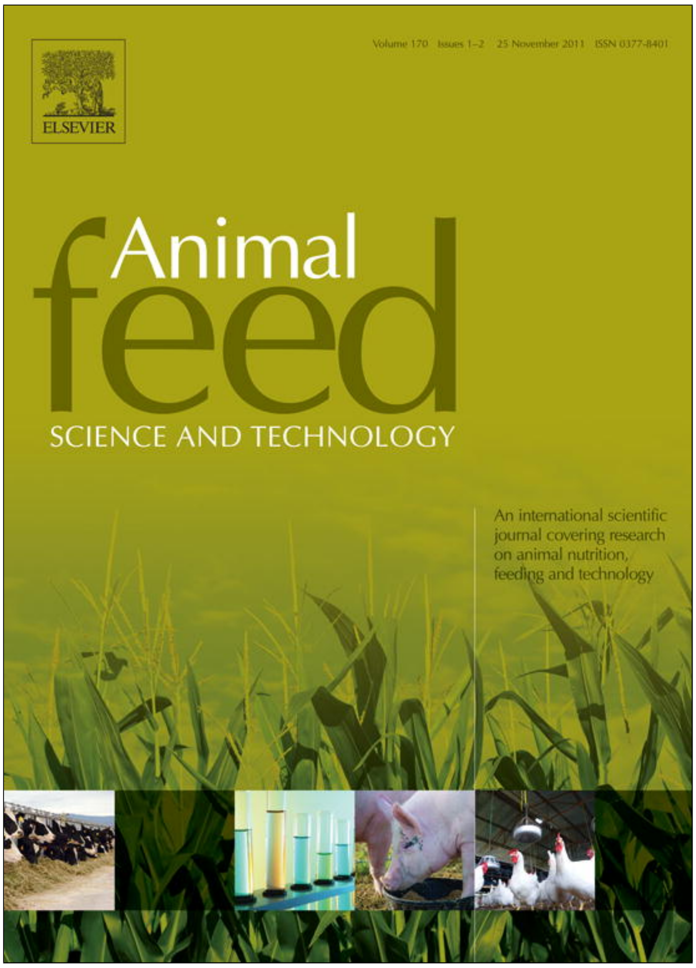
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Short communication

Effect of crude glycerol combined with solvent-extracted or expeller-pressed canola meal on growth performance and diet nutrient digestibility of weaned pigs

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ABSTRACT

Partially substituting soybean meal and wheat with canola co-products was evaluated using 240 weaned pigs [6.3 kg initial body weight (BW)]. Pigs were fed for 4 week pelleted diets containing 150 g/kg of solvent-extracted or expeller-pressed canola meal either with 0 or 50 g/kg crude glycerol or a soybean meal control diet to measure performance and diet nutrient digestibility. The wheat-based diets were formulated to contain 9.45 MJ/kg net energy (NE) and 1.13 g standardised ileal digestible (SID) lysine (Lys)/MJ NE. Glycerol increased ($P<0.05$) diet digestible energy content by 0.6 and 0.2 MJ/kg of dry matter for solvent-extracted and expeller-pressed canola meal diets, respectively. Canola co-product diets had a lower ($P<0.05$) nutrient digestibility than the control diet, while DE content did not differ. For days 0–28, BW gain and feed efficiency did not differ between the types of canola meal, the two levels of glycerol, and the canola co-product diets and control diet, although feed intake was 6% higher ($P<0.05$) for the control than canola co-product diets. In conclusion, 150 g/kg of solvent-extracted or expeller-pressed canola meal or with 50 g/kg glycerol can partially replace soybean meal and wheat in diets formulated to equal NE and SID amino acid content fed to weaned pigs without affecting growth performance.

1. Introduction

Feed is the highest variable cost of pork production. Feeding canola co-products such as solvent-extracted canola meal, expeller-pressed canola meal and crude glycerol may provide opportunities to reduce feed cost. Feeding expeller-pressed canola meal to weaned pigs has not been reported; however, grower–finisher pigs fed expeller-pressed canola meal maintained feed efficiency [(G:F); Seneviratne et al., 2010], but dietary inclusion of 150–225 g/kg reduced average daily feed intake (ADFI) and thereby average daily gain (ADG). Inclusion of solvent-extracted canola meal in swine diets has two limitations. First, solvent-extracted canola meal has been associated with reduced palatability and growth performance in weaned pigs (McIntosh et al., 1986). Second, the available energy content is low. Both palatability and energy value might be improved by the addition of crude glycerol (Groesbeck et al., 2008).

Feeding of crude glycerol as a partial replacement for cereal grain has been evaluated in swine (Kijora et al., 1995; Zijlstra et al., 2009). Glycerol is readily absorbed and converted to glucose via gluconeogenesis or oxidized for energy via glycolysis

Abbreviations: ADFI, average daily feed intake; ADG, average daily gain; BW, body weight; ATTD, apparent total tract digestibility; CP, crude protein; DE, digestible energy; DM, dry matter; G:F, feed efficiency (ADG/ADFI); Lys, lysine; NE, net energy; SID, standardised ileal digestible.

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and the citric acid cycle. Crude glycerol is a reasonable source of dietary energy providing 13.42 MJ/kg of ME for growing pigs (Lammers et al., 2007). Feeding of crude glycerol may increase energy digestibility (Zijlstra et al., 2009) and enhance feed intake (Groesbeck et al., 2008; Zijlstra et al., 2009). However, research that determines the effect of crude glycerol on growth performance of weaned pigs is limited. Furthermore, research combining crude glycerol with solvent-extracted or expeller-pressed canola meal to increase dietary energy for weaned pigs has not been published.

The hypothesis tested was that solvent-extracted or expeller-pressed canola meal could partly replace soybean meal and crude glycerol could partly replace wheat and canola oil in diets offered to weaned pigs formulated to equal net energy (NE) and standardised ileal digestible (SID) amino acid content without reducing growth performance. The objectives were to measure growth performance and apparent total tract digestibility (ATTD) of energy and crude protein (CP) in weaned pigs fed diets containing either 150 g/kg solvent-extracted or expeller-pressed canola meal with or without 50 g/kg crude glycerol or a soybean meal control diet.

2. Materials and methods

2.1. Experimental design and diets

The animal use and procedures were approved by the University of Alberta Animal Care and Use Committee for Livestock, and followed principles established by the Canadian Council on Animal Care (CCAC, 2009). The study was conducted at the Swine Research and Technology Centre at the University of Alberta (Edmonton, AB, Canada).

In total, 240 pigs (Duroc × Large White/Landrace F_1; Hypor, Regina, SK, Canada) were weaned at 20 ± 2 days of age. During 7 days prior to weaning, piglets were provided a commercial phase 1 (241 g/kg CP, 11.1 MJ/kg NE) diet as creep feed. Pigs were selected based on BW gain during the first 7 days post-weaning and BW on day 7 after weaning (6.3 ± 0.94 kg) at 27 days of age and were sorted within gender into heavy and light BW. One heavy and one light barrow and gilt were then randomly placed into one of 60 pens, for 4 pigs per pen. After weaning, pigs were fed sequentially the commercial phase 1 (0.3 kg/pig as feed budget for 2–3 days) and phase 2 (203 g/kg CP, 11.0 MJ/kg NE) diets (Unifeed, Edmonton, AB, Canada) for the remainder of 7 days. Housing was described previously (Avelar et al., 2010).

The study started 7 days after weaning as a randomized complete block design with 60 pens in three nursery rooms. Four diets containing 2 types of canola meal (150 g/kg solvent-extracted or expeller-pressed) and 2 levels of crude glycerol (0 or 50 g/kg) and a fifth soybean meal control diet (Table 1) were randomly assigned to pens of pigs, for a total of 12 observations per diet. Diets were formulated to provide 9.45 MJ/kg NE and 1.13 g SID Lys/MJ NE and other amino acids as an ideal ratio to Lys (NRC, 1998). Crude glycerol NE was assumed equal to wheat. Premixes were added to meet or exceed vitamins and mineral requirements (NRC, 1998). Acid-insoluble ash (Celite 281, World Minerals, Santa Barbara, CA, USA) was included as a digestibility marker. Diets were steam pelleted (70 hp; CPM, Crawfordsville, IN, USA). Expeller-pressed canola meal and crude glycerol that originated from canola oil were sourced from Associated Proteins (Ste. Agathe, MB, Canada) and Milligan Bio-Tech (Foam Lake, Saskatoon, SK, Canada), respectively, while solvent-extracted canola meal was of unknown origin. Pigs had free access to feed and water throughout the entire 28-day study.

Weekly, pigs, feed added and orts remaining were weighed. Changes in pen BW and feed disappearance were used to calculate ADG, ADFI and G:F (ADG/ADFI). Freshly-voided faeces were collected from 0800 to 1600 h by grab sampling on days 17 and 18 (equivalent to days 38 and 39 of age), pooled by pen, and frozen at −20 °C. Upon completion of the growth trial, faeces were thawed, homogenised, sub-sampled, and freeze-dried.

2.2. Chemical analyses

Diets, ingredients and lyophilised faeces were ground through a 1-mm screen in a centrifugal mill (Retch GmbH, Haan, Germany) and analysed for dry matter (DM), CP, ether extract, crude fibre and ash [Association of Official Analytical Chemists (AOAC, 2006)]. Diets and faeces were analysed for acid-insoluble ash and gross energy as described previously (Avelar et al., 2010). Canola meals and diets were analysed for crude fibre, ADF and NDF without amylase and expressed inclusive of residual ash (AOAC, 2006). Diets were analysed for amino acids (method 982.30E; AOAC, 2006) and available Lys (method 975.44; AOAC, 2006). Crude glycerol was analysed for Na, K and Cl (AOAC, 2006) and for methanol by gas chromatography (ECN, 2003). Total glucosinolates content was determined by gas chromatography (Daun and McGregor, 1981).

2.3. Statistical analysis

Growth and digestibility data were analysed using the MIXED procedure of SAS (2003), using pen as the experimental unit. The model included diet as fixed effect, block as random effect. The 4 canola co-product diets were compared as a 2×2 factorial arrangement and were together compared to the soybean meal control diet, using four pre-planned, orthogonal contrasts. Growth performance data were analysed as repeated measures and initial BW was included as covariate; effects for time and time × treatment interaction were not shown. Means for the interaction were separated using the PDIFF statement of SAS. To test the hypotheses, $P<0.05$ was considered significant.

Table 1
Ingredient composition of experimental diets.

Ingredient (g/kg diet)[a]	Soybean meal control	Canola meal			
		Solvent-extracted		Expeller-pressed	
		−Glycerol	+Glycerol	−Glycerol	+Glycerol
Wheat, ground	628.3	530.5	489.9	565.8	525.2
Soybean meal	150.0	75.0	75.0	75.0	75.0
Canola meal					
Solvent-extracted	–	150.0	150.0	–	–
Expeller-pressed[b]	–	–	–	150.0	150.0
Lactose	100.0	100.0	100.0	100.0	100.0
Crude glycerol[c]	–	–	50.0	–	50.0
Soy protein concentrate	25.0	25.0	25.0	25.0	25.0
Herring fish meal	25.0	25.0	25.0	25.0	25.0
Canola oil	20.0	45.0	35.0	10.0	–
Limestone	11.3	10.0	10.0	10.4	10.2
Mono/dical phosphate	11.0	10.5	10.8	10.0	10.5
Acid-insoluble ash[d]	8.0	8.0	8.0	8.0	8.0
Vitamin premix[e]	5.0	5.0	5.0	5.0	5.0
Mineral premix[f]	5.0	5.0	5.0	5.0	5.0
Salt	5.0	5.0	5.0	5.0	5.0
L-Lysine HCl	3.5	3.5	3.6	3.4	3.5
L-Threonine	1.6	1.4	1.5	1.4	1.5
DL-Methionine	0.9	0.6	0.7	0.6	0.7
Choline chloride (60 g/kg)	0.3	0.3	0.3	0.3	0.3
L-Tryptophan	0.1	0.2	0.2	0.1	0.1

[a] The crude protein content was 460 g/kg for soybean meal, 660 g/kg for soy protein concentrate (Soycomil, ADM, Decatur, IL, USA), and 700 g/kg for herring meal.
[b] Associated Proteins, Ste. Agathe, MB, Canada.
[c] Milligan Bio-Tech, Foam Lake, SK, Canada.
[d] Celite 281, World Minerals Inc. (Santa Barbara, CA, USA).
[e] Vitamin premix provided per kilogram of diet: 8250 IU of vitamin A, 825 IU of vitamin D_3, 40 IU of vitamin E, 35 mg of niacin, 15 mg of D-pantothenic acid, 5 mg of riboflavin, 4 mg of menadione, 2 mg of folic acid, 1 mg of thiamine, 0.2 mg of D-biotin and 0.025 mg of vitamin B_{12}.
[f] Mineral premix provided per kilogram of diet: 100 mg of Zn as $ZnSO_4$, 80 mg of Fe as $FeSO_4$, 50 mg of Cu as $CuSO_4$, 25 mg of Mn as $MnSO_4$, 0.5 mg of I as $Ca(IO_3)_2$ and 100 mg of Se as Na_2SeO_3.

Table 2
Analysed nutrient composition of canola co-products included in the experimental diets.

Nutrient (g/kg dry matter)	Canola meal		Crude glycerol
	Solvent-extracted	Expeller-pressed	
Moisture	121	48	152
Crude protein	437	404	9
Ether extract	24	102	496
Crude fibre	114	99	–
Crude ash[a]	80	73	108
Acid detergent fibre	206	167	–
Neutral detergent fibre	329	257	–
Total glucosinolates (μmol/g)	3.7	11.6	–
Methanol	N/A[b]	N/A	0.2

[a] Crude glycerol contained 0.2 g/kg Na, 33.6 g/kg K, and Cl was not detected.
[b] Not analysed.

3. Results

Solvent-extracted canola meal contained 32.7 g/kg more CP, 15.2 g/kg more crude fibre, 78.1 g/kg less ether extract, and 8.0 μmol/g less glucosinolates than expeller-pressed canola meal (Table 2). The CP and amino acid content was similar among canola meal diets, while the control diet required less CP and total Lys to meet amino acid requirements (Table 3).

Canola meal type and glycerol inclusion interacted for energy and CP digestibility and DE content (Table 4). Glycerol inclusion reduced ($P<0.05$) CP digestibility by 4% for the expeller-pressed canola meal diet, and increased ($P<0.05$) energy digestibility by 1% for solvent-extracted canola meal. Glycerol increased DE content by 0.6 and 0.2 MJ/kg of DM for solvent-extracted and expeller-pressed canola meal diets, respectively. Digestibility of CP and energy of the control diet was 4% higher ($P<0.05$) than that of the 4 canola co-product diets. The DE content of the control diet did not differ from that of the canola co-product diets.

Table 3
Analysed nutrient content of experimental diets.

Nutrient (g/kg dry matter)	Soybean meal control	Canola meal			
		Solvent-extracted		Expeller-pressed	
		−Glycerol	+Glycerol	−Glycerol	+Glycerol
Moisture	105	112	103	100	103
Gross energy (MJ/kg)	18.2	19.0	19.5	18.5	18.8
Crude protein	219	223	220	230	227
Ether extract	38	65	81	43	56
Crude fibre	23	37	35	33	34
Crude ash	66	67	68	65	69
Acid detergent fibre	40	64	62	62	61
Neutral detergent fibre	145	205	223	250	180
Indispensable amino acid					
Arginine	12.6	13.1	13.0	12.8	13.3
Histidine	5.0	5.4	5.3	5.3	5.5
Isoleucine	8.6	8.9	8.5	8.9	9.1
Leucine	15.1	15.9	15.6	15.4	16.1
Lysine	13.2	14.2	14.2	13.4	14.1
Methionine	3.1	3.7	3.7	3.6	3.8
Phenylalanine	9.7	9.8	9.6	9.7	9.9
Threonine	8.3	9.0	9.5	8.7	9.3
Tryptophan	3.1	2.9	2.9	3.1	3.0
Valine	9.8	10.7	10.4	10.5	10.9
Total amino acid	199.8	210.1	207.2	206.0	211.9
Available lysine	12.6	13.3	13.4	12.8	13.4

For days 0–28, pigs fed canola co-product diets had a 6% lower ($P<0.05$) ADFI than pigs fed the control diet (Table 5). Canola meal type and dietary glycerol inclusion did not affect ADFI, ADG or G:F for the entire trial. For days 0–7, ADFI was 10% higher ($P<0.05$) for pig fed solvent-extracted than expeller-pressed canola meal diets. For days 8–14, glycerol reduced ($P<0.05$) ADFI by 12% and increased G:F by 21% in pigs fed the solvent-extracted canola meal diet, but did not affect ADFI or G:F in pigs fed the expeller-pressed canola meal diet.

4. Discussion

Following extraction of canola oil from canola seed using expeller-pressing or solvent extraction, canola meal is produced. Converting canola oil into biodiesel produces crude glycerol from esterification as another canola co-product (Thompson and He, 2006). Growth studies with weaned pigs fed diets containing these canola co-products have rarely been conducted.

In the present study, ADG and G:F of weaned pigs fed combinations of these canola co-products did not differ from pigs fed the soybean meal control diet, indicating that feeding of canola co-products is a worthwhile pursuit. We used 12 observations per diet so that the chance of a type II error, *i.e.*, failing to reject the null hypothesis, was reduced; however, with further replicates reduced ADG might have been shown for pigs fed diets containing canola-co-products. Regardless, these results contradict earlier research indicating that dietary inclusion of more than 90 g/kg solvent-extracted canola meal drastically reduced ADG in young pigs (*e.g.*, McIntosh et al. (1986) as summarized by Thacker (1990)), in part by reducing ADFI. The reduced ADG in previous research might be partly due to feeding diets formulated to equal DE and CP content instead of equal NE and SID amino acid content so that canola meal was not properly ranked against other feedstuffs. In the present study, pigs fed canola co-products diets ate 6% less than pigs fed the soybean meal control diet with several possible explanations. First, due to the higher than anticipated ether extract content of crude glycerol, the NE content of two of four diets containing canola co-products was likely higher than anticipated, which may reduce ADFI because pigs adjust feed intake to meet energy needs (Azain, 2001). Second, dietary glucosinolates may reduce feed intake due to bitter taste. Both canola meals contained more glucosinolates than the tolerance level of 2.5 μmol/g (Schöne et al., 1997).

For the entire trial, growth performance did not differ between the two types of canola meal. However, ADFI was 9% higher for pigs fed solvent-extracted canola meal than pigs fed expeller-pressed canola meal diets for days 0–7 that may reflect the lower glucosinolate content in solvent-extracted than expeller-pressed canola meal diets (0.5 μmol/g vs. 1.7 μmol/g; calculated from feedstuff values). In the present study, expeller-pressed canola meal diets contained less ether extract overall and less free canola oil as a specific feedstuff than the solvent-extracted canola meal diet, indicating that relatively more residual canola oil was bound inside the feedstuff expeller-pressed canola meal than solvent-extracted canola meal. Pigs may eat initially more of free canola oil than oil bound to meal, because bound oil is not used as effectively as free canola oil (Thacker, 1998).

In the present study, adding 50 g/kg glycerol by replacing wheat and canola oil as energy sources did not affect growth performance. Crude glycerol in swine diets did not or marginally affected growth performance in a range of swine studies (Kijora et al., 1995; Groesbeck et al., 2008; Zijlstra et al., 2009) indicating that crude glycerol can serve as energy source for pigs within existing logistical and feed processing constraints.

Table 4
Apparent total tract digestibility (ATTD) coefficients of crude protein and energy and digestible energy (DE) content of diets.[a]

Variable	Soybean meal control	Canola meal				SEM	P-value			
		Solvent-extracted		Expeller-pressed			Control vs. Rest	Canola meal	Glycerol	Canola meal × Glycerol
		−Glycerol	+Glycerol	−Glycerol	+Glycerol					
ATTD										
Crude protein[b]	0.779	0.739^{y}	$0.762^{z,y}$	0.768^{z}	0.737^{y}	0.009	0.007	0.818	0.662	0.009
Energy[b]	0.841	0.810^{y}	0.819^{z}	0.810^{y}	0.805^{y}	0.003	<0.001	0.019	0.339	0.020
DE content (MJ/kg DM)[b]	15.3	15.4^{y}	16.0^{z}	15.0^{w}	15.2^{x}	0.02	0.523	<0.001	<0.001	0.002

[a] Least-squares means based on 12 pen observations of 4 pigs each per diet.
[b] Within a row, means without a common superscript differ (P<0.05). DM, dry matter.

Adding crude glycerol by replacing wheat enhanced energy digestibility and the DE content of the solvent-extracted canola meal diet, with a smaller effect for the expeller-pressed canola meal diet. Solvent-extraction of canola oil is practiced using hexane to maximize oil recovery from the seed (Leming and Lember, 2005), resulting in a very low residual oil and low energy content in solvent-extracted canola meal. Adding crude glycerol to solvent-extracted canola meal creates a complementary feedstuff, because crude glycerol contains more energy than canola meal that may assist in meeting swine energy needs (Lammers et al., 2007). Combining crude glycerol and expeller-pressed canola meal might be feasible in co-located oil extraction and biodiesel plants. Mixing of crude glycerol into canola meal might thus create new alternative feedstuffs for swine and address the poor handling characteristics of a gel such as crude glycerol.

A concern with crude glycerol is variable composition due to esterification and purification. Our crude glycerol contained 12.4 g/kg less Na and 33.5 g/kg more K than previous research (Lammers et al., 2007), indicating that salts used during biodiesel production differ. Moreover, our crude glycerol contained 496 g/kg ether extract. Previously, crude glycerol ranged in ether extract content from 2 to 492 g/kg (Kijora and Kupsch, 1996), 0.l to 348 g/kg (calculated from % fatty acids; Kerr et al., 2009), 131 g/kg (Thompson and He, 2006) and purified glycerol contained 1.2 g/kg (Lammers et al., 2007), emphasizing that composition of glycerol studied in swine research varies widely. Indeed, ether extract in crude glycerol may be a major factor determining its dietary energy value.

In summary, canola co-product diets resulted in ADG and G:F similar to the soybean meal control diet, even though ADFI was lower for pigs fed canola co-products diets. For the solvent-extracted canola meal diet, adding 50 g/kg glycerol provided extra DE, indicating that crude glycerol can be added to solvent-extracted canola meal to enhance its energy content. In conclusion, 150 g/kg of either solvent-extracted or expeller-pressed canola meal or combined with 50 g/kg glycerol can

Table 5
Effect of solvent-extracted or expeller-pressed canola meal and crude glycerol on growth performance of weaned pigs starting 1 week after weaning.[a]

Variable	Soybean meal control	Canola meal				SEM	P-value			
		Solvent-extracted		Expeller-pressed			Control vs. Rest	Canola meal	Glycerol	Canola meal × Glycerol
		−Glycerol	+Glycerol	−Glycerol	+Glycerol					
ADFI[b] (g/day)										
Day 0–7	286	303	295	285	257	11	0.896	0.016	0.108	0.394
Day 8– 14[c]	555	535^{z}	470^{y}	$510^{z,y}$	540^{z}	21	0.056	0.267	0.371	0.035
Day 15– 21	757	743	741	710	699	32	0.292	0.209	0.829	0.887
Day 22–28	1022	931	961	950	986	26	0.017	0.450	0.251	0.930
Day 0–28	655	624	606	616	619	17	0.037	0.909	0.642	0.573
ADG (g/day)										
Day 0–7	270	272	252	268	256	25	0.759	0.999	0.494	0.866
Day 8–14	419	400	427	391	380	23	0.453	0.236	0.751	0.455
Day 15–21	528	512	475	471	503	26	0.174	0.800	0.940	0.228
Day 22–28	650	595	638	651	635	21	0.361	0.227	0.540	0.205
Day 0–28	469	445	448	445	443	13	0.156	0.870	0.956	0.860
Feed efficiency										
Day 0–7	0.94	0.91	0.88	0.94	1.01	0.09	0.912	0.315	0.868	0.579
Day 8–14[c]	0.76	0.75^{y}	0.91^{z}	0.76^{y}	0.71^{y}	0.04	0.598	0.027	0.233	0.018
Day 15–21	0.70	0.70	0.65	0.66	0.73	0.03	0.502	0.466	0.654	0.074
Day 22–28	0.64	0.64	0.66	0.69	0.64	0.02	0.215	0.543	0.583	0.134
Day 0–28	0.71	0.71	0.74	0.72	0.72	0.01	0.182	0.323	0.115	0.094

[a] Least-squares means based on 12 pen observations of 4 pigs each per diet.
[b] ADFI, average daily feed intake; ADG, average daily gain.
[c] Within a row, means without a common superscript differ (P<0.05).

partially replace soybean meal and wheat in diets formulated to an equal NE and SID amino acid content fed to weaned pigs starting 1 week after weaning without affecting growth performance.

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