Published July 17, 2015

Apparent and standardized total tract digestibility by growing pigs of phosphorus in canola meal from North America and 00-rapeseed meal and 00-rapeseed expellers from Europe without and with microbial phytase[1]

T. Maison, Y. Liu, and H. H. Stein[2]

Department of Animal Sciences, University of Illinois, Urbana 61801

ABSTRACT: An experiment was conducted to determine apparent total tract digestibility (ATTD) and standardized total tract digestibility (STTD) by growing pigs of P in canola meal, 00-rapeseed meal, and 00-rapeseed expellers. Canola meal and 00-rapeseed meal are the coproducts produced after the residual oil has been solvent extracted from the prepressed canola seeds and 00-rapeseeds, respectively, whereas 00-rapeseeed expellers is the coproduct from 00-rapeseeds that have been only expeller pressed. Two hundred sixteen barrows (18.0 ± 1.5 kg initial BW) were allotted to 36 diets and 6 replicate pigs per diet. Five samples of canola meal from solvent-extraction crushing plants in North America, 8 samples of 00-rapeseed meal from solvent-extraction crushing plants in Europe, and 5 samples of 00-rapeseed expellers from mechanical-press crushing plants in Europe were used in the experiment. Eighteen diets were prepared by including 40% of each source of canola meal, 00-rapeseed meal, or 00-rapeseed expellers in 1 diet. Eighteen additional diets were formulated by adding 1,500 units of microbial phytase to the diets. The only source of P in the diets was canola meal, 00-rapeseed meal, or 00-rapeseed expellers. Pigs were placed in metabolism crates that allowed for total fecal collection. Pigs were fed at 2.5 times their estimated energy requirement for maintenance. Ingredients, diets, and feces were analyzed for P, and the ATTD and STTD of each source of canola meal, 00-rapeseed meal, and 00-rapeseed expellers were calculated. A value for endogenous P loss of 190 mg/kg DMI was used to calculate the STTD of P. Results indicated that the ATTD and STTD of P for canola meal were not different from values obtained in 00-rapeseed meal, and the ATTD and STTD of P in 00-rapeseed meal were not different from values for 00-rapeseed expellers. The ATTD and STTD of P increased ($P < 0.001$) from 44.99 and 48.82% to 64.08 and 67.97% for canola meal, from 46.77 and 50.36% to 63.53 and 67.29% for 00-rapeseed meal, and from 44.83 and 48.60% to 69.18 and 72.99%, respectively, for 00-rapeseed expellers by adding microbial phytase to the diets. In conclusion, although the concentration of ether extract is much greater in 00-rapeseed expellers than in 00-rapeseed meal and canola meal, the ATTD and STTD of P for these ingredients are not different, and addition of microbial phytase results in improved digestibility of P in canola meal, 00-rapeseed meal, and 00-rapeseed expellers.

Key words: canola meal, digestibility, phosphorus, pig, 00-rapeseed meal, 00-rapeseed expellers

J. Anim. Sci. 2015.93:3494–3502
doi:10.2527/jas2015-9055

INTRODUCTION

Canola meal, 00-rapeseed meal, and 00-rapeseed expellers may be used as alternative ingredients in animal diets because these ingredients have low concentrations of glucosinolates, a high concentration of CP, and relatively high concentration of minerals (Thomas, 2005; Newkirk, 2011). Solvent-extracted canola meal and 00-rapeseed meal usually contain 1.00 to 1.10% total P (Liu et al., 1998; Newkirk, 2009; NRC, 2012), but most of the P in canola meal is bound to phytic acid (Spragg and Mailer, 2007; Newkirk, 2009). As a consequence, apparent total tract digestibility (**ATTD**) and standardized total tract digestibility (**STTD**) of P in canola meal fed to pigs

[1]Financial and/or in-kind support for this research by Archer Daniels Midland Company (Decatur, IL), Agrifirm (Apeldoorn, Netherlands), Bunge (St. Louis, MO), Cargill (Minneapolis, MN), and Charoen Pokphand Group (Bangrak, Thailand) is greatly appreciated.
[2]Corresponding author: hstein@illinois.edu
Received February 28, 2015.
Accepted May 4, 2015.

Table 1. Analyzed composition of canola meal, 00-rapeseed meal, and 00-rapeseed expellers, as-fed basis[1]

Sample origin	DM, %	CP, %	AEE,[2] %	GE, kcal/kg	Ash, %	Ca, %	P, %	Phytate, %	Phytate P,[3] %	Phytate P, % of total P	Nonphytate P,[4] %	Nonphytate P, % of total P
Canola meal												
1	90.47	39.35	4.31	4,229	8.40	1.21	1.04	2.93	0.82	79.31	0.22	20.69
2	90.18	39.79	3.01	4,207	7.32	0.79	1.05	2.95	0.83	79.09	0.22	20.91
3	89.81	38.11	4.44	4,237	7.36	0.67	0.95	2.72	0.77	80.60	0.18	19.40
4	90.40	36.71	3.79	4,196	7.39	0.83	0.94	2.59	0.73	77.56	0.21	22.44
5	89.44	37.57	3.58	4,235	6.93	0.76	1.01	2.97	0.84	82.78	0.17	17.22
Average	90.06	38.31	3.83	4,221	7.48	0.85	1.00	2.83	0.80	79.87	0.20	20.13
00-rapeseed meal												
1	89.09	36.37	3.58	4,150	6.57	0.68	0.96	2.60	0.73	76.24	0.23	23.76
2	90.31	38.03	4.19	4,254	7.39	0.71	1.13	3.21	0.90	79.97	0.23	20.03
3	88.08	37.50	3.47	4,173	6.61	0.75	1.12	3.27	0.92	82.19	0.20	17.81
4	89.09	35.60	5.25	4,257	6.89	0.76	1.05	3.00	0.84	80.43	0.21	19.57
5	88.56	37.10	3.72	4,229	6.61	0.71	1.03	3.08	0.87	84.18	0.16	15.82
6	89.02	37.25	3.68	4,234	6.86	0.67	1.05	3.03	0.85	81.23	0.20	18.77
7	90.47	39.35	4.31	4,229	8.40	1.21	1.04	2.93	0.82	79.31	0.22	20.69
8	90.18	39.79	3.01	4,207	7.32	0.79	1.05	2.95	0.83	79.09	0.22	20.91
Average	88.96	36.82	3.70	4,203	6.87	0.74	1.07	3.08	0.87	80.97	0.20	19.03
00-rapeseed expellers												
1	89.88	36.08	10.79	4,668	6.33	0.71	1.10	3.31	0.93	84.71	0.17	15.29
2	89.86	34.50	12.99	4,771	5.74	0.59	0.97	2.85	0.80	82.71	0.17	17.29
3	91.23	36.24	13.84	4,768	6.01	0.63	1.00	2.78	0.78	78.26	0.22	21.74
4	95.15	35.25	11.70	4,835	6.54	0.73	1.07	3.13	0.88	82.35	0.19	17.65
5	93.04	35.84	8.27	4,561	6.51	0.76	1.06	3.01	0.85	79.94	0.21	20.06
Average	91.83	35.58	11.52	4,721	6.23	0.68	1.04	3.02	0.85	81.59	0.19	18.41

[1]Canola meals were sourced from Canada (3 samples) and the United States (2 samples); 00-rapeseed meals were sourced from Belgium, France, Germany, the Netherlands (2 samples), Poland (2 samples) and the United Kingdom; and 00-rapeseed expellers were sourced from Germany (2 samples), Hungary, the Netherlands, and Poland.

[2]AEE = acid-hydrolyzed ether extract.

[3]Calculated as 28.2% of phytate (Tran and Sauvant, 2004).

[4]Calculated as total P – phytate P.

is low (Sauvant et al., 2004; NRC, 2012), but microbial phytase may improve the digestibility of P in canola meal (Zhang et al., 2000; Akinmusire and Adeola, 2009; Arntfield and Hickling, 2011; Rodríguez et al., 2013). However, there are no comparative data for P digestibility in canola meal and 00-rapeseed meal.

If oil is removed from oilseeds using mechanical expelling rather than solvent extraction, the resulting expellers may be used as feed. 00-rapeseed expellers contain more oil and GE than 00-rapeseed meal, but there are limited data on the effects of microbial phytase on P digestibility in 00-rapeseed expellers. It is also not known if values for digestibility of P with microbial phytase in 00-rapeseed meal are representative for 00-rapeseed expellers.

Therefore, the objectives of this experiment were to 1) compare the ATTD and STTD of P in canola meal and 00-rapeseed meal; 2) compare the ATTD and STTD of P between 00-rapeseed meal and 00-rapeseed expellers; 3) determine if there is variation among sources of canola meal, 00-rapeseed meal, and 00-rapeseed expellers; and 4) determine the effect of microbial phytase on the ATTD and STTD of P in canola meal, 00-rapeseed meal, and 00-rapeseed expellers.

MATERIALS AND METHODS

Animals, Housing, and Experimental Design

The experiment was approved by the Institutional Animal Care and use Committee at the University of Illinois, Urbana, IL. The experiment was conducted over 6 periods using 36 pigs in each period. Therefore, a total of 216 growing barrows (18.0 ± 1.50 kg initial BW; G-Performer boars × F-25 females; Genetiporc, Alexandria, MN) were used and allotted to a randomized complete block design with 36 diets and 6 replicate pigs per diet. All 36 experimental diets were fed to 1 pig during each of the 6 periods. Each experimental period was 12 d. Pigs were placed in metabolism crates (0.7 by 0.8 m) that were equipped with a feeder and a nipple drinker, fully slatted floors, and a screen floor. This allowed for the total collection of feces from each pig.

Table 2. Ingredient composition (%) of experimental diets, as-fed basis[1,2]

Item	Canola meal	00-rapeseed meal	00-rapeseed expellers	Cornstarch	Sucrose	Soy oil	Limestone	Salt	Vitamin–mineral premix[3]
Canola meal									
1	40.0	–	–	45.6	10.0	3.0	0.7	0.4	0.3
2	40.0	–	–	45.6	10.0	3.0	0.7	0.4	0.3
3	40.0	–	–	45.6	10.0	3.0	0.7	0.4	0.3
4	40.0	–	–	45.6	10.0	3.0	0.7	0.4	0.3
5	40.0	–	–	45.6	10.0	3.0	0.7	0.4	0.3
00-rapeseed meal									
1	–	40.0	–	45.6	10.0	3.0	0.7	0.4	0.3
2	–	40.0	–	45.6	10.0	3.0	0.7	0.4	0.3
3	–	40.0	–	45.6	10.0	3.0	0.7	0.4	0.3
4	–	40.0	–	45.6	10.0	3.0	0.7	0.4	0.3
5	–	40.0	–	45.6	10.0	3.0	0.7	0.4	0.3
6	–	40.0	–	45.6	10.0	3.0	0.7	0.4	0.3
7	–	40.0	–	45.6	10.0	3.0	0.7	0.4	0.3
8	–	40.0	–	45.6	10.0	3.0	0.7	0.4	0.3
00-rapeseed expellers									
1	–	–	40.0	47.6	10.0	1.0	0.7	0.4	0.3
2	–	–	40.0	48.6	10.0	–	0.7	0.4	0.3
3	–	–	40.0	48.6	10.0	–	0.7	0.4	0.3
4	–	–	40.0	48.1	10.0	0.5	0.7	0.4	0.3
5	–	–	40.0	46.6	10.0	2.0	0.7	0.4	0.3

[1]Eighteen additional diets that were similar to the above 18 diets, with the exception that 0.03% phytase premix (Optiphos 2000; Enzyvia, Sheridan, IN) was included to each diet to provide 1,500 units of microbial phytase/kg diet, were also formulated.

[2]Canola meals were sourced from Canada (3 samples) and the United States (2 samples); 00-rapeseed meals were sourced from Belgium, France, Germany, the Netherlands (2 samples), Poland (2 samples) and the United Kingdom; and 00-rapeseed expellers were sourced from Germany (2 samples), Hungary, the Netherlands, and Poland.

[3]Provided the following quantities of vitamins and microminerals per kilogram of complete diet: 11,136 IU vitamin A as retinyl acetate, 2,208 IU vitamin D_3 as cholecalciferol, 66 IU vitamin E as DL-alpha tocopheryl acetate, 1.42 mg vitamin K as menadione dimethylprimidinol bisulfite, 0.24 mg thiamin as thiamine mononitrate, 6.59 mg riboflavin, 0.24 mg pyridoxine as pyridoxine hydrochloride, 0.03 mg vitamin B_{12}, 23.5 mg D-pantothenic acid as D-calcium pantothenate, 44.1 mg niacin, 1.59 mg folic acid, 0.44 mg biotin, 20 mg Cu as copper sulfate and copper chloride, 126 mg Fe as ferrous sulfate, 1.26 mg I as ethylenediamine dihydriodide, 60.2 mg Mn as manganese sulfate, 0.3 mg Se as sodium selenite and selenium yeast, and 125.1 mg Zn as zinc sulfate.

Ingredients, Diets, and Feeding

Five samples of canola meal were obtained from solvent-extraction crushing plants in North America with 3 samples being sourced from Canada and 2 samples were from the United States (Table 1). Eight samples of 00-rapeseed meal were obtained from solvent-extraction crushing plants in Belgium, France, Germany, the Netherlands (2 samples), Poland (2 samples), and the United Kingdom, and 5 samples of 00-rapeseed expellers were obtained from mechanical-press crushing plants in Germany (2 samples), Hungary, the Netherlands, and Poland. Eighteen diets were prepared by including 40% of each source of canola meal, 00-rapeseed meal, and 00-rapeseed expellers in 1 diet (Table 2). Eighteen additional diets that were similar to the previous 18 diets, with the exception that 1,500 units/kg of microbial phytase (Optiphos 2000; Huvepharma, Sofia, Bulgaria) was included in the diets, were also formulated. Vitamins and minerals other than P were included in all diets to meet or exceed requirements for growing pigs (NRC, 2012).

Experimental diets were fed to the pigs at a daily level of 2.5 times the estimated maintenance requirement for energy (i.e., 197 kcal ME/kg $BW^{0.60}$; NRC, 2012). Daily feed allotments were divided into 2 equal meals and fed at 0700 and 1700 h. Pigs had free to access water throughout the experiment.

Data and Sample Collection

Pig weights were recorded at the beginning and at the end of each period, and the amount of feed supplied to each pig each day was recorded. The initial 5 d of each period was considered an adaptation period to the diet. Fecal samples were collected from d 6 through 12 according to standard procedures using the marker to marker approach (Adeola, 2001). Briefly, fecal markers were fed on d 6 (0.5% chromic oxide) and on d 11 (0.5% ferric oxide), and fecal collections were initiated when chromic oxide appeared in the feces and ceased when ferric oxide appeared. Fecal samples were collected twice daily and stored at –20°C immediately after collection. Orts that were removed from feeders

Table 3. Analyzed composition of experimental diets, as-fed basis[1]

Item	Phytase, FTU[2]/kg	DM, %	CP, %	GE, kcal/kg	Ca, %	P, %
Canola meal						
1	59.00	90.09	15.94	4,043	0.76	0.45
1	1,700	89.92	15.01	4,021	0.74	0.46
2	68.00	90.37	15.33	4,043	0.58	0.47
2	1,800	90.96	15.41	4,046	0.76	0.45
3	<50.00	90.03	14.97	4,085	0.66	0.44
3	1,800	90.92	14.07	4,041	0.64	0.43
4	63.00	90.00	13.64	4,005	0.62	0.43
4	1,700	91.06	13.88	3,981	0.65	0.43
5	<50.00	90.17	14.80	4,094	0.63	0.45
5	1,700	91.21	14.81	4,100	0.57	0.45
00-rapeseed meal						
1	64.00	90.50	14.52	4,052	0.62	0.44
1	1,800	91.46	13.94	4,086	0.51	0.42
2	<50.00	90.71	13.90	4,065	0.69	0.49
2	1,800	91.60	15.59	4,066	0.55	0.48
3	<50.00	90.33	14.80	4,039	0.68	0.51
3	1,600	91.04	15.00	4,053	0.62	0.50
4	<50.00	90.08	14.45	4,060	0.61	0.47
4	1,800	90.91	13.88	4,047	0.56	0.45
5	66.00	90.88	14.71	4,006	0.60	0.46
5	1,800	91.57	14.56	4,061	0.59	0.45
6	77.00	90.08	13.95	4,033	0.63	0.47
6	1,700	90.03	14.06	4,032	0.56	0.44
7	<50.00	89.95	14.25	3,987	0.70	0.52
7	1,700	90.90	14.97	4,067	0.63	0.50
8	<50.00	89.97	14.26	3,974	0.59	0.47
8	1,600	90.80	14.71	4,007	0.56	0.46
00-rapeseed expellers						
1	57.00	90.53	15.34	4,110	0.64	0.50
1	1,600	91.39	15.00	4,136	0.56	0.50
2	60.00	89.99	12.76	4,050	0.51	0.41
2	1,500	90.99	14.21	4,083	0.62	0.43
3	53.00	90.95	14.53	4,044	0.47	0.46
3	1,900	91.45	15.05	4,146	0.52	0.46
4	<50.00	91.54	13.82	4,069	0.56	0.47
4	1,800	92.48	13.60	4,090	0.53	0.44
5	<50.00	90.94	14.20	4,080	0.62	0.46
5	1,600	91.74	14.61	4,115	0.59	0.46

[1]Canola meals were sourced from Canada (3 samples) and the United States (2 samples); 00-rapeseed meals were sourced from Belgium, France, Germany, the Netherlands (2 samples), Poland (2 samples) and the United Kingdom; and 00-rapeseed expellers were sourced from Germany (2 samples), Hungary, the Netherlands, and Poland.

[2]FTU = phytase units.

by pigs were also collected for the calculation of the total feed consumption of each pig. At the conclusion of the experiment, fecal samples were thawed and mixed within animal and diet, and a subsample was collected for chemical analysis. Fecal samples were dried in a forced-air oven at 60°C, ground, and thoroughly mixed before a subsample was collected for analysis.

Chemical Analysis

Samples of canola meal, 00-rapeseed meal, 00-rapeseed expellers, diets, and feces were analyzed for DM (method 930.15; Hortwitz and Latimer, 2007) and Ca and P were analyzed by inductively coupled plasma–optical emission spectrometry (method 985.01 (A, B, and C); Hortwitz and Latimer, 2007). Canola meal, 00-rapeseed meal, and 00-rapeseed expellers were analyzed for phytate (Ellis et al., 1977), ash (method 942.05; Hortwitz and Latimer, 2007), and acid-hydrolyzed ether extract (**AEE**), which was determined by acid hydrolysis using 3 *N* HCl (Sanderson, 1986) followed by crude fat extraction with petroleum ether (method 954.02; Hortwitz and Latimer, 2007) on a Soxtec 2050 Automated Analyzer (FOSS North America, Eden Prairie, MN). Canola meal, 00-rapeseed meal, 00-rapeseed expellers, and diets were also analyzed for CP by combustion (method 990.03; Hortwitz and Latimer, 2007) on an Elementar Rapid N-cube Protein/Nitrogen Apparatus (Elementar Americas Inc., Mt. Laurel, NJ) and GE by bomb calorimetry (model 6300; Parr Instruments, Moline, IL). Diets were also analyzed for phytase activity (Phytex method, version 1; Eurofins, Des Moines, IA; Table 3).

Calculations and Statistic Analysis

Phytate-bound P in canola meal, 00-rapeseed meal, and 00-rapeseed expellers was calculated as 28.2% of the concentration of analyzed phytate (Tran and Sauvant, 2004), and non-phytate-bound P was calculated by subtracting phytate-bound P from the concentration of total P. The ATTD of Ca and P and the STTD of P in each diet were calculated using the following equation (Almeida and Stein, 2010):

$$\text{STTD of P (\%)} = [P_{intake} - (P_{feces} - \text{basal endogenous loss})/P_{intake}] \times 100,$$

in which P_{intake} and P_{feces} are calculated in grams per day and the basal endogenous loss of P is 190 mg/kg DMI (NRC, 2012).

Data were analyzed using PROC MIXED in SAS (SAS Inst. Inc., Cary, NC). The presence of outliers was tested using the UNIVARIATE procedure of SAS. The differences among sources of canola meal, 00-rapeseed meal, or 00-rapeseed expellers were analyzed using source as fixed effects, whereas the effects of phytase were analyzed using phytase as fixed effects. Period was included in the model as random effect. The mean values for each ingredient were calculated using the LSMEANS statement. To compare the differences between canola meal and 00-rapeseed meal, the model included ingredient, phytase, and their

Table 4. Apparent total tract digestibility (ATTD) of P and Ca and standardized total tract digestibility (STTD) of P in canola meal[1]

Item	Phytase	Feed intake, g DM/d	P intake, g/d	P output, g/d	Absorbed P, g/d	ATTD of P, %	STTD of P,[2] %	Ca intake, g/d	Ca output, g/d	Absorbed Ca, g/d	ATTD of Ca, %
Canola meal											
1	Without phytase	718	3.59	2.03	1.55	44.03	47.84	6.06	2.70	3.35	60.10
1	With phytase	708	3.62	1.40	2.23	61.31	65.02	5.83	2.00	3.83	65.88
2	Without phytase	677	3.52	1.86	1.66	46.81	50.46	4.35	1.86	2.49	57.14
2	With phytase	681	3.37	1.34	2.03	59.76	63.60	5.69	1.66	4.03	71.22
3	Without phytase	741	3.62	1.91	1.71	47.32	51.21	5.43	1.88	3.56	65.58
3	With phytase	703	3.33	1.05	2.28	68.05	72.07	4.95	1.24	3.71	74.33
4	Without phytase	670	3.20	1.73	1.47	45.28	49.26	4.62	1.83	2.79	59.45
4	With phytase	717	3.39	1.22	2.16	66.47	70.49	5.12	1.35	3.77	73.58
5	Without phytase	705	3.52	2.07	1.45	41.52	45.33	4.93	1.86	3.07	62.62
5	With phytase	697	3.44	1.20	2.24	64.83	68.68	4.36	1.16	3.20	72.89
Average	Without phytase	702	3.49	1.92	1.57	44.99	48.82	5.08	2.02	3.05	60.98
Average	With phytase	701	3.43	1.24	2.19	64.08	67.97	5.19	1.48	3.71	71.58
SEM[3]	Without phytase	58.17	0.29	0.20	0.15	2.85	2.85	0.44	0.28	0.30	3.14
P-value[3]	Without phytase	0.105	0.042	0.106	0.084	0.286	0.282	<0.001	<0.01	<0.01	0.275
SEM[4]	With phytase	53.75	0.26	0.10	0.21	1.80	1.80	0.39	0.19	0.35	3.00
P-value[4]	With phytase	0.799	0.301	<0.01	0.420	<0.01	<0.01	<0.001	<0.01	0.094	0.206
SEM[5]	–	65.942	4.892	0.164	0.197	1.853	1.857	0.492	0.231	0.338	2.006
P-value[5]	–	0.954	0.373	<0.001	<0.001	<0.001	<0.001	0.527	<0.001	<0.001	<0.001

[1]Canola meals were sourced from Canada (3 samples) and the United States (2 samples); 00-rapeseed meals were sourced from Belgium, France, Germany, the Netherlands (2 samples), Poland (2 samples) and the United Kingdom.; and 00-rapeseed expellers were sourced from Germany (2 samples), Hungary, the Netherlands, and Poland.

[2]Values for STTD were calculated by correcting values of ATTD using a constant value for endogenous P loss of 190 mg/kg DMI (NRC, 2012).

[3]Comparison of the 5 diets containing canola meal without microbial phytase.

[4]Comparison of the 5 diets containing canola meal with microbial phytase.

[5]Phytase effects.

interaction as fixed effects and period as random effect. To compare the differences between 00-rapeseed meal and 00-rapeseed expellers, the model included processing method, phytase, and their interaction as fixed effects and period as random effect. The pig was the experimental unit, and significance among means was assessed at an α level of 0.05.

RESULTS AND DISCUSSION

Concentrations of CP and ash in canola meal, 00-rapeseed meal, and 00-rapeseed expellers observed in this experiment (Table 1) are in agreement with values for canola meal and canola expellers reported by Spragg and Mailer (2007), Rostagno et al. (2011), and the NRC (2012). The GE in canola meal and 00-rapeseed meal agree with the values for canola meal reported by Rostagno et al. (2011), but the concentrations of GE and AEE for canola meal, 00-rapeseed meal, and 00-rapeseed expellers are greater than the values for canola meal, 00-rapeseed meal, canola expellers, and 00-rapeseed expellers reported by de Blas et al. (2010), the Philippine Society of Animal Nutritionists (2010), and the NRC (2012). Concentrations of Ca and P in canola meal, 00-rapeseed meal, and 00-rapeseed expellers are in agreement with values for canola meal, rapeseed meal, canola expellers, and rapeseed expellers reported by de Blas et al. (2010) and the NRC (2012). Concentrations of phytate P and nonphytate P in canola meal, 00-rapeseed meal, and 00-rapeseed expellers are also in agreement with the values for 00-rapeseed meal and 00-rapeseed expellers reported by de Blas et al. (2010), and the concentrations of phytate P and nonphytate P for 00-rapeseed expellers are in agreement with values for canola expellers reported by the NRC (2012). However, the concentration of phytate P in canola meal is greater than values for canola meal reported by Rostagno et al. (2011) and the NRC (2012). The concentration of phytate in canola and rapeseed is influenced by variety and availability of P in soil (Uppström and Svensson, 1980). Therefore, the observed differences in concentration of phytate P in canola meal and 00-rapeseed meal may vary due to differences among varieties and differences in environmental conditions among locations where canola and rapeseeds are grown.

Without adding microbial phytase, P and Ca intake, excretion of Ca in feces, and absorbed Ca were

Table 5. Apparent total tract digestibility (ATTD) of P and Ca and standardized total tract digestibility (STTD) of P in 00-rapeseed meal[1]

Item	Phytase	Feed intake, g DM/d	P intake, g/d	P output, g/d	Absorbed P, g/d	ATTD of P, %	STTD of P,[2] %	Ca intake, g/d	Ca output, g/d	Absorbed Ca, g/d	ATTD of Ca, %
00-rapeseed meal											
1	Without phytase	735	3.58	1.88	1.69	43.97	47.88	5.04	1.79	3.25	63.96
1	With phytase	715	3.29	1.13	2.15	65.42	69.56	3.99	1.29	2.70	68.06
2	Without phytase	715	3.86	1.93	1.93	49.53	53.05	5.44	1.80	3.64	66.60
2	With phytase	729	3.82	1.33	2.46	64.00	67.63	4.38	1.53	2.84	64.52
3	Without phytase	725	4.10	1.94	2.16	47.89	51.26	5.46	1.71	3.75	68.15
3	With phytase	704	3.87	1.53	2.34	60.16	63.62	4.80	1.41	3.39	70.32
4	Without phytase	750	3.92	2.29	1.63	42.38	46.02	5.08	2.08	2.91	57.92
4	With phytase	712	3.52	1.34	2.18	62.46	66.29	4.39	1.50	3.10	66.05
5	Without phytase	715	3.62	2.16	1.46	46.32	50.07	4.72	1.68	2.72	57.57
5	With phytase	695	3.42	1.18	2.24	65.31	69.18	4.48	1.25	3.22	71.95
6	Without phytase	728	3.80	2.05	1.75	46.25	49.90	5.09	2.00	3.09	60.76
6	With phytase	689	3.37	1.26	2.10	62.28	66.16	4.29	1.54	2.75	63.75
7	Without phytase	735	4.25	2.00	2.25	52.62	55.91	5.72	1.95	3.78	65.48
7	With phytase	683	3.75	1.36	2.40	62.81	66.26	4.73	1.49	3.25	67.30
8	Without phytase	714	3.73	2.07	1.67	45.18	48.81	4.69	1.92	2.76	59.49
8	With phytase	670	3.40	1.18	2.38	65.83	69.58	4.13	1.04	3.33	75.67
Average	Without phytase	727	3.86	2.04	1.82	46.77	50.36	5.15	1.87	3.24	62.49
Average	With phytase	700	3.56	1.29	2.28	63.53	67.29	4.40	1.38	3.07	68.45
SEM[3]	Without phytase	52.45	0.28	0.22	0.20	3.10	3.10	0.38	0.19	0.32	3.80
P-value[3]	Without phytase	0.944	<0.01	0.605	0.014	0.252	0.307	<0.01	0.738	<0.01	0.163
SEM[4]	With phytase	51.44	0.26	0.13	0.22	2.54	2.54	0.32	0.16	0.29	3.22
P-value[4]	With phytase	0.848	<0.05	<0.05	0.578	0.553	0.462	0.036	0.108	0.158	0.091
SEM[5]	–	62.64	0.33	0.18	0.20	1.83	1.83	6.77	2.33	0.32	2.82
P-value[5]	–	0.024	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.083	<0.001

[1]Canola meals were sourced from Canada (3 samples) and the United States (2 samples); 00-rapeseed meals were sourced from Belgium, France, Germany, the Netherlands (2 samples), Poland (2 samples) and the United Kingdom; and 00-rapeseed expellers were sourced from Germany (2 samples), Hungary, the Netherlands, and Poland.

[2]Values for STTD were calculated by correcting values of ATTD using a constant value for endogenous P loss of 190 mg/kg DMI (NRC, 2012).

[3]Comparison of the 8 diets containing 00-rapeseed meal without phytase.

[4]Comparison of the 8 diets containing 00-rapeseed meal with phytase.

[5]Phytase effects.

different ($P < 0.05$) among pigs fed diets containing different sources of canola meal (Table 4). Without adding microbial phytase, P and Ca intake and absorbed P and Ca were also different ($P < 0.05$) among pigs fed diets containing different sources of 00-rapeseed meal (Table 5). However, the ATTD and STTD of P, excretion of P in feces, and ATTD of Ca were not different among pigs fed diets containing canola meal. Likewise, these values were also not different among pigs fed diets containing 00-rapeseed meal, but the P and Ca intake, excretion of P in feces, and ATTD and STTD of P were different ($P < 0.01$) among pigs fed diets containing 00-rapeseed expellers (Table 6). The ATTD and STTD of P for canola meal, 00-rapeseed meal, and 00-rapeseed expellers that were calculated in this experiment are greater than the values for canola meal, rapeseed meal, canola expellers, and rapeseed expellers reported by de Blas et al. (2010) and the NRC (2012).

The observation that the ATTD and STTD of P and ATTD of Ca were not different among pigs fed diets containing either canola meal or 00-rapeseed meal indicates that sources of canola meal and 00-rapeseed meal are relatively consistent in terms of P digestibility and Ca digestibility. However, the observation that there are differences in the ATTD and STTD of P among pigs fed diets containing the different sources of 00-rapeseed expellers indicates that variability exists in terms of P digestibility among sources of 00-rapeseed expellers.

The ATTD of Ca for canola meal diets observed in this experiment is greater than the ATTD of Ca in canola meal reported by González-Vega et al. (2013). This is likely because in this experiment, both limestone and canola meal contributed Ca to the diets, whereas all the Ca in the diets used by González-Vega et al. (2013) was from canola meal.

Phosphorus intake for pigs fed diets containing canola meal was less ($P < 0.001$) than for pigs fed diets

Table 6. Apparent total tract digestibility (ATTD) of P and Ca and standardized total tract digestibility (STTD) of P in 00-rapeseed expellers[1]

Item	Phytase	Feed intake, g DM/d	P intake, g/d	P output, g/d	Absorbed P, g/d	ATTD of P, %	STTD of P,[2] %	Ca intake, g/d	Ca output, g/d	Absorbed Ca, g/d	ATTD of Ca, %
00-rapeseed expellers											
1	Without phytase	724	4.00	2.30	1.71	42.79	46.23	5.12	2.61	2.68	52.39
1	With phytase	721	3.94	1.31	2.63	67.09	70.56	4.42	1.47	2.95	67.09
2	Without phytase	665	3.03	1.72	1.32	43.20	47.37	3.77	1.74	2.02	53.97
2	With phytase	575	2.72	0.73	1.99	73.22	77.24	3.92	0.76	3.00	76.60
3	Without phytase	728	3.68	1.80	1.88	50.24	54.00	3.76	1.84	1.93	50.55
3	With phytase	754	3.80	1.06	2.74	71.86	75.64	4.29	1.26	3.03	70.12
4	Without phytase	775	3.98	2.41	1.57	39.65	43.36	4.74	2.24	2.50	52.94
4	With phytase	756	3.60	1.23	2.37	65.40	69.39	4.33	1.65	2.92	61.15
5	Without phytase	690	3.49	1.83	1.67	48.26	52.02	4.71	2.37	2.34	51.09
5	With phytase	697	3.49	1.12	2.37	68.33	72.12	4.48	1.40	3.08	67.03
Average	Without phytase	716	3.64	2.01	1.63	44.83	48.60	4.42	2.16	2.29	52.19
Average	With phytase	701	3.51	1.09	2.42	69.18	72.99	4.29	1.31	2.99	68.40
SEM[3]	Without phytase	60.79	0.30	0.21	0.21	2.64	2.64	0.36	0.31	0.28	5.08
P-value[3]	Without phytase	0.207	<0.01	<0.001	0.195	<0.001	<0.001	<0.001	0.148	0.098	0.981
SEM[4]	With phytase	146.72	0.28	0.14	0.21	2.48	2.48	0.38	0.21	0.30	3.61
P-value[4]	With phytase	<0.001	<0.001	<0.01	0.083	0.081	0.072	0.41	0.304	0.893	0.027
SEM[5]	–	69.46	0.35	0.19	2.92	1.97	1.98	0.43	0.19	0.27	2.92
P-value[5]	–	0.482	0.355	<0.001	<0.001	<0.001	<0.001	0.391	<0.001	<0.001	<0.001

[1]Canola meals were sourced from Canada (3 samples) and the United States (2 samples); 00-rapeseed meals were sourced from Belgium, France, Germany, the Netherlands (2 samples), Poland (2 samples) and the United Kingdom; and 00-rapeseed expellers were sourced from Germany (2 samples), Hungary, the Netherlands, and Poland.

[2]Values for STTD were calculated by correcting values of ATTD using a constant value for endogenous P loss of 190 mg/kg DMI (NRC, 2012).

[3]Comparison of the 5 diets containing 00-rapeseed expellers without phytase.

[4]Comparison of the 5 diets containing 00-rapeseed expellers with phytase.

[5]Phytase effects.

containing 00-rapeseed meal, and P intake was greater ($P < 0.05$) for pigs fed 00-rapeseed meal diets than pigs fed 00-rapeseed expeller diets (Table 7). Calcium intake was not different between pigs fed diets containing canola meal and pigs fed 00-rapeseed meal, but Ca intake by pigs fed diets containing 00-rapeseed meal was greater ($P < 0.001$) than by pigs fed diets containing 00-rapeseed expellers. Absorption of P by pigs fed canola meal diets was less ($P < 0.01$) than by pigs fed 00-rapeseed meal diets, but the value was not different between pigs fed 00-rapeseed meal diets and 00-rapeseed expellers diets. The ATTD and STTD of P were not different between canola meal and 00-rapeseed meal, and the values did not differ between 00-rapeseed meal and 00-rapeseed expellers. Absorption and ATTD of Ca were not different between pigs fed diets containing canola meal and 00-rapeseed meal, but absorption and ATTD of Ca were greater ($P < 0.001$) in 00-rapeseed meal diets than in 00-rapeseed expellers diets.

Canola meal and 00-rapeseed meal were selected from the same variety (*Brassica napus*) and the same oil extraction procedure (mechanical press followed by solvent extraction) was used to extract the oil from the 2 ingredients. As a consequence, the concentration of phytate P and nonphytate P (80 and 20%, respectively) were not different between canola meal and rapeseed meal, which likely is the reason ATTD and STTD of P in canola meal are similar to the ATTD and STTD of P in 00-rapeseed meal. The observation that ATTD and STTD of P for 00-rapeseed meal did not differ from the values for 00-rapeseed expellers indicates that different oil extraction procedures have no effects on the digestibility of P.

When microbial phytase was added to diets, ATTD and STTD of P were different ($P < 0.01$) among pigs fed diets containing canola meal, but this was not the case for pigs fed diets containing 00-rapeseed meal or 00-rapeseed expellers (Tables 4, 5, and 6). However, ATTD of Ca was different ($P < 0.05$) among pigs fed diets containing 00-rapeseed expellers. Daily P output were reduced ($P < 0.001$) by addition of microbial phytase to diets containing canola meal, 00-rapeseed meal, or 00-rapeseed expellers. As a consequence, the ATTD and STTD of P was increased ($P < 0.001$) as microbial phytase was used. Daily Ca output were also reduced ($P < 0.001$) and ATTD of Ca was increased ($P < 0.001$) by using microbial phytase. This observation is in agreement with results reported by Akinmusire and Adeola

Table 7. Apparent total tract digestibility (ATTD) of P and Ca and standardized total tract digestibility (STTD) of P in canola meal, 00-rapeseed meal, and 00-rapeseed expellers[1]

Item	Phytase, FTU[2]/kg	Feed intake, g DM/d	P intake, g/d	P output, g/d	Absorbed P, g/d	ATTD of P, %	STTD of P,[3] %	Ca intake, g/d	Ca output, g/d	Absorbed Ca, g/d	ATTD of Ca, %
Canola meal	–	702	3.49	1.92	1.57	44.99	48.82	5.08	2.02	3.05	60.98
Canola meal	+	701	3.43	1.24	2.19	64.08	67.97	5.19	1.48	3.71	71.58
00-rapeseed meal	–	727	3.86	2.04	1.82	46.77	50.36	5.15	1.87	3.24	62.49
00-rapeseed meal	+	700	3.56	1.29	2.28	63.53	67.29	4.40	1.38	3.07	68.45
00-rapeseed expellers	–	716	3.64	2.01	1.63	44.83	48.60	4.42	2.16	2.29	52.19
00-rapeseed expellers	+	701	3.51	1.09	2.42	69.18	72.99	4.29	1.31	2.99	68.40
Canola meal vs. 00-rapeseed meal											
SEM[4]	–	65.58	0.34	0.23	0.17	1.90	1.90	0.47	0.22	0.33	2.75
P-value[4]	–	0.039	<0.001	0.125	<0.01	0.251	0.316	0.572	0.141	0.187	0.324
SEM[4]	+	62.44	0.31	0.12	0.23	1.99	2.00	0.42	0.16	0.33	2.41
P-value[5]	+	0.902	0.128	0.453	0.272	0.721	0.648	<0.001	0.280	<0.001	0.066
Interaction[6]											
SEM		52.22	0.27	0.14	0.16	1.62	1.62	0.37	0.15	0.27	2.14
P-value		0.15	0.028	0.368	0.143	0.225	0.251	<0.001	0.684	<0.001	0.055
00-rapeseed meal vs. 00-rapeseed expellers											
SEM[7]	–	64.07	0.34	0.22	0.17	1.92	1.90	0.43	0.21	0.30	3.01
P-value[7]	–	0.470	0.026	0.744	0.050	0.255	0.304	<0.001	0.019	<0.001	<0.001
SEM[8]	+	66.42	0.34	0.14	0.23	2.13	2.13	0.41	0.16	0.30	2.60
P-value[8]	+	0.956	0.678	<0.01	0.076	<0.001	<0.001	0.313	0.639	0.585	0.976
Interaction[9]											
SEM		53.59	0.28	0.15	0.16	1.62	1.62	0.35	0.15	0.25	2.40
P-value		0.607	0.209	0.166	<0.01	<0.01	<0.01	<0.01	0.061	<0.001	<0.001

[1]Canola meals were sourced from Canada (3 samples) and the United States (2 samples); 00-rapeseed meals were sourced from Belgium, France, Germany, the Netherlands (2 samples), Poland (2 samples) and the United Kingdom; and 00-rapeseed expellers were sourced from Germany (2 samples), Hungary, the Netherlands, and Poland.

[2]FTU = phytase units.

[3]Values for STTD were calculated by correcting values of ATTD using a constant value for endogenous P loss of 190 mg/kg DMI (NRC, 2012).

[4]Comparison of canola meal diets and 00-rapeseed meal diets without phytase.

[5]Comparison of canola meal diets and 00-rapeseed meal diets with phytase.

[6]Interaction between phytase and type of meal.

[7]Comparison of 00-rapeseed meal diets and 00-rapeseed expellers diets without phytase.

[8]Comparison of 00-rapeseed meal diets and 00-rapeseed expellers diets with phytase.

[9]Interaction between phytase and processing procedure.

(2009), González-Vega et al. (2013), and Rodríguez et al. (2013). Addition of microbial phytase to growing pig diets decreases excretion of P and increases digestibility of P because phytate P is degraded in the gastrointestinal tract of pigs (Adeola et al., 2004; Selle et al., 2009). This explains why P digestibility increased as microbial phytase was added to the diets. The increased digestibility of Ca that was observed when microbial phytase was used may be the result of an increased digestibility of Ca in limestone and canola coproducts, because dietary Ca may bind to phytate as Ca–phytate complexes in the gastrointestinal tract of pigs (Taylor, 1965). Therefore, adding microbial phytase to diets may reduce the Ca–phytate complex, which will result in increased digestibility of Ca from limestone and canola coproducts (Selle et al., 2009; González-Vega et al., 2013).

In conclusion, the ATTD and STTD of P and ATTD of Ca were not different among sources of canola meal or sources of 00-rapeseed meal, which indicates that a common book value for the digestibility of P and Ca may be used for canola meal or 00-rapeseed meal. However, differences in ATTD and STTD of P among sources of 00-rapeseed expellers were observed. The ATTD and STTD of P in canola meal were not different from the ATTD and STTD of P in 00-rapeseed meal, and the values did not differ between 00-rapeseed meal and 00-rapeseed expellers. Therefore, the digestibility of P in canola meal is also representative of the digestibility in 00-rapeseed meal and 00-rapeseed expellers. The ATTD of Ca in diets containing canola meal was also not different from values for diets containing 00-rapeseed meal. However, the ATTD of Ca in diets containing 00-rapeseed meal was greater than in diets containing 00-rapeseed expellers, which indicates the oil extraction procedures may influence Ca digestibility. The ATTD and STTD of P and the

ATTD of Ca are greater if microbial phytase is added to the diets, which is likely a result of microbial phytase hydrolyzing phytate-P bonds and reducing Ca–phytate complexes in the gastrointestinal tract of pigs.

LITERATURE CITED

Adeola, O. 2001. Digestion and balance techniques in pigs. In: A. J. Lewis and L. L. Southern, editors, Swine Nutrition. 2nd ed. CRC Press, New York, NY. p. 903–916.

Adeola, O., J. S. Sands, P. H. Simmins, and H. Schulze. 2004. The efficacy of an *E. coli*-derived phytase preparation. J. Anim. Sci. 82:2657–2666.

Akinmusire, A. S., and O. Adeola. 2009. True digestibility of phosphorus in canola and soybean meals for growing pigs: Influence of microbial phytase. J. Anim. Sci. 87:977–983. doi:10.2527/jas.2007-0778.

Almeida, F. N., and H. H. Stein. 2010. Performance and phosphorus balance of pigs fed diets formulated on the basis of values for standardized total tract digestibility of phosphorus. J. Anim. Sci. 88:2968–2977. doi:10.2527/jas.2009-2285.

Arntfield, S., and D. Hickling. 2011. Meal nutrition and utilization. In: J. K. Daun, N. A. M. Eskin, and D. Hickling, editors, Canola: Chemistry, production, processing, and utilization. AOCS Press, Urbana, IL. p. 281–312.

de Blas, C., G. G. Mateos, and P. Garcia-Rebollar. 2010. Tablas FEDNA de composicion y valor nutritive de alimentos para la fabricacion de piensos compuestos. 3th rev. ed. Fundacion Española para el Desarrollo de la Nutricion Animal.

Ellis, R., E. R. Morris, and C. Philpot. 1977. Quantitative determination of phytate in the presence of high inorganic phosphate. Anal. Biochem. 77:536–539. doi:10.1016/0003-2697(77)90269-X.

González-Vega, J. C., C. L. Walk, Y. Liu, and H. H. Stein. 2013. Determination of endogenous intestinal losses of calcium and apparent and true total tract digestibility of calcium in canola meal fed to growing pigs. J. Anim. Sci. 91:4807–4816. doi:10.2527/jas.2013-6410.

Hortwitz, W., and G. W. Latimer Jr., editors. 2007. Official methods of analysis of AOAC International. 18th ed. Rev. 2. AOAC Int., Gaithersburg. MD.

Liu, J., D. R. Ledoux, and T. L. Veum. 1998. In vitro prediction of phosphorus availability in feed ingredients for swine. J. Agric. Food Chem. 46:2678–2681. doi:10.1021/jf9801421.

Newkirk, R. 2009. Canola meal. Feed industries guide, 4th ed. Canadian International Grains Institute, Winnipeg, MB, Canada.

Newkirk, R. 2011. Meal nutrient composition. In: J. K. Daun, N. A. M. Eskin, and D. Hickling, editors, Canola: Chemistry, production, processing, and utilization. AOCS Press, Urbana, IL. p. 229–244.

NRC. 2012. Nutrient requirements of swine. 11th ed. Natl. Acad. Press, Washington, DC.

Philippine Society of Animal Nutritionists. 2010. Nutrient composition and usage limitations of common feed ingredients. In: B. A. Oliverios, editor, Feed reference standards. 4th ed. Philippine Society of Animal Nutritionists, Laguna, Philippines. p. 51–102.

Rodríguez, D. A., R. C. Sulabo, J. C. González-Vega, and H. H. Stein. 2013. Energy concentration and phosphorus digestibility in canola, cottonseed, and sunflower products fed to growing pigs. Can. J. Anim. Sci. 93:493–503. doi:10.4141/cjas2013-020.

Rostagno, H. H., L. F. T. Albino, J. L. Donzele, P. C. Gomes, R. T. Oliveira, D. C. Lopes, A. S. Ferreira, S. L. T. Barreto, and R. F. Euclides. 2011. Brazilian tables for poultry and swine. Composition of feedstuffs and nutritional requirements. 3rd ed. UFV, Viçosa, Brazil.

Sanderson, P. 1986. A new method of analysis of feeding stuffs for the determination of crude oils and fats. In: W. Haresign and D. J. A. Cole, editors, Recent advances in animal nutrition. Butterworths, London, UK. p. 77–81.

Sauvant, D., J. M. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials. 2nd ed. Wageningen Academic Publishers, Amstelveen, the Netherlands.

Selle, P. H., A. J. Cowieson, and V. Ravindran. 2009. Consequences of calcium interactions with phytate and phytase for poultry and pigs. Livest. Sci. 124:126–141. doi:10.1016/j.livsci.2009.01.006.

Spragg, J. C., and R. J. Mailer. 2007. Canola meal value chain quality improvement: A final report prepared for AOF and CRC. Project code 1B-103-0506. http://www.porkcrc.com.au/Final_Report_1B-103.pdf. (Accessed January 25, 2015.)

Taylor, T. G. 1965. The availability of the calcium and phosphorus of plant materials for animals. Proc. Nutr. Soc. 24:105–112. doi:10.1079/PNS19650017.

Thomas, P. 2005. Review of University of Alberta canola breeding program. http://www.acidf.cafilesfocuscanola.pdf. (Accessed January 25, 2015)

Tran, G., and D. Sauvant. 2004. Chemical data and nutritional value. In: D. Sauvant, J. M. Pérez, and G. Tran, editors, Tables of composition and nutritional value of feed materials: Pigs, poultry, cattle, sheep, goats, rabbits, horses, fish. Institut National de la Recherche Agronomique, Association Française de Zootechnie, Paris, France. p. 17–24.

Uppström, B., and R. Svensson. 1980. Determination of phytic acid in rapeseed meal. J. Sci. Food Agric. 31:651–656. doi:10.1002/jsfa.2740310706.

Zhang, Z. B., E. T. Kornegay, J. S. Radcliffe, J. H. Wilson, and H. P. Veit. 2000. Comparison of phytase from genetically engineered *Aspergillus* and canola in weanling pig diets. J. Anim. Sci. 78:2868–2878.