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Short communication

Standardized total tract digestibility of phosphorus in canola meal fed to gestating or lactating sows without or with a multi-enzyme complex

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ABSTRACT

An experiment was conducted to determine coefficients of standardized total tract digestibility (CSTTD) of P in canola meal (CM) fed to gestating and lactating sows without or with a multi-enzyme complex (MC). Eight sows cannulated on day 40 of gestation were assigned at random to the 4 dietary treatments in a replicated 4 × 4 Latin square design. The 4 diets included 2 cornstarch-based diets with 313 g/kg solvent-extracted CM as the only source of P, without or with MC, a casein-cornstarch diet to determine ileal endogenous amino acid losses (amino acid digestibility data reported elsewhere), and a P-free diet to determine the endogenous P losses. All diets contained 3 g/kg titanium dioxide as an indigestible marker. Gestating sows were fed 3.0 kg/day, whereas, during lactation, sows had *ad libitum* access to diets. Samples were collected over 3 phases; mid-gestation, late-gestation, and lactation. Each phase had 4 experimental periods lasting 8 days. In each period, after 5-day acclimation to the experimental diets, fecal samples were collected by grab sampling via rectal palpation on day 6. Results indicated no differences in total tract digestibility of nutrients between mid-gestation, late-gestation, and lactation. Enzyme supplementation improved ($P < 0.05$) the apparent total tract digestibility of dry matter and P, and CSTTD of P during lactation. The CSTTD of P in CM was 0.445 (without MC) and 0.504 (with MC) in mid-gestation, 0.455 (without MC) and 0.492 (with MC) in late-gestation, and 0.442 (without MC) and 0.489 (with MC) in lactation. In conclusion, the average CSTTD for P in CM fed to sows was 0.447 and MC significantly improved the CSTTD of P in CM during lactation.

1. Introduction

Phosphorus is an essential nutrient for sows, mainly utilized in replacing endogenous losses, fetal, uterine, and mammary gland development during gestation, milk production during lactation, and growth and development of the sows (Bikker and Blok, 2017).

Abbreviations: ANDF, amylase-treated neutral detergent fiber inclusive residual ash; CATTD, coefficients of apparent total tract digestibility; CM, canola meal; CP, crude protein; CSTTD, coefficients of standardized total tract digestibility; DM, dry matter; DMI, dry matter intake; EPL, endogenous phosphorus losses; MC, multi-enzyme complex.

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However, when diets are formulated with excess P, it may result in increased P excretion which may have a negative impact on the external environment. Hence, assigning the appropriate P value of an ingredient is essential for proper diet formulation. Swine diets when formulated on digestible P concentration closely match the dietary supply with requirements, thereby minimizing P excretion (NRC, 2012). Digestible P contents of most feed ingredients are determined in growing or finishing pigs (Adhikari et al., 2015; Liu et al., 2018; Mejicanos et al., 2018). Accordingly, diet formulation for sows has to rely on P digestibility values estimated in growing or finishing pigs.

Solvent-extracted canola meal (CM) is an important protein source in swine diets. Results of previous experiments have demonstrated that inclusion of up to 300 g/kg of CM in lactating sow diets did not have a negative impact on performance (Velayudhan and Nyachoti, 2017; Liu et al., 2018; Velayudhan et al., 2018). The majority of the P in CM is present as phytate P and pigs are unable to digest phytate as they lack or have insufficient activity of endogenous phytase and therefore, the coefficient of digestibility of P in CM fed to growing pigs is only 0.25–0.30 (Newkirk, 2009; Adhikari et al., 2015; Mejicanos et al., 2018).

There is, however, limited information about the digestibility of P in various feed ingredients fed to sows, and to our knowledge, the coefficient of standardized total tract digestibility (CSTTD) of P in CM fed to sows in different stages of reproduction has not been reported. Supplementation of diets containing CM with a multi-enzyme complex (MC) may improve nutrient utilization in CM, but data to confirm this hypothesis have not been reported. Therefore, it was hypothesized that the CSTTD of P in CM in both gestating and lactating sows differ from those reported for growing-finishing pigs and that the CSTTD of P in CM fed to gestating or lactating sows increases with MC supplementation in the diet. The objectives of this experiment were to 1) determine the CSTTD of P in CM fed to gestating and lactating sows, and 2) determine the effect of MC on CSTTD of P in CM fed to gestating and lactating sows.

2. Material and methods

All experimental procedures were reviewed and approved by the University of Manitoba Animal Care Committee, and sows and piglets were cared for according to the guidelines of the Canadian Council on Animal Care (Canadian Council on Animal Care., 2009).

2.1. Animals, housing, and diets

Eight gestating sows (Yorkshire-Landrace female × Duroc male; day 35 of gestation) with an average parity of 2.8 (SD = 0.83) were obtained from the University of Manitoba Glenlea Swine Research Unit and fitted with a T-cannula at the distal ileum as described by Stein et al. (1998) on day 40 of gestation. After surgery, sows were housed individually in gestating pens (3.0 × 2.4 m) with smooth sides and plastic-covered, expanded metal sheet flooring, equipped with a stainless-steel sow feeder, and a nipple drinker. On day 112 of gestation, sows were moved from gestation pens and housed individually in fully slatted farrowing crates (2.3 × 1.7 m) with a stainless-steel sow feeder and a nipple drinker. All rooms were mechanically ventilated, and the temperature was maintained at 18–20°C. Sows were allowed a 10-day recovery period after surgery, during which they were fed a corn-soybean meal-based diet before the commencement of the experiment.

The 4 experimental diets included 2 cornstarch-based diets, containing 313 g/kg solvent-extracted CM as the only source of amino acids (amino acid digestibility data published elsewhere; Velayudhan et al., 2019) and P without or with a MC, a casein-cornstarch diet to determine ileal endogenous amino acid losses, and a P-free diet to determine the endogenous P losses (EPL; Table 1). The MC used was a mixture of carbohydrases (0.15 % of Superzyme-OM in the diets, supplying 2550 U of cellulase; 1650 U of pectinase; 360 U of mannanase; 45 U of galactanase; 1800 U of xylanase; 540 U of glucanase; 2250 U of amylase; and 180 U of protease per kg of diet) and phytase (0.025 % of Bio-phytase in the diets, supplying 1250 phytase units per kg of diet) provided by CBS Bio Platforms Inc. (Calgary, Alberta, Canada). All diets contained 3 g/kg titanium dioxide as an indigestible marker and were fed in mash form.

2.2. Experimental design and procedures

After a 10-day recovery period, the 8 sows were assigned at random to the dietary treatments in a repeated 4 × 4 Latin square design to give 8 observations per treatment. Gestating sows were fed 3.0 kg of the respective experimental diet daily in two equal meals at 0700 and 1300 h as dry mash, whereas, during lactation, sows had *ad libitum* access to their diets. Sample collection was done over 3 phases; mid-gestation (day 50–82 of gestation), late-gestation (day 83–116 of gestation), and lactation (day 2–34 of lactation). Each phase had 4 experimental periods lasting for 8 days each. In each period, after 5-day acclimation to experimental diets, fecal samples were collected by grab sampling via rectal palpation on day 6 and were immediately frozen at −20°C until further processing. Rectal palpation was done twice daily after feeding and samples were pooled per pig per day.

2.3. Sample preparation and chemical analyzes

Fecal samples were dried in an oven at 50°C for 5 days and sub-sampled. Dried feces, canola meal and experimental diets were ground to pass through a 1 mm screen before chemical analysis. Fecal and diet samples were analyzed for dry matter (DM), crude protein (CP), Ca, total P, and titanium. Canola meal was analyzed for DM, CP, ether extract, ash, amylase-treated neutral detergent fiber inclusive residual ash (aNDF), total P, phytate P, Ca, and glucosinolates.

Dry matter content was determined according to AOAC., (1990); method 925.09) by oven drying 5 g of sample at 102°C overnight. Gross energy was measured using an isoperibol bomb calorimeter (model 6400, Parr Instrument, Moline, IL, USA), which was calibrated using benzoic acid as a standard. Nitrogen was determined using the combustion method (AOAC., (1990); method 990.03)

Table 1
Ingredient and analyzed nutrient composition of experimental diets, as-fed basis.

Item, g/kg	Diets	
	CM[a]	PFD[b]
Ingredient		
Canola meal[c]	313.0	-
Cornstarch	613.5	511.0
Casein	-	-
Dextrose	-	230.0
Pork gelatin	-	140.0
Vegetable oil	50.0	40.0
Limestone	10.0	14.0
Solka flock	-	35.0
Iodized salt	4.0	4.0
Vitamin-mineral premix[d]	6.5	6.5
L-Lys-HCl, 78.8 %	-	3.0
DL-Met	-	1.5
L-Thr	-	3.0
L-Trp	-	1.5
L-Ile	-	2.5
L-Leu	-	2.0
L-Val	-	3.0
Titanium dioxide	3.0	3.0
Analyzed nutrient composition		
Dry matter	890	880
Crude protein	129	135
Gross energy, MJ/kg	17.2	16.7
Ca	6.2	7.0
P	4.3	0.0

[a] CM = Canola meal-containing diet with or without multi-enzyme complex (MC). The MC used was a mixture of carbohydrases (0.15 % of Superzyme-OM in the diets, supplying 2550 U of cellulase; 1650 U of pectinase; 360 U of mannanase; 45 U of galactanase; 1800 U of xylanase; 540 U of glucanase; 2250 U of amylase; and 180 U of protease per kg of diet) and phytase (0.025 % of Bio-phytase in the diets, supplying 1250 phytase units per kg of diet) provided by CBS Bio Platforms Inc. (Calgary, Alberta, Canada), and was added to the CM-containing diet (top dress) to make the second treatment.

[b] PFD = phosphorus-free diet.

[c] Analyzed composition of CM (dry matter basis): crude protein = 415 g/kg, ether extract = 39 g/kg, ash = 74 g/kg, aNDF (amylase-treated neutral detergent fiber inclusive residual ash) = 288 g/kg, Ca = 7 g/kg, P = 12.8 g/kg, phytate P = 8.1 g/kg, non-phytate P = 4.6 g/kg, phytate P:total P ratio = 0.63, and glucosinolates = 7.8 μmol/g.

[d] Supplied the following per kg of finished feed: vitamin A, 6058 IU; vitamin D, 805 IU; vitamin E, 66 IU; vitamin K, 6 mg; choline, 550 mg; pantothenic acid, 23 mg; riboflavin, 7 mg; folic acid, 1.65 mg; niacin, 33 mg; thiamin, 1.01 mg; vitamin B_6, 2.5 mg; biotin, 0.30 mg; vitamin B_{12}, 0.04 mg, Cu, 12 mg as copper sulfate; Zn, 122 mg as zinc oxide; Fe, 122 mg as ferrous sulfate; Mn, 15 mg as manganese sulfate; I, 0.4 mg as potassium iodate; Se, 0.3 mg as sodium selenite.

using the LECO N analyzer (model CNS-2000; LECO Corp., St. Joseph, MI, USA) and CP was calculated as N × 6.25. Amylase-treated neutral detergent fiber inclusive of residual ash was analyzed according to the method of Van Soest et al. (1991) using the Ankom Fiber Analyzer (Ankom Technology, Fairport, NY, USA). Ether extract in samples was determined after hexane extraction (AOAC., (1990); method 920.39) in an Ankom extraction system (Macedon, NY, USA). Samples for analysis of Ca and P were ashed for 12 h and digested according to AOAC. (2005); method 985.01) and read on a Varian inductively coupled plasma mass spectrometer (Varian Inc., Palo Alto, CA, USA). Phytate P was assayed using the procedure described by Haug and Lantzsch (1983). Non-phytate P was calculated by subtracting phytate P from total P. Titanium was determined according to the procedures described by Lomer et al. (2000) and read on an inductively coupled plasma mass spectrometer (Varian Inc., Palo Alto, CA, USA). Glucosinolates were determined according to the procedures described by Niu et al. (2015).

2.4. Calculations and statistical analysis

The coefficient of apparent total tract digestibility (CATTD) of nutrients was calculated using the equation of Adeola (2001).

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC, USA). The model included treatment as the fixed variable and pen and period as the random variables. The effects of pen and period were not statistically significant, and thus the final model had treatment as the main effect. Enzyme effects were tested within each phase, and phase effects were analyzed separately. Results were considered significant at $P < 0.05$ and tendencies were observed at $0.05 \leq P < 0.10$.

3. Results

The EPL determined in sows fed a P-free diet were 614.1, 609.1, and 343.0 mg/kg dry matter intake (DMI) for mid-gestation, late-gestation, and lactation, respectively (Table 2). There were no differences in total tract digestibility of nutrients among collection

Table 2
Coefficient of apparent (CATTD) and standardized total tract digestibility (CSTTD) of nutrients in canola meal (CM) fed to sows (n = 8) without or with a multi-enzyme complex.

Item	Phase									P-value			
	Mid-gestation			Late-gestation			Lactation						
	Diets[a]		SEM	Diets		SEM	Diets		SEM				
	CM (−)	CM (+)		CM (−)	CM (+)		CM (−)	CM (+)		Mid-gestation	Late-gestation	Lactation	Phase
CATTD[b]													
DM	0.840	0.838	0.013	0.836	0.850	0.012	0.845	0.862	0.006	0.896	0.589	0.024	0.383
CP	0.837	0.845	0.011	0.832	0.854	0.014	0.840	0.857	0.006	0.622	0.406	0.054	0.800
aNDF	0.569	0.562	0.048	0.566	0.561	0.046	0.557	0.564	0.016	0.668	0.773	0.500	0.887
Ca	0.588	0.582	0.027	0.586	0.593	0.051	0.588	0.589	0.030	0.480	0.776	0.889	0.741
P	0.339	0.396	0.027	0.349	0.384	0.045	0.382	0.429	0.009	0.197	0.344	0.012	0.165
CSTTD[c]													
P	0.445	0.504	0.027	0.455	0.492	0.045	0.442	0.489	0.009	0.188	0.326	0.011	0.904

[a] CM = Canola meal-containing diet at 313 g/kg inclusion and as the only source of P; (−)/(+) represents the absence or presence of the multi-enzyme complex.
[b] DM = dry matter; CP = crude protein; aNDF = amylase-treated neutral detergent fiber inclusive residual ash.
[c] The endogenous losses of P estimated in sows fed the P-free diet were 614.1, 609.1, and 343.0 mg/kg dry matter intake for mid-gestation, late-gestation, and lactation, respectively.

phases (mid-gestation, late-gestation, and lactation). Enzyme supplementation improved ($P < 0.05$) the CATTD of DM and P, and CSTTD of P during lactation. With MC addition, CATTD of CP tended ($P = 0.054$) to improve in lactation. The CSTTD of P in CM was 0.445 (without MC) and 0.504 (with MC) in mid-gestation, 0.455 (without MC) and 0.492 (with MC) in late-gestation, and 0.442 (without MC) and 0.489 (with MC) in lactation, respectively.

4. Discussion

The nutrient composition of the solvent-extracted CM used in the current experiment was comparable to published values (Adhikari et al., 2015; Maison et al., 2015; Mejicanos et al., 2018). However, the P concentration in CM varies depending on differences in soil concentration of minerals and seasonal variations (Bell and Keith, 1991).

4.1. *Total tract digestibility of nutrients*

The observed CATTD of CP in CM by sows (ranging from 0.832 to 0.857) was greater than reported by Stein et al. (1999); 70.8 and 75.0% for gestating and lactating sows, respectively). The CATTD of CP in lactation sows calculated in this experiment was greater than reported for growing pigs (Stein et al., 1999). An improvement in digestive capacity in pigs with age has been observed which results in an increased CATTD of CP by sows than by growing pigs (Fernández et al., 1986; Noblet and Shi, 1993). Hindgut fermentation of fiber in sows is more efficient owing to an increased cellulolytic bacterial activity than in growing pigs (Fernández et al., 1986), which is likely the reason for the greater CATTD of aNDF that was observed in the current experiment (ranging from 0.557 to 0.569) compared with values reported for CM in growing pigs by Maison et al. (2015); 51.9%). Lowell et al. (2015) also reported that gestating sows had greater ATTD of aNDF than growing pigs when they were fed corn, distillers dried grains with solubles, or soybean hulls.

To our knowledge, the CSTTD of P has not been previously reported for CM fed to gestating or lactating sows. The CATTD and CSTTD of P did not differ between gestating and lactating sows, and on average, the CATTD and CSTTD of P in CM in sows were 0.357 and 0.447, respectively. Phosphorus excreted in the feces comprises non-digested P and endogenous P. The basal EPL determined in the current experiment varied between gestating and lactating sows, with gestating sows having a greater basal EPL (614 vs. 343 mg/kg DMI). Lee et al. (2021) reported the basal EPL of gestating sows as approximately 780 mg/kg DMI, which is slightly greater than the value in the current study. Basal EPL is an expression based on DMI, therefore, the difference in feed intake between Lee et al. (2021) and the current study might cause the lower basal EPL observed in this study. A 2-kg diet is a limited amount for a sow, leading to increased retention time of digesta in the gut, eventually increasing EPL to 800 mg/kg of DMI in the work by Lee et al. (2021). In the current study, however, feed intake for gestating sows was 3 kg per day, which could result in a shorter digesta retention time compared to Lee et al. (2021), and therefore could show a slightly lower amount of EPL. Furthermore, during the lactation period in the current study, sows were fed ad libitum, therefore, basal EPL might be much lower, around 343 mg/kg DMI.

Phosphorus digestibility in oilseed meals fed to pigs varies according to the content of phytate P, which may be one reason for the wide variation in the CSTTD of P in CM (0.30–0.50) fed to growing pigs (Rodríguez et al., 2013; Adhikari et al., 2015; Mejicanos et al., 2018). The CSTTD of P that was calculated in the current experiment (0.447) was within the range observed in growing pigs, but it is difficult to make a comparison due to the wide variation in the digestibility of P in CM by growing pigs. Studies have reported a greater CATTD and CSTTD of P in growing pigs or growing gilts than in gestating sows (Lee et al., 2018, 2021). It appears that the physiological differences between sows and growing pigs affect P digestibility, however, the mechanisms behind these differences remain to be fully understood. Another aspect to consider for comparing P digestibility in CM is the phytate content, which can be influenced by the plant variety and P availability in soil (Uppström and Svensson, 1980). Phytate P in CM may vary depending on canola varieties, environmental conditions, and the area where the canola is grown (Rodríguez et al., 2013). Therefore, when comparing P digestibility in CM among experiments, the phytate-P content of the meal should also be taken into consideration. There is a negative correlation between the digestibility of P and dietary phytate in both growing pigs and sows, but growing pigs were more likely to be affected by dietary phytate than gestating sows (Lee et al., 2021).

4.2. Enzyme supplementation

Canola meal when used at high inclusion rates in a diet for pigs or sows, contributes to increased concentrations of non-starch polysaccharides and phytate in the diet. The amount of phytate P in CM ranges from 360 to over 700 g/kg of the total P in the ingredient (Khajali and Slominski, 2012), which reduces digestibility of P in CM.

Carbohydrases used in combination with phytase may result in cell wall hydrolysis, which enhances phytase activity by improving the contact of phytase with phytate (Woyengo and Nyachoti, 2011). In sows, the stage of reproduction influences the effect of enzyme supplementation (Olukosi and Adeola, 2013). Nyachoti et al. (2006) observed an improvement in P digestibility during late-gestation compared to early gestation in sows fed diets supplemented with phytase. In contrast, in this experiment, phytase supplementation only improved P digestibility during lactation. This observation is in agreement with Kemme et al. (1997), who reported that phytase has a greater efficacy in lactating sows than in gestating sows. The effect of phytase on P utilization also varies depending on the hydrolyzing activity of phytase, which in turn varies among sources (Nyachoti et al., 2006).

In conclusion, no differences in total tract digestibility of nutrients were observed among sows at different reproductive stages. The average CSTTD for P in CM fed to sows was 0.447, which was within the range of values determined for P digestibility in CM fed to growing pigs. Supplementation of a mixture of carbohydrases and phytase improved CATTD and CSTTD of P in CM of sows during lactation, however, no significant improvements in CATTD of other nutrients were observed.

CRediT authorship contribution statement

Deepak E. Velayudhan: Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Martin Nyachoti:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **Hans H. Stein:** Writing – review & editing. **Jinyoung Lee:** Writing – review & editing, Visualization. **Manik. M. Hossain:** Investigation.

Declaration of Competing Interest

The authors have no conflicts of interest.

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