that dietary phytase supplementation and extrusion improve the digestibility of P in HH fed to growing pigs.

MATERIALS AND METHODS

The experimental protocol used in the current study was reviewed and approved by the University of Manitoba Animal Care Committee, and pigs were handled according to the guidelines of the Canadian Council on Animal Care (2009). The HH and EHH evaluated in the current study were obtained from a local farm (Starlite Colony, Starbuck, MB, Canada). The hemp seed was grown in Starbuck, MB, Canada, the summer of 2015, and harvested by Starlite Colony (Starbuck, MB, Canada). The hemp seed was dehulled, and then the hull fraction was used in the current study. To obtain EHH, the HH was dry-extruded on a single flight screw extruder (model 2000R, Insta-Pro, Des Moines, IA) without preconditioning. Internal barrel temperature during the extrusion was kept at 135 °C.

Animals and Housing

Thirty-six growing barrows [(Yorkshire × Landrace) × Duroc] with an average initial BW

of 30.3 ± 2.7 kg (mean $\pm$ SD) were obtained from the Glenlea Swine Research Unit, University of Manitoba (Winnipeg, MB, Canada) and individually housed in metabolism crates (1.8 by 0.6 m) equipped with a feeder and a nipple drinker within an environmentally controlled room in the T. K. Cheung Centre for Animal Science Research. The experiment was conducted in 2 consecutive periods (18 pigs per period) using the same facility and similar experimental conditions and procedures. Pigs were randomly allotted to 1 of 6 experimental diets in a complete randomized design with 3 replicates per diet (per period).

Experimental Diets and Feeding

A corn-soybean meal (SBM)-based basal diet was formulated (Table 1). Two additional diets were formulated by replacing 40% of corn and SBM (on a 100% of total diet basis) with HH or EHH. The ratio between corn and SBM was maintained constant at 2.2:1. The test ingredients, corn, and SBM were the only sources of P in the diets. Three additional diets were also prepared by supplementing 500 phytase unit (FTU)/kg of microbial phytase to the initial 3 diets (a corn-SBM basal diet and diets containing test ingredients). Vitamins and minerals except P were included in the diets to meet or exceed the requirements for growing pigs (NRC, 2012). Pigs were fed their diets at 3 times the maintenance energy requirement based on their BW at the beginning of experiment (i.e., 197 kcal ME/kg BW^{0.60}; NRC, 2012). The daily feed allowance was offered in 2 equal portions at 0830 and 1630 h. Pigs had free access to the water.

Sample Collection and Chemical Analyses

Pigs were fed experimental diets for 12 d, including 5 d for adaptation to the experimental diets and 5 d for total collection of feces. During the collection period, 5 g of indigestible marker (ferric oxide) was added to 100 g of feed that was fed in the morning on day 6 and day 11 to mark the beginning and the end, respectively, of fecal collections (Kim et al., 2017). The remaining portion of the morning feed was offered after all the marked feed was consumed. Feces were collected once daily at 0830 h and stored at −20 °C immediately.

Fecal samples were dried in a forced air drying oven at 60 °C for 5 d, weighed, pooled on a pig basis, and subsampled. Samples of ingredients and experimental diets were ground through a 1-mm screen in a Wiley mill (Thomas Scientific,

Table 1. Composition of experimental diets with-out or with microbial phytase (as-fed basis)

Item, %	Diet ^a		
	Basal	HH	EHH
Ingredients			
Corn	65.96	38.47	38.47
Soybean meal	30.00	17.49	17.49
Hemp hulls		40.00	
Extruded hemp hulls			40.00
Vegetable oil	2.00	2.00	2.00
Limestone	1.50	1.50	1.50
Iodized salt	0.40	0.40	0.40
Vitamin-mineral premix ^b	0.14	0.14	0.14
Analyzed composition, %			
Diets without microbial phytase			
DM	87.6	89.6	90.6
GE, kcal/kg	3,949	4,521	4,447
CP	19.0	20.3	18.9
Ash	3.03	4.83	4.70
Ca	0.65	0.69	0.70
P	0.39	0.47	0.44
Diets with microbial phytase^c			
DM	87.5	90.0	90.9
GE, kcal/kg	3,959	4,563	4,455
CP	18.7	19.8	19.0
Ash	3.19	4.97	4.81
Ca	0.69	0.69	0.70
P	0.40	0.48	0.43

^aBasal diet = corn-soybean meal-based basal diet; HH = a diet containing a basal diet and 40% of hemp hulls with constant corn:soybean meal ratio; EHH, a diet containing a basal diet and 40% of extruded hemp hulls with constant corn:soybean meal ratio.

^bSupplied the following per kilogram of finished feed: vitamin A, 2,000 IU; vitamin D, 200 IU; vitamin E, 40 IU; vitamin K, 2 mg; choline, 350 mg; pantothenic acid, 14 mg; riboflavin, 7 mg; folic acid, 1 mg; niacin, 21 mg; thiamin, 1.5 mg; vitamin B6, 2.5 mg; biotin, 70 µg; vitamin B12, 20 mg; Cu, 10 mg; Zn, 110 mg; Fe, 120 mg; Mn, 10 mg; I, 0.4 mg; Se, 0.3 mg.

^cAnalyzed microbial phytase activity was 4,880 FTU/g (Canadian Bio-System Inc., Calgary, AB, Canada); phytase was included at 0.102 g/1 kg of feed to provide 500 FTU/kg of complete feed.

Swedesboro, NJ), whereas fecal samples were finely ground in a coffee grinder (Smart Grind; Applica Consumer Products, Inc., Miami Lakes, FL) before chemical analysis. Samples of ingredients, diets, and feces were analyzed for DM (Method 930.15; AOAC, 2006) and Ca and P (Methods 985.01A, B, and C; AOAC, 2006). Diets and ingredients were also analyzed for ash (Method 942.05; AOAC, 2006), GE by adiabatic bomb calorimeter, CP by combustion (Method 990.03; AOAC, 2006), ether extract by using hexane (Method 920.39A; AOAC, 2006), ADF (Goering and Van Soest, 1970), and NDF (Goering and Van Soest, 1970). Phytate concentrations in the HH and EHH were also determined according to Ellis et al. (1977). The AA

contents were determined according to AOAC (Method 994.12; 2006). Briefly, 100 mg of each sample was digested in 4 mL of 6 M HCl for 24 h at 110 °C followed by neutralization with 4 mL of 25% (wt/vol) NaOH and cooled to room temperature. The mixture was then equalized to 50 mL volume with sodium citrate buffer (pH 2.2) and analyzed using an AA analyzer (Sykam GmbH, Fürstentfeldbruck, Germany). For analysis of sulfur-containing AA (Met and Cys), samples were subjected to performic acid oxidation before acid hydrolysis. Tryptophan was not determined.

Calculations

The concentrations of nonphytate and phytate-bound P in HH and EHH were calculated as previously described by Tran and Sauvant (2004). The ATTD of P in experimental diets was calculated according to the following equation (Almeida and Stein, 2010):

$$\text{ATTD}(\%) = [(P_i - P_f) / P_i] \times 100$$

where P_i is the total P intake (g) from day 6 to 10 and P_f is the total P output (g) in the same period. The STTD of P was calculated by correcting the ATTD of P for the basal endogenous P loss (EPL), which was assumed to be 200 mg/kg DMI (NRC, 2012). The corn-SBM basal diet was used to calculate the contribution of P from corn and SBM to the diets containing HH and EHH. The ATTD and STTD of P in HH and EHH were then calculated using the difference procedure according to Casas and Stein (2015):

$$D_A = (D_T - D_B \times S_B) / S_A$$

where D_A is the ATTD or STTD of P in the test ingredient (%), D_T is the ATTD or STTD of P in the diet containing the test ingredient (%), D_B is the ATTD or STTD of P in the basal diet (%), S_B is the contribution level of basal diet to the test diet (%), and S_A is the contribution level of P from the test feed ingredient to the assay diet (%). The ATTD and STTD of P in test ingredients without or with phytase were calculated using the basal diet without or with phytase, respectively.

Statistical Analysis

The UNIVARIATE procedure in SAS was used to test the homogeneous variances and to identify outliers, but no outliers were identified. Data from experimental diets were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) as a

3 × 2 factorial arrangement. The individual pig was considered the experimental unit for all analyses. The model included main effects of the diet and phytase, and their interaction. However, data for the comparison of ATTD and STTD of P in test ingredients were analyzed using the MIXED procedure as a 2 × 2 factorial arrangement. In this analysis, the fixed effects were the extrusion, phytase, and the interaction between extrusion and phytase. The LSMEANS procedure was used to calculate mean values, and the PDIF option of SAS was used to separate means if differences were detected. A probability of $P < 0.05$ was considered significant.

RESULTS

The total P contents were 0.30% in corn and 0.70% in SBM (Table 2). The HH and EHH contained 0.58% and 0.53% of total P, respectively. The concentration of phytate-bound P in HH and EHH were 0.39% and 0.26%, respectively, which were 67.2% and 49.1% of total P, respectively. All experimental diets contained the expected Ca and P contents based on the formulated values (Table 1).

Daily P intake was greater ($P < 0.05$) for pigs fed the EHH diet than for pigs fed the basal diet but less ($P < 0.05$) than for those fed the HH diet (Table 3). However, dietary phytase did not affect daily P intake. The concentration of P in feces was the lowest ($P < 0.05$) in pigs fed the EHH diet but the highest ($P < 0.05$) in pigs fed the basal diet with an intermediate value in pigs fed the HH diet. Dietary phytase inclusion reduced ($P < 0.05$) the concentration of P in feces. Daily P output from pigs fed the basal diet was less ($P < 0.05$) than that of pigs fed the HH and EHH diets. The daily P output was reduced ($P < 0.05$) in pigs fed diets with dietary phytase compared with pigs fed diets without dietary phytase. The ATTD and STTD of P in the basal, HH, and EHH diets were not different. However, the ATTD and STTD of P in experimental diets supplemented with dietary phytase were increased ($P < 0.05$) compared with the diets without phytase. No interactions were observed in all measurements except for the concentration of P in feces.

The ATTD and STTD of P in HH were 18.8% and 22.0%, respectively (Table 4). Respective values for EHH were 22.5% and 26.3%. Extrusion had no effects on ATTD and STTD of P in HH. However, the ATTD and STTD of P in HH increased ($P < 0.05$) when dietary phytase was added to the diets.

Table 2. Analyzed nutrient composition of corn, soybean meal, hemp hulls (HH), and extruded hemp hulls (EHH) (as-fed basis)

Item	Ingredient			
	Corn	Soybean meal	HH	EHH
DM, %	86.3	88.5	92.4	94.3
GE, kcal/kg	3,831	4,107	5,383	5,149
CP, %	7.8	46.3	21.6	20.0
Ether extract, %	2.4	0.6	19.4	16.0
NDF, %	8.2	8.5	50.7	52.3
ADF, %	3.1	5.4	39.9	40.2
Ca, %	0.01	0.48	0.14	0.15
P, %	0.30	0.70	0.58	0.53
Phytate, %	—	—	1.38	0.92
Phytate-bound P ^a , %	—	—	0.39	0.26
Phytate-bound P, % of total P	—	—	67.2	49.1
Nonphytate P ^b , %	—	—	0.19	0.27
Nonphytate-bound P, % of total P	—	—	32.8	50.9
Indispensable AA, %				
Arg	—	—	1.76	1.63
His	—	—	0.49	0.50
Ile	—	—	0.51	0.53
Leu	—	—	0.97	1.06
Lys	—	—	0.64	0.72
Met	—	—	0.27	0.26
Phe	—	—	0.67	0.72
Thr	—	—	0.46	0.50
Val	—	—	0.71	0.71
Dispensable AA, %				
Ala	—	—	0.60	0.64
Asp	—	—	1.35	1.75
Cys	—	—	0.25	0.20
Glu	—	—	2.14	2.35
Gly	—	—	0.68	0.72
Pro	—	—	0.67	0.70
Ser	—	—	0.68	0.65
Tyr	—	—	0.44	0.42

^aPhytate-bound P was calculated as 28.2% of phytate (Tran and Sauvant, 2004).

^bNonphytate P was calculated as the difference between total P and phytate-bound P.

No interactions were observed for daily Ca intake, fecal Ca concentration, daily Ca output, and ATTD of Ca among dietary treatments (Table 5). The concentration of Ca in feces was greater ($P < 0.05$) for pigs fed the basal diet than for those fed the HH and EHH diets. Daily Ca output from pigs fed the basal diet was less ($P < 0.05$) than those fed the HH and EHH diets. The concentration of Ca in feces and daily Ca output were reduced ($P < 0.05$) as a result of phytase supplementation. Addition of dietary phytase increased

Table 3. Apparent total tract digestibility (ATTD) and standardized total tract digestibility (STTD) of P (%) by pigs fed a corn-soybean meal-based basal diet or diets containing hemp hulls (HH) and extruded hemp hulls (EHH) without or with microbial phytase^{a,b,c}

Item	Feed intake, g/d	P intake, g/d	P in feces, %	P output, g/d	ATTD of P, %	Basal EPLd, mg/d	STTD of P, %
Without phytase							
Basal diet	1,328	5.24 ^c	2.90 ^a	3.59 ^b	31.5 ^b	232.7	36.0 ^b
HH	1,323	6.27 ^a	1.34 ^c	4.70 ^a	25.0 ^b	237.1	28.8 ^b
EHH	1,345	5.90 ^{ab}	1.13 ^d	4.30 ^a	27.3 ^b	243.9	31.4 ^b
With phytase							
Basal diet	1,347	5.43 ^c	2.17 ^b	2.49 ^d	54.1 ^a	235.8	58.5 ^a
HH	1,303	6.29 ^a	0.92 ^c	3.16 ^{bc}	49.7 ^a	234.5	53.4 ^a
EHH	1,313	5.67 ^{bc}	0.78 ^c	2.86 ^{cd}	49.7 ^a	238.8	53.9 ^a
SEM	36.3	0.161	0.055	0.212	3.13	6.50	3.13
P-value							
Diet	0.755	<0.001	<0.001	<0.001	0.148	0.484	0.102
Phytase	0.682	0.974	<0.001	<0.001	<0.001	0.763	<0.001
Diet × phytase	0.735	0.402	0.002	0.512	0.911	0.791	0.914

^aMicrobial phytase was supplemented at 500 FTU/kg of complete feed.

^bBasal diet = corn-soybean meal-based basal diet; HH = a diet containing a basal diet and 40% of hemp hulls with constant corn:soybean meal ratio; EHH, a diet containing a basal diet and 40% of extruded hemp hulls with constant corn:soybean meal ratio.

^cEach value represents the mean of 6 observations.

^dBasal EPL = basal endogenous P loss.

^{a-c}Within a column, means without a common superscript differ ($P < 0.05$).

($P < 0.05$) the ATTD of Ca regardless of experimental diets, and the ATTD of Ca was greater ($P < 0.05$) in the basal and HH diets than in the EHH diet.

DISCUSSION

Table 4. Apparent total tract digestibility (ATTD) and standardized total tract digestibility (STTD) of P (%) by pigs in hemp hulls (HH) and extruded hemp hulls (EHH) without or with microbial phytase^{a,b}

Item	ATTD	STTD
Without phytase		
HH	18.8 ^b	22.0 ^b
EHH	22.5 ^b	26.3 ^b
With phytase		
HH	44.5 ^a	48.5 ^a
EHH	45.5 ^a	48.6 ^a
SEM	6.57	6.57
P-value		
Extrusion	0.828	0.733
Phytase	0.001	0.001
Extrusion × phytase	0.705	0.721

^aMicrobial phytase was supplemented at 500 FTU/kg of complete feed.

^bEach value represents the mean of 6 observations.

^{ab}Within a column, means without a common superscript differ ($P < 0.05$).

Hemp (*C. sativa* L.) is receiving renewed interest as a profitable agricultural and industrial crop due to its potential health benefits such as high level of dietary fiber and essential fatty acids (Jing et al., 2017; Kim and Nyachoti, 2017). In the past, the commercial production of hemp was strictly regulated because of the high concentration of Δ -9 tetrahydrocannabinol, a psychoactive substance found in the hemp plant. However, since 1998, the legal cultivation of industrial hemp under a strict licensing system has been allowed in Canada (Health Canada, 2012). Consequently, the availability of HH is increasing as a coproduct along with the increase in cultivation of hemp for human consumption and creates opportunities to use them in livestock diets (Kim and Nyachoti, 2017). In Canada, about 40,000 acres are licensed in 2011 for hemp production and over 32,000 acres were for seed production. Although an average yield varies, the estimated yield of hemp seed per acre is 500 kg per acre, and therefore the estimate for the production of hemp seed was about 20,000 tonnes in 2011 (Laate, 2011). Despite of its current availability, the hemp related coproducts such as hemp oil, meal, cake, and hulls are not approved for use in commercial livestock diets in Canada. More evidence regarding its efficacy and safety as a feed ingredient for livestock diets is required for approval. In poultry, several attempts have been made to prove

Table 5. Apparent total tract digestibility (ATTD) of Ca (%) by pigs fed a corn-soybean meal-based basal diet or diets containing hemp hulls (HH) and extruded hemp hulls (EHH) without or with microbial phytase^{a,b}

Item	Ca intake, g/d	Ca in feces, %	Ca output, g/d	ATTD of Ca, %
Without phytase				
Basal diet	8.68 ^b	3.70 ^a	4.57 ^b	47.3 ^{cd}
HH	9.00 ^{ab}	1.37 ^c	4.79 ^{ab}	46.8 ^{cd}
EHH	9.44 ^a	1.44 ^c	5.50 ^a	41.9 ^d
With phytase				
Basal diet	9.32 ^{ab}	3.11 ^b	3.55 ^c	61.7 ^a
HH	8.93 ^{ab}	1.02 ^d	3.51 ^c	60.6 ^{ab}
EHH	9.22 ^{ab}	1.15 ^{cd}	4.37 ^{bc}	52.9 ^{bc}
SEM	0.222	0.123	0.324	3.23
<i>P</i> -value				
Diet	0.211	<0.001	0.020	0.001
Phytase	0.529	<0.001	<0.001	<0.001
Diet × phytase	0.140	0.382	0.923	0.885

^aMicrobial phytase was supplemented at 500 FTU/kg of complete feed.

^bEach value represents the mean of 6 observations.

^{a-d}Within a column, means without a common superscript differ ($P < 0.05$).

its safety and efficacy as a feed ingredient (Gakhar et al., 2012; Neijat et al., 2014; Jing et al., 2017), but more studies are needed in swine.

With respect to dietary P supply in swine diets formulation, the use of standardized total tract digestible P values have been recommended because these values are additive in mixed diets (NRC, 2012). Values for the STTD of P in experimental diets were calculated by correcting the ATTD of P with the basal EPL (Casas and Stein, 2015; 200 mg/kg DMI). The estimated basal EPL output was, on average, 237 mg/d. This value is also close to the predicted basal EPL output (266 mg/d) calculated from the prediction equation [basal EPL (mg/kg DMI) = $2.23 \times \text{initial BW} + 156.4$; Son et al., 2013].

In the current experiment, the STTD of P in the basal diet without phytase supplementation was similar (36.0% vs. 40.2%) to the expected value calculated from NRC (2012), which indicates that the values for the test ingredients are accurate. Because there is no study that has reported the digestibility of P in HH for swine, it is difficult to compare the results of the current study. However, we have attempted to compare the results of this study with similar studies on coproducts of oilseed which contains high levels of fiber because HH is also a coproduct of oilseed and contains high levels of fiber. The phytate-bound P contents in camelina

meal (0.63%; Adhikari et al., 2016b), canola meal (0.64%; Adhikari et al., 2016a), and flaxseed meal (0.45%; Kim et al., 2017) were greater than in the HH (0.39%) used in the current study, but, the contents of phytate-bound P (% of total P) were similar among the ingredients (canola meal, 63%; camelina meal, 66%; flaxseed meal, 58%; HH, 67%). Regardless of phytate-bound P contents, the STTD of P in HH (22.0%) was much less than that in camelina meal (56.0%), canola meal (30.7%), and flaxseed meal (37.3%), which indicates that there is no direct relationship between the P digestibility of feed ingredients and concentration of phytate-bound P.

In the current study, extrusion decreased phytate-bound P in HH by 33%, which agrees with the study of Alonso et al. (2001) who reported that extruded pea and kidney bean contained less phytate-bound P compared with their native materials. The concentration of phytate-bound P in corn and wheat was also reduced by 15% as a result of extrusion (Pontoppidan et al., 2007). Degradation of phytate during extrusion can be explained by 2 mechanisms; either the endogenous phytase in ingredients of plant origin is shortly activated during the extrusion or the high temperature and pressure during the extrusion degrade the phytate molecule (Eeckhout and De Paepe, 1994; Pontoppidan et al., 2007). However, the reduction in the concentration of phytate-bound P did not result in improved ATTD or STTD of P in HH in the current experiment. This result is in agreement with the study of Kraler et al. (2014) who reported that the ATTD of P in diet containing 20% of extruded wheat bran was comparable to that in a diet containing 20% native wheat bran although phytate-bound P in wheat bran was reduced as a result of extrusion. Denaturation of endogenous phytase in HH due to the high temperature during extrusion may partly explain the lack of extrusion effect on the ATTD or STTD of P although the concentration of phytate-bound P was reduced.

Addition of dietary phytase to swine diets has been reported to improve digestibility of P in diets and ingredients and reduce P excretion (Casas and Stein, 2015; Kiarie et al., 2016; She et al., 2017). However, there is limited information about the effect of dietary phytase supplementation on ATTD and STTD of P in HH. In the current study, the addition of dietary phytase increased the STTD of P in diets and test ingredients by 48% and 67%, respectively, which is due to the release of P from the phytate-bound P (Selle and Ravindran, 2008). Similar efficacy of dietary phytase at the level of 500

FTU/kg was also observed in camelina meal and flaxseed meal fed to growing pigs (Adhikari et al., 2016b; Kim et al., 2017). No interaction between phytase and extrusion was observed in the current study, which may suggest that there is no synergetic or antagonistic effect of extrusion and phytase supplementation on P utilization in pigs.

The reduction in daily Ca output and increase in ATTD of Ca observed in the current study as a result of dietary phytase addition is in agreement with previous studies (Velayudhan et al., 2015; Adhikari et al., 2016a; Woyengo et al., 2016). This result might have been due to increased availability of Ca in diets supplemented with phytase as a consequence of reduced phytate content and thus reduced formation of insoluble Ca-phytate complexes (Selle et al., 2009).

In conclusion, the ATTD and STTD of P in HH fed to growing pigs were 18.8% and 22.0%, respectively, and values for EHH were 22.5% and 26.3%. Extrusion did not affect the ATTD and STTD of P in HH. However, addition of microbial phytase to experimental diets increased the ATTD and STTD of P in diets and test ingredients and decreased fecal P output from pigs fed experimental diets. There was no interaction between extrusion and dietary phytase supplementation.

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