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Non Ruminant Nutrition

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Standardized ileal digestibility of amino acids in canola meal fed to gestating and lactating sows[1]

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Abstract

An experiment was conducted to determine the standardized ileal digestibility (**SID**) of CP and AA in solvent extracted canola meal (**CM**) fed to gestating and lactating sows without or with a multi-enzyme complex. Eight sows cannulated on day 40 of gestation were randomly assigned to 1 of 4 dietary treatments in a replicated 4 × 4 Latin square design. The 4 diets included 2 cornstarch-based diets with 31.3% CM as the only source of AA, without or with a multi-enzyme complex, a casein-cornstarch diet to determine ileal endogenous AA losses, and a phosphorus-free diet (phosphorus digestibility data reported elsewhere). All diets contained 0.3% titanium dioxide. Gestating sows were fed 3.0 kg/d of the respective experimental diets, whereas, during lactation, sows had ad libitum access to experimental diets. Ileal digesta samples were collected in midgestation, late gestation, and lactation. In each period, after 6-d acclimation to the experimental diets, on days 7 and 8, ileal digesta samples were collected continuously for 12 h. Results indicated that sows in lactation had greater apparent ileal digestibility (**AID**) of CP and all AA ($P < 0.05$) compared with sows in gestation. Enzyme supplementation improved ($P < 0.05$) the AID of histidine, lysine, methionine, valine, and alanine, and a tendency ($P < 0.10$) for improvement in AID was observed for arginine, isoleucine, tryptophan, and cysteine during lactation, but not during gestation. However, the SID of most AA was not affected by collection phase, but enzyme supplementation improved ($P < 0.05$) the SID of arginine, histidine, lysine, methionine, and valine during lactation. The SID of indispensable AA in CM fed to gestating and lactating sows were as follows: arginine, 89.2 and 91.3%; histidine, 93.1 and 94.0%; isoleucine, 85.9 and 87.0%; leucine, 89.2 and 89.2%; lysine, 87.0 and 87.7%; methionine, 92.2 and 93.2%; phenylalanine, 89.2 and 87.8%; threonine, 84.3 and 82.7%; tryptophan, 88.1 and 91.5%; valine, 85.9 and 84.3%. In conclusion, the SID of AA in CM fed to lactating sows may be improved if a mixture of carbohydrases is included in the diet, but under the conditions of this experiment, the carbohydrase mixture did not affect SID of AA in CM fed to gestating sows in midgestation or late gestation.

Key words: amino acids, canola meal, digestibility, gestating sows, lactating sows

Introduction

Canola meal (**CM**) is a commonly used feed ingredient in swine diets; however, its content of antinutritional factors such as glucosinolates and fiber has restricted its use as a major protein source (Newkirk, 2009; Barthet and Daun, 2011). Even though the AA content in CM is reasonably high (NRC, 2012), high dietary inclusion has resulted in a reduction in feed intake, and energy

and nutrient utilization in growing pigs (González-Vega and Stein, 2012). However, newly developed canola varieties have a reduced fiber content and low contents of glucosinolates (Slominski, 1997; Mejicanos, 2015). Results of recent experiments have indicated that inclusion of CM up to 30% in lactating sow diets did not have a negative impact on performance if diets were formulated to have similar net energy content and standardized ileal digestible AA concentrations (Velayudhan and Nyachoti, 2017; Liu et al., 2018; Velayudhan et al., 2018). Hence, determination of standardized ileal digestibility (**SID**) of AA of CM is necessary for accurate diet formulation.

Ileal digestibility of AA for feed ingredients including CM in pigs has been determined in numerous experiments. However, most experiments were conducted using either weaned, growing, or finishing pigs (Fan and Sauer, 1995; Fan et al., 1996; Grala et al., 1998; Woyengo et al., 2010; Kim et al., 2015), and only limited data have reported for ileal digestibility of AA in ingredients fed to sows. Accordingly, dietary supply of AA in studies involving sows rely on digestibility values from growing pigs. Factors such as age, body weight, and feeding level may influence the ability of pigs to digest AA in a given diet (Moughan, 1993; Stein et al., 2001). Consequently, sows and growing pigs may digest dietary proteins differently. Also, Stein et al. (1999) reported that apparent total tract and apparent ileal AA digestibility of various ingredients obtained in growing pigs are not always representative of values in gestating or lactating sows. Moreover, supplementation of diets containing CM with carbohydrases could improve nutrient utilization in CM. Thus, it was the objective of the present experiment to test the hypothesis that the SID of AA in CM fed to gestating or lactating sows will increase if a carbohydrase mixture is included in the diet. The specific objectives of this experiment were to determine 1) the SID of AA in CM fed to gestating and lactating sows and 2) the effect of enzymes on ileal digestibility of AA in CM in gestating and lactating sows.

Materials 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 (2009).

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 in 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 to fully slatted farrowing crates (2.30 × 1.70 m) with a stainless-steel sow feeder and a nipple drinker. Rooms were mechanically ventilated, and the temperature was maintained at 18 to 20 °C. Sows were allowed a recovery period of 10 d after surgery, during which they were fed a corn-soybean meal-based diet before feeding of experimental diets was initiated.

The 4 experimental diets included a cornstarch-based diet containing 31.3% CM as the only source of AA and this diet was fed either without or with an enzyme mixture. A casein-cornstarch diet was used to determine basal ileal endogenous losses of AA and a phosphorus-free diet was used to determine the endogenous phosphorus loss (phosphorus digestibility data are reported elsewhere). The enzyme mixture that was included in one of the CM diets was procured from Canadian Bio-System Inc. (Calgary, Alberta, Canada) and provided 2,550 U of cellulase, 1,650 U of pectinase, 360 U of mannanase, 45 U of galactanase, 1,800 U of xylanase, 540 U of glucanase, 2,250 U of amylase, 180 U of protease, and 1,250 U of phytase per kg of diet. All diets also contained 0.3% titanium dioxide as an indigestible marker and were fed in mash forms.

Experimental Design and Procedures

After a 10-d recovery period, the 8 sows were randomly assigned to a repeated 4 × 4 Latin square for a total of 8 observations per treatment. Gestating sows were fed 3.0 kg/d of the respective experimental diets, whereas, during lactation, sows had ad libitum access to experimental diets. Two equal meals were offered at 0700 and 1300 h as dry mash. The experiment included 3 phases: midgestation, late gestation, and lactation. Each phase had 4 experimental periods lasting for 8 d each. In each period, after 6-d acclimation to the experimental diets, on days 7 and 8, ileal digesta samples were collected continuously for 12 h (0700 to 1900 h) into plastic bags that were attached to the barrel of the ileal T-cannulas by a hose clamp as described by Nyachoti et al. (2002). Collection bags contained 10 mL of 10% (vol/vol) formic acid. Every 1 h or whenever the bags were three-quarters full, bags were removed and replaced with a new bag. Digesta samples were frozen at –20 °C until processing.

Sample Preparation and Chemical Analyzes

Ileal digesta samples were thawed and pooled for each sow and period, homogenized in a heavy-duty blender (Waring Commercial, Torrington, CT), subsampled, and freeze-dried. Dried digesta and experimental diets were ground to pass through a 1-mm screen before chemical analysis. Ileal digesta, diet, and CM samples were analyzed for DM, AA, and CP. Diets and digesta samples were analyzed for titanium. Canola meal samples were also analyzed for ether extract, ash, neutral detergent fiber, total and phytate phosphorus, gross energy, calcium, and glucosinolates.

Dry matter was determined according to the AOAC (1990; method 925.09) by oven drying 5 g of sample at 102 °C overnight. Gross energy was measured using an adiabatic bomb calorimeter (model 6400, Parr Instrument, Moline, IL), which was calibrated using benzoic acid as a standard. Nitrogen content was determined using the combustion method (method 990.03; AOAC, 1990) using the LECO N analyzer (model CNS-2000; LECO Corp., St. Joseph, MI), and CP was calculated as nitrogen × 6.25. Neutral detergent fiber was analyzed according to the method of Van Soest et al. (1991) using the Ankom Fiber Analyzer (Ankom Technology, Fairport, NY). Ether extract in samples was determined after hexane extraction (method 920.39; AOAC, 1990) in an Ankom extraction system (Macedon, NY). Samples for analysis of calcium and phosphorus were ashed for 12 h and digested according to AOAC Int. (2005; method 985.01) and read on a Varian inductively coupled plasma mass spectrometer (Varian Inc, Palo Alto, CA). Phytate-bound phosphorus was determined using the procedure by Haug and Lantzsch (1983). Nonphytate phosphorus was calculated by subtracting phytate-bound phosphorus from total phosphorus. 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). Glucosinolates were

determined according to the procedures described by Niu et al. (2015). Amino acids were analyzed as described in method 994.12 (AOAC, 1990) and modified by Mills et al. (1989). Briefly, a 100-mg sample was digested in 4 mL of 6M HCl for 24 h at 110 °C. The digested mixture was neutralized with 4 mL of 6.25 M NaOH and allowed to cool at room temperature. The neutralized mixture was made up to a 50-mL volume with sodium citrate buffer solution (19.6 g/L; pH 2.2) and analyzed using an AA analyzer (Sykam, Eresing, Germany). Samples for analysis of S-containing AA (Met and Cys) were subjected to performic acid oxidation before acid hydrolysis. Tryptophan was determined according to the procedures described by Hugli and Moore (1972). Briefly, 50 mg of sample was hydrolyzed with 25% NaOH at 120 °C for 20 h and was analyzed using an AA analyzer (Sykam, Eresing, Germany).

Calculations and Statistical Analysis

Apparent ileal digestibility (**AID**) coefficient was calculated using the following equation:

$$\text{Apparent nutrient digestibility } (\%) = 100 - \{[(N_d/N_f) \times (Ti_f/Ti_d)] \times 100\},$$

where N_d = nutrient concentration in digesta (mg/kg DM), N_f = nutrient concentration in feed (mg/kg DM), Ti_f = titanium concentration in feed (mg/kg DM), Ti_d = titanium concentration in digesta (mg/kg DM).

Standardized ileal digestibility of AA was calculated using the following equation:

$$\%\ \text{SID} = \text{AID} + [(\text{EAL}/\text{AA}_f) \times 100]$$

where EAL = basal endogenous loss of AA (mg/kg DM intake), AA_f = dietary content of the AA (mg/kg DM). EAL for AA was calculated according to the following equation:

$$\text{EAL} = N_{ex} \times (Ti_f/Ti_d)$$

where N_{ex} = concentration of AA in ileal digesta from sows fed the casein-cornstarch diet, Ti_f = titanium concentration in feed (mg/kg DM), and Ti_d = titanium concentration in ileal digesta (mg/kg DM).

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) with sow as the experimental unit. The statistical model included the fixed effect of diet and the random effects of period, animal, and the reproductive phase. Statistical differences among the treatments were separated by Tukey's multiple range test. Treatment means were calculated using the LSMEANS statement. Results were considered significant at $P \leq 0.05$, and tendencies were observed at $0.05 < P < 0.10$.

Results

Analyzed chemical composition of the experimental diet and CM is presented in Tables 1 and 2. The analyzed CP content of the diet were close to the calculated values.

Apparent Ileal Digestibility

Sows in lactation had greater ($P < 0.05$) AID of CP and all AA than sows in midgestation or late gestation, with the exception that the AID of proline tended ($P = 0.062$) to be greater in lactating sows than in gestating sows (Table 3). Exogenous enzymes improved ($P < 0.05$) the AID of histidine, lysine, methionine, valine, and alanine, and tended ($P < 0.10$) to increase AID of arginine, isoleucine, tryptophan, and cysteine in lactating sows.

Table 1. Ingredient composition and analyzed nutrient content of experimental diets (as-fed basis)

Item	CM[1]	LND[2]
Ingredient, %		
Canola meal	31.30	—
Cornstarch	61.35	59.75
Casein	—	5.00
Dextrose	—	25.20
Soybean oil	5.00	2.00
Limestone	1.00	0.40
Solka flock	—	4.00
Monocalcium phosphate	—	2.30
Iodized salt	0.40	0.40
Vitamin-mineral premix[3]	0.65	0.65
Titanium dioxide	0.30	0.30
Analyzed nutrient content		
DM, %	89.0	90.0
CP, %	12.9	4.7
GE, kcal/kg	4,103	3,963
Calcium, %	0.62	0.67
Phosphorus, %	0.43	0.57
Indispensable amino acids, %		
Arginine	0.60	0.17
Histidine	0.35	0.16
Isoleucine	0.40	0.24
Leucine	0.72	0.45
Lysine	0.62	0.39
Methionine	0.25	0.16
Phenylalanine	0.40	0.23
Threonine	0.46	0.23
Tryptophan	0.16	0.06
Valine	0.52	0.32
Dispensable amino acids, %		
Alanine	0.48	0.15
Aspartic acid	0.77	0.33
Cysteine	0.26	0.04
Glycine	0.54	0.09
Glutamic acid	1.95	1.10
Proline	0.64	0.51
Serine	0.50	0.30
Tyrosine	0.26	0.20

[1]CM = canola meal containing diet without exogenous enzymes. The CM diet was formulated without and with addition of exogenous enzymes. The exogenous enzymes (Canadian Bio-System Inc., Calgary, AB, Canada) included 2,550 U of cellulase, 1,650 U of pectinase, 360 U of mannanase, 45 U of galactanase, 1,800 U of xylanase, 540 U of glucanase, and 2,250 U of amylase, 180 U of protease, and 1,250 U of phytase per kg of diet).
[2]LND = low nitrogen diet (casein-cornstarch diet).
[3]Supplied the following per kg of finished feed: vitamin A, 6,058 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.

However, no effect of enzyme supplementation on the AID of AA was observed in midgestation or late gestation with the exception that glutamic acid had greater ($P < 0.05$) AID and the AID of serine tended ($P = 0.071$) to increase during midgestation if enzymes were added to the diet.

Standardized Ileal Digestibility

The SID of arginine, histidine, lysine, methionine, tryptophan, and serine was greater ($P < 0.05$), and the SID of glutamic

Table 2. Analyzed composition of canola meal (DM basis)

Item	Canola meal
CP, %	41.5
Ether extract, %	3.90
Ash, %	7.40
NDF, %	28.80
Calcium, %	0.7
Phosphorus, %	1.28
Phytate phosphorus, %	0.81
Nonphytate phosphorus, %	0.46
Glucosinolates, μmol/g	7.80
Indispensable amino acids, %	
Arginine	2.27
Histidine	1.18
Isoleucine	1.29
Leucine	2.57
Lysine	2.07
Methionine	0.68
Phenylalanine	1.51
Threonine	1.56
Tryptophan	0.56
Valine	1.68
Dispensable amino acids, %	
Alanine	1.73
Aspartic acid	2.73
Cysteine	0.87
Glycine	1.77
Glutamic acid	6.59
Proline	2.83
Serine	1.82
Tyrosine	0.97

acid tended ($P = 0.091$) to be greater in lactating sows than in gestating sows, but for all other AA, no difference among midgestation, late gestation, and lactation was observed (Table 4). Supplementation of CM with exogenous enzymes improved ($P < 0.05$) the SID of glutamic acid in midgestation, and SID of arginine, histidine, lysine, methionine, and valine was increased in lactating sows if enzymes were added to the diet ($P < 0.05$). During lactation, a tendency for an increase in the SID of tryptophan ($P = 0.059$) and alanine ($P = 0.068$) was observed if enzymes were added to the diet.

Nonspecific endogenous nitrogen and AA losses determined using the low-protein casein-cornstarch diet are shown in Table 5. Each value was the mean of data from 8 sows. The endogenous nitrogen losses averaged 3.2, 3.1, and 2.4 g/kg of DMI for midgestation, late gestation, and lactation, respectively.

Discussion

The CM used in the current experiment had concentrations of CP, NDF, AA, and minerals that are within the range of values observed in previous experiments (González-Vega and Stein, 2012; Maison and Stein, 2014; Adewole et al., 2016, 2017). However, CM from different processing plants in Canada may vary in nutrient composition due to differences in growing and harvesting conditions, and also due to variation in heat treatment during processing (Bell and Keith, 1991; Adewole et al., 2016).

Apparent Ileal Digestibility

To our knowledge, only one experiment has been conducted to determine the AID of AA in CM fed to gestating and lactating sows (Stein et al., 1999). The AID of CP and most AA in CM fed to gestating and lactating sows in the current experiment was greater compared with the values reported by Stein et al. (1999). Protein and AA digestibility in CM fed to pigs is influenced by the age of the pig (Maison and Stein, 2014), canola variety, and oil extraction procedure used (Woyengo et al., 2010; Trindade Neto et al., 2012; Adewole et al., 2017). The AID of AA in CM used in different studies may also vary depending on the concentrations of tannin, neutral detergent fiber, and the hull in different varieties of canola being used (Fan et al., 1996). The heat treatment during processing may have a negative effect on AA digestibility, mainly because of overheating (Parsons et al., 1991; Khajali and Slominski, 2012; Almeida et al., 2014; Adewole et al., 2016).

Values for AID of CP and AA in CM fed to lactating sows that were calculated in the current experiment were greater than reported values for growing-finishing pigs (Stein et al., 1999; González-Vega and Stein, 2012; Maison and Stein, 2014; Adewole et al., 2017). The AID of most AA in CM fed to gestation sows in the current experiment was either similar or lower than values in growing-finishing pigs.

The reason why sows may have greater AID of protein and AA compared with growing pigs is a more efficient digestive system, and a larger and more developed gastrointestinal tract (Bridges et al., 1986). An increase in the intestinal volume may result in longer residence time for digesta in sows (Varel, 1987; Low, 1993), resulting in increased absorption of nutrients. Another factor that influences digestibility of nutrients is the feed intake by the animals. Lactating sows and growing pigs are usually allowed ad libitum access to feed, whereas feed intake for gestating sows usually is restricted. Lower levels of feed intake have shown to have a significant effect on AID of AA in pigs (Moter and Stein, 2004), and also a reduced feed intake increases digestibility of energy, crude fiber, and fat (Cunningham et al., 1962; Everts et al., 1986; Shi and Noblet, 1993). However, the nonspecific or basal endogenous losses of AA (g/kg DMI) are elevated with a reduction in feed intake (Moter and Stein, 2004; Adeola et al., 2016), and a greater excretion of nonspecific endogenous AA results in reduced AID of AA (Hess and Sève, 1999; Hodgkinson et al., 2000; Leterme and Théwis, 2004; Adeola et al., 2016). The nonspecific endogenous losses of AA are related only to DM intake of the animal and are not influenced by the type of diet or the feed ingredient itself. Gestating sows in the current experiment had elevated endogenous AA losses compared with lactating sows. Values for basal endogenous AA losses observed in the current experiment were greater for gestating sows compared with values reported for growing pigs (Adeola et al., 2016; Adewole et al., 2017). This may be attributed to the restricted feed intake used for the gestating sows and this resulted in a reduced estimate of AID for AA in gestating sows compared with lactating sows (average feed intake of 6.8 kg/d). Accordingly, because lactating sows generally have endogenous losses of AA that are not different from losses in growing pigs, it is expected that the AID for AA will not be different between lactating sows and growing pigs.

Standardized Ileal Digestibility

The SID of CP and AA in CM in gestating and lactating sows that were observed in the current experiment were in agreement with SID values for CP and AA in CM reported for gestating and lactating sows by Stein et al. (2001). The observations that SID of certain AA in lactating sows were greater than in gestating sows indicate that lactating sows digest AA better than gestating sows

Table 3. Apparent ileal digestibility of DM, CP, and AA in canola meal fed to sows[1]

	Phase												
	Midgestation			Late gestation			Lactation						
	Diets[2]			Diets[2]			Diets[2]			P-value			
Item Enzymes:	CM (–)	CM (+)	SEM	CM (–)	CM (+)	SEM	CM (–)	CM (+)	SEM	Midgestation	Late gestation	Lactation	Phase
DM, %	75.9	79.4	1.63	75.8	78.5	2.34	75.9	77.0	0.95	0.124	0.349	0.126	0.936
CP, %	65.2	65.9	0.83	65.6	65.6	0.96	67.0	69.4	0.95	0.554	0.999	0.135	0.004
Indispensable AA, %													
Arginine	75.8	75.3	0.90	77.3	75.9	0.74	83.5	86.1	0.71	0.699	0.279	0.059	<0.001
Histidine	35.8	35.3	0.58	37.8	37.2	0.75	53.2	57.2	0.39	0.611	0.218	<0.001	<0.001
Isoleucine	72.6	73.5	1.09	74.5	73.3	1.09	79.4	81.6	0.64	0.672	0.333	0.087	<0.001
Leucine	77.3	76.6	0.68	78.3	77.0	0.63	80.5	82.5	0.85	0.625	0.270	0.222	<0.001
Lysine	74.7	74.5	0.57	75.4	74.5	0.82	80.3	82.8	0.58	0.779	0.401	0.041	<0.001
Methionine	84.0	83.6	0.78	85.4	84.8	0.54	87.6	89.9	0.39	0.757	0.307	0.007	<0.001
Phenylalanine	76.3	76.8	1.35	77.7	77.2	0.63	79.9	82.5	1.02	0.764	0.650	0.123	0.003
Threonine	61.8	61.1	1.28	62.9	61.0	2.62	72.5	73.3	0.80	0.798	0.506	0.472	<0.001
Tryptophan	73.8	75.6	1.90	75.8	76.0	1.36	85.7	88.1	0.63	0.505	0.895	0.053	<0.001
Valine	72.4	72.1	1.06	73.0	72.6	0.61	74.5	81.1	0.79	0.853	0.720	0.001	<0.001
Dispensable AA, %													
Alanine	70.5	72.0	0.93	70.9	71.6	1.44	76.7	78.9	0.64	0.373	0.678	0.031	<0.001
Aspartic acid	59.1	59.4	1.10	59.2	59.5	2.36	71.1	71.0	1.19	0.871	0.884	0.954	<0.001
Cysteine	71.2	71.1	1.63	72.7	71.9	1.30	78.5	81.0	0.79	0.974	0.683	0.059	<0.001
Glycine	67.0	68.0	0.49	67.1	68.1	0.66	73.2	74.6	1.40	0.344	0.502	0.506	<0.001
Glutamic acid	81.4	83.5	0.49	83.5	83.9	0.42	86.6	87.8	0.68	0.007	0.352	0.158	<0.001
Proline	55.2	55.8	4.58	56.4	53.9	3.93	64.8	66.0	2.25	0.944	0.578	0.781	0.062
Serine	69.8	72.5	0.76	71.8	72.6	0.56	73.9	75.8	0.60	0.071	0.471	0.134	0.001
Tyrosine	69.5	70.2	1.13	70.5	70.4	1.41	78.1	78.6	1.09	0.740	0.979	0.772	<0.001

[1]n = 8.
[2]CM = canola meal containing diet at 31.3% inclusion and as the only source of AA.

despite the greater feed intake. However, values for SID of AA are influenced by the level of feed intake (Stein et al., 2007), and SID values obtained in restrictedly fed pigs are not comparable to values obtained from pigs allowed ad libitum access to diets (Moter and Stein, 2004).

Enzyme Supplementation

Oilseeds, when used at high inclusion rates in swine diets, may contribute to the total quantity of nonstarch polysaccharides (**NSP**) and phytate in the diet. High-NSP diets reduce AA digestibility in pigs (Torre et al., 1991; Myrie et al., 2008), mainly by physical entrapment of nutrients, thereby creating a barrier for absorption (Bedford and Schulze, 1998), or due to a greater flow of endogenous AA caused by fiber (Le Goff and Noblet, 2001; Bartelt et al., 2002). Phytate, on the other hand, binds 6 phosphate groups, making phosphorus unavailable because pigs and poultry do not secrete sufficient quantities of phytase to break these bonds.

The use of a mixture of carbohydrases that target different NSP may result in greater benefits than if individual NSP-degrading enzymes are used because one enzyme may facilitate the activity of the other (Olukosi and Adeola, 2013). As an example, use of a carbohydrase and phytase combination may result in hydrolysis of the cell wall by the carbohydrases, which may improve the contact between phytase and phytate, thus enhancing phytase activity (Simon, 1998; Woyengo, 2007).

The use of exogenous enzymes in sow diets has not been extensively studied because sows can utilize fibrous feedstuffs more effectively than growing pigs and the stage of reproduction may influence the effect of enzyme supplementation in sows (Olukosi and Adeola, 2013). The efficacy of multi-carbohydrases in degradation of cell wall polysaccharide of CM has been verified by Meng et al. (2005) in an in-vitro study. However, results from experiments in which combinations of carbohydrases were used in, have been inconsistent. Inclusion of Superzyme OM (the carbohydrase combination used in the current experiment) in diets fed to growing pigs did not result in improved AA digestibility (Sanjayan, 2013). However, because the improved SID of AA as a result of enzyme addition was only observed in lactating sows, it is possible that lactating sows respond better to the enzyme mix than gestating sows and growing pigs. However, it is not clear from the present data what the mechanism behind this effect may be, but in broilers it was observed that improvement in growth performance as a result of enzyme supplementation was more evident in ad libitum fed birds compared with birds fed restricted amounts of feed (Lázaro et al., 2004).

In conclusion, AID of AA are greater in lactating sows than in gestating sows because of elevated basal endogenous losses of AA in gestating sows compared with lactating sows. However, lactating sows also have greater SID values for some, but not all, AA compared with gestating sows indicating that there are physiological differences between the 2 groups of sows. The SID of AA was also increased in lactating sows by addition of a combination of enzymes to the diet, but that was not the case for gestating sows.

Table 4. Standardized ileal digestibility of DM, CP, and AA in canola meal fed to sows[1]

	Phase												
	Midgestation			Late gestation			Lactation						
	Diets2			Diets2			Diets2			P-value			
Item Enzymes:	CM (–)	CM (+)	SEM	CM (–)	CM (+)	SEM	CM (–)	CM (+)	SEM	Midgestation	Late gestation	Lactation	Phase
CP, %	79.9	80.6	0.83	79.7	80.3	0.96	77.9	80.3	0.95	0.551	0.736	0.135	0.457
Indispensable AA, %													
Arginine	88.7	88.4	0.88	89.8	88.9	0.74	91.3	94.2	0.68	0.831	0.486	0.036	<0.001
Histidine	93.5	92.6	0.56	92.6	93.1	0.75	94.0	95.8	0.38	0.265	0.571	0.030	0.001
Isoleucine	85.9	86.7	1.09	86.0	86.6	1.09	87.0	88.9	0.65	0.675	0.636	0.150	0.127
Leucine	88.8	88.7	0.70	89.5	88.7	0.63	89.2	90.5	0.91	0.909	0.445	0.446	0.469
Lysine	86.9	86.8	0.59	87.0	86.7	0.82	87.7	89.9	0.58	0.881	0.781	0.045	0.005
Methionine	91.6	90.9	0.76	92.9	92.0	0.54	93.3	95.1	0.39	0.615	0.203	0.026	<0.001
Phenylalanine	88.7	88.0	1.36	89.6	88.7	0.63	87.8	89.9	0.99	0.686	0.416	0.253	0.819
Threonine	84.7	84.0	1.29	83.9	84.0	2.62	82.7	83.8	0.74	0.786	0.975	0.355	0.670
Tryptophan	87.5	89.1	1.92	88.8	89.8	1.36	91.5	93.8	0.63	0.548	0.574	0.059	0.006
Valine	85.8	84.7	1.00	86.1	84.9	0.61	84.3	89.3	0.78	0.512	0.328	0.004	0.281
Dispensable AA, %													
Alanine	85.8	85.6	0.93	87.5	85.7	1.44	84.9	86.7	0.69	0.894	0.277	0.068	0.561
Aspartic acid	84.8	84.8	1.15	82.5	85.3	2.36	84.7	83.9	1.17	0.982	0.192	0.751	0.676
Cysteine	87.0	86.3	1.51	87.5	86.5	1.30	87.2	88.5	0.80	0.812	0.615	0.215	0.665
Glycine	90.2	91.3	0.51	91.0	91.3	0.66	90.7	91.6	1.46	0.296	0.813	0.684	0.885
Glutamic acid	90.6	92.6	0.49	93.6	93.1	0.42	92.4	93.6	0.67	0.008	0.331	0.138	0.091
Proline	101.8	102.5	4.59	103.0	100.7	7.92	97.0	99.1	2.30	0.941	0.780	0.635	0.603
Serine	88.8	91.7	0.75	90.6	91.7	0.56	84.6	86.7	0.61	0.052	0.360	0.101	<0.001
Tyrosine	86.5	85.6	1.15	86.1	86.0	1.41	87.5	88.3	1.06	0.684	0.974	0.677	0.232

[1]n = 8.
[2]CM = canola meal containing diet at 31.3% inclusion and as the only source of AA.

Table 5. Nonspecific endogenous nitrogen and AA losses in sows[1]

	Nonspecific endogenous losses[2], mg/kg DMI		
Item	Midgestation	Late gestation	Lactation
Nitrogen	3,206.6	3,065.9	2,382.8
Indispensable AA			
Arginine	797.9	769.4	502.7
Histidine	2,091.9	19,84.1	1,479.2
Isoleucine	599.6	520.5	318.7
Leucine	868.4	842.6	600.1
Lysine	857.8	816.4	502.9
Methionine	201.3	198.8	148.1
Phenylalanine	520.1	503.8	306.8
Threonine	1,094.8	900.5	501.2
Tryptophan	236.3	224.8	98.8
Valine	719.8	701.8	405.6
Dispensable AA			
Alanine	762.6	725.9	424.6
Aspartic acid	1,971.2	1,711.2	994.6
Cysteine	423.6	395.1	217.4
Glycine	1,406.4	1,448.7	1,033.4
Glutamic acid	2,033.2	2,042.3	1,289.9
Proline	3,407.2	3,254.1	2,419.7
Serine	993.5	985.8	569.7
Tyrosine	466.9	428.7	264.1

[1]n = 8.
[2]The nonspecific endogenous loss of AA was estimated from sows fed the low nitrogen diet.

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