SHORT COMMUNICATION

The effect of feeding crude glycerol on growth performance and nutrient digestibility in weaned pigs

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[1]Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, Alberta, Canada T6G 2P5 (e-mail: ruurd.zijlstra@ualberta.ca); [2]Alberta Agriculture and Rural Development, Edmonton, Alberta, Canada T6H 5T6. Received 26 June 2008, accepted 17 October 2008.

Zijlstra, R. T., Menjivar, K., Lawrence, E. and Beltranena, E. 2009. **The effect of feeding crude glycerol on growth performance and nutrient digestibility in weaned pigs.** Can. J. Anim. Sci. **89**: 85–89. The effects of substituting wheat with crude glycerol as a dietary energy source were evaluated. Seventy-two weaned pigs were fed for 4 wk one of three pelleted wheat-based diets containing 0, 4, or 8% glycerol and formulated to 2.28 Mcal kg^{-1} net energy (NE) and 5.02 g standardized ileal digestible lysine Mcal^{-1} NE. For day 0 to 28, body weight increased linearly ($P = 0.04$); pigs fed 8% glycerol were 1.11 kg heavier than pigs fed 0% glycerol. Glycerol inclusion tended to increase average daily gain linearly ($P = 0.066$) and increased average daily feed intake quadratically ($P = 0.037$) without affecting feed efficiency ($P > 0.10$). Feeding up to 8% dietary crude glycerol by substituting wheat can enhance the growth performance of weaned pigs.

Key words: Co-product, digestibility, glycerol, weaned pig

Zijlstra, R. T., Menjivar, K., Lawrence, E. et Beltranena, E. 2009. **Incidence de l'administration de glycérol brut sur la croissance et la digestibilité des aliments chez les porcelets sevrés**. Can. J. Anim. Sci. **89**: 85–89. L'étude devait établir si on peut remplacer le blé par du glycérol brut comme source d'aliment. À cette fin, 72 porcelets sevrés ont reçu pendant quatre semaines une de trois rations à base d'agglomérés de blé renfermant 0, 4 ou 8% de glycérol et formulées pour fournir 2,28 Mcal d'énergie nette par kg et 5,02 g de lysine normalisée digestible dans l'iléon par Mcal d'énergie nette. Le poids corporel des animaux s'est accru linéairement ($P = 0{,}04$) jusqu'au 28^{e} jour; les sujets recevant 8 % de glycérol pesaient 1,11 kg de plus que ceux n'en recevant pas. Le glycérol a tendance à augmenter le gain quotidien moyen linéairement ($P = 0{,}066$) et la prise alimentaire quotidienne moyenne de façon quadratique ($P = 0{,}037$), sans modifier l'indice de consommation ($P > 0{,}10$). Remplacer jusqu'à 8 % du blé par du glycérol brut permettrait de rehausser la croissance des porcelets sevrés.

Mots clés: Coproduit, digestibilité, glycérol, porcelet sevré

Fossil fuels are a main source of energy for anthropogenic activity. Considerable demand thus exists to replace fossil fuels with renewable fuel sources such as biodiesel and ethanol. To produce biodiesel, oil extracted from oilseeds is hydrolyzed using an alcohol and catalyst, thereby producing methyl esters (biodiesel) and crude glycerol (Kerr et al. 2007). Production of 1 L of biodiesel may yield 79 g of crude glycerol. The biofuel industry competes for grains and oilseeds with the livestock industry; hence, prices for grain and vegetable oil have increased, forcing the livestock industry to look for alternative feedstuffs. Glycerol is a sugar alcohol and should be easy to digest by pigs with a maturing digestive tract. The energy values of corn, wheat, and glycerol are similar; thus, glycerol might be an attractive feedstuff to replace corn or wheat and enhance physical properties of pelleted diets for weaned pigs (Groesbeck et al. 2008).

The feed value of crude glycerol resulting from canola seed processing for biodiesel in Canada is relatively unknown. In Germany, the average daily gain (ADG) of grower pigs was increased 8% by replacing 10% dietary barley with crude glycerol originating from rapeseed oil (Kijora and Kupsch 1996). In the United States of America, replacing up to 6% of dietary corn with crude glycerol originating from soybean oil increased ADG of nursery pigs (Groesbeck et al. 2008). Apparent total tract energy digestibility of diets containing 0 to 20% crude glycerol originating from soybean oil ranged from 89 to 92%, indicating that crude glycerol is digested well by grower pigs (Lammers et al. 2008). For crude glycerol, gross energy was 3.63 Mcal kg^{-1}, digestible energy (DE) was 3.34 Mcal kg^{-1}, and metabolizable energy was 3.21 Mcal kg^{-1} for starter and grower pigs (Lammers et al. 2008). The metabolizable energy content was lower for

Abbreviations: **ADG**, average daily gain; **ADFI**, average daily feed intake; **BW**, body weight; **DE**, digestible energy; **NE**, net energy starter pigs fed more than 10% crude glycerol, likely due to reduced metabolizability (Lammers et al. 2008).

The hypotheses tested in the present study were that (1) weaned pigs fed diets containing 4 or 8% crude glycerol had a similar growth performance and nutrient digestibility to pigs fed a diet without glycerol, and (2) weaned pigs would improve their capacity to digest the diets within the timeframe of the study similarly among diets. The objectives were to determine growth performance and apparent total tract digestibility of energy of weaned pigs fed diets with 0, 4, or 8% glycerol formulated to an equal energy and amino acid content.

The animal protocol for the study was approved by the University of Alberta Faculty Animal Policy and Welfare Committee and followed principles established by the Canadian Council on Animal Care (1993). The experiment was conducted at the Swine Research and Technology Centre at the University of Alberta (Edmonton, AB). Seventy-two pigs (Duroc × Large White/Landrace F_1; Genex Hybrid; Hypor, Regina, SK) weaned at 20 d of age, were selected at 27 to 30 d of age based on similar weaning weight (7.39 ± 0.13 kg), and divided within gender into heavy and light based on body weight (BW). One heavy and one light barrow and one heavy and one light gilt were placed randomly into one of 18 pens, for four pigs per pen.

A wheat-based control diet and two diets containing either 4 or 8% glycerol were formulated by replacing wheat with crude glycerol (Milligan Bio-Tech, Foam Lake, SK). The main dietary ingredients were wheat, soybean meal, lactose, and fish meal (Table 1). Diets were formulated to provide 2.28 Mcal kg^{-1} net energy (NE) and 5.02 g $Mcal^{-1}$ NE standardized ileal digestible lysine, with other amino acids formulated as a ratio to lysine [National Research Council (NRC) 1998]. For feed formulation, the NE values of Sauvant et al. (2004) and averaged amino acid values of NRC (1998) and Sauvant et al. (2004) were used; glycerol NE was assumed equal to wheat (2.45 Mcal kg^{-1}). Premixes were added to meet or exceed mineral and vitamin requirements (NRC 1998). Acid-insoluble ash (Celite 281, World Minerals, Santa Barbara, CA) was included as an indigestible marker. Diets were mixed and steam pelleted (70 hp; CPM, Crawfordsville, IN).

The study was a completely randomized design with 18 pens in one nursery room. Each pen was fed one of three diets during the 4-wk study starting 7 to 10 d post-weaning for six observations per diet. Pens (1.1 × 1.5 m) were equipped with a multiple-space self-feeder, nipple drinker, and plastic slatted flooring. During the first 7 to 10 d after weaning, pigs were fed a commercial starter diet (Unifeed, Edmonton, AB). Pigs had free access to feed and water during the entire 4-wk study.

Individual pigs were weighed weekly to monitor BW gain. The amount of feed consumed was determined on a weekly basis. The measured BW changes and feed disappearance were used to determine ADG, average daily feed intake (ADFI), and feed efficiency (ADG/ADFI) for the pen. Freshly voided faeces were collected from 0800 to 1500 by grab sampling from pen floors on days 9 and 10 and on days 23 and 24; specimens were pooled by pen and week. Following collections, faeces were thawed, homogenized, sub-sampled, and freeze-dried.

Table 1. Ingredient composition of experimental diets

	Crude glycerol		
Item	0%	4%	8%
Ingredient (%)			
Wheat	70.80	66.77	62.72
Common ingredients[z,y,x]	27.85	27.85	27.85
Crude glycerol[w]	–	4.00	8.00
Limestone	0.80	0.79	0.79
L-Lysine HCl	0.36	0.37	0.38
L-Threonine	0.10	0.11	0.12
DL-Methionine	0.06	0.08	0.10
L-Tryptophan	0.03	0.03	0.04
Analyzed nutrient content (% of DM)			
Starch	45.1	43.8	40.2
Crude protein	24.5	23.7	24.2
Ether extract	1.8	2.1	3.7
Crude fibre	2.1	2.1	2.3
Acid detergent fibre	4.0	4.0	4.2
Neutral detergent fibre	13.5	13.6	12.6

[z]Ingredients included at an identical rate among the three diets (%): soybean meal, 15.00; lactose, 5.00; fish meal, 5.00; acid-insoluble ash, 0.80; mono/dicalcium phosphate, 0.50; vitamin premix, 0.50, mineral premix, 0.50; salt, 0.50, choline chloride 60%, 0.05.
[y]Vitamin premix provided per kg of diet: vitamin A, 8250 IU; vitamin D_3, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantothenic acid, 15 mg; riboflavin, 5 mg; menadione, 4 mg; folic acid, 2 mg; thiamine, 1 mg; D-biotin, 200 µg; vitamin B_{12}, 25 µg.
[x]Mineral premix provided per kg of diet: Zn, 100 mg as zinc sulphate; Fe, 80 mg as ferrous sulphate; Cu, 50 mg as copper sulphate; Mn, 25 mg as manganous sulphate; I, 0.5 mg as calcium iodate; Se, 100 µg as sodium selenite.
[w]Milligan Bio-Tech (Foam Lake, SK); contained 15.6% ether extract and 6.8% ash (as fed).

Freeze-dried faeces and diets were ground through a 1-mm screen in a mill (Retsch GmbH, Haan, Germany). Faeces and diet were analysed for moisture by drying at 135°C for 2 h [method 930.15; Association of Official Analytical Chemists (AOAC) 2006], acid-insoluble ash, and gross energy using an adiabatic bomb calorimeter (model 5003; Ika-Werke GMBH & Co. KG, Staufen, Germany). Diets were analyzed for starch, crude protein, ether extract, crude fibre, and acid and neutral detergent fibre, and crude glycerol for ether extract and ash (AOAC 2006). Based on the results of chemical analyses, apparent digestibility of energy was calculated using the acid-insoluble ash concentration in diet and faeces using the indicator method.

Pen was considered the experimental unit. Growth performance and digestibility values were analyzed as repeated measures for time using the MIXED procedure of SAS (SAS Institute, Inc. 1996). Diet was the main factor in the statistical model. For growth performance, initial BW was added to the model as a covariate. Two orthogonal contrasts tested if linear or quadratic effects of glycerol inclusion to the control diet existed. For energy digestibility, a collection period effect and a period × diet interaction were also tested. Probability levels of $P < 0.05$ and $0.05 < P < 0.10$ were defined as significant differences and trends, respectively. Data are reported as least-square means.

Overall, glycerol increased growth performance of weaned pigs ($P < 0.05$; Table 2). Glycerol inclusion did not affect BW at day 7 ($P > 0.10$), but linearly increased ($P < 0.05$) BW at day 14, day 21, and day 28. Specifically, pigs fed 8%-glycerol diet were 0.52, 0.90, and 1.11 kg heavier ($P < 0.05$) at days 14, 21, and 28, respectively, than pigs fed the 0% glycerol diet. Glycerol inclusion did not affect ADG from days 0 to 7 or 15 to 28 ($P > 0.10$), but linearly increased ADG from days 8 to 14 ($P = 0.042$). From days 0 to 28, glycerol inclusion tended to linearly increase ($P = 0.066$) ADG; ADG of pigs fed the 8%-glycerol diet was 0.040 kg d^{-1} higher than pigs fed the 0%-glycerol diet.

Overall, glycerol inclusion increased ADFI quadratically ($P = 0.037$; Table 2). The ADFI of pigs fed the 4%-glycerol diet was 0.065 and 0.030 kg d^{-1} higher than pigs fed the 0% or 8% glycerol diets, respectively. Overall, feed efficiency did not differ among diets ($P > 0.10$). However, glycerol inclusion tended to increase feed efficiency linearly ($P = 0.080$) from day 0 to 7 and quadratically ($P = 0.056$) from days 22 to 28.

Glycerol inclusion linearly increased ($P < 0.01$; Table 3) the apparent total tract digestibility of energy and DE content for d 9 and 10; energy digestibility was 1.62%-unit and DE content was 0.24 Mcal kg^{-1} higher for pigs fed the 8%-glycerol diet than pigs fed the 0%-glycerol diet. Glycerol inclusion quadratically increased ($P = 0.026$) the apparent total tract digestibility of energy and linearly increased ($P = 0.001$) DE content for d 23 and 24; energy digestibility was 2.77%-unit and DE content was 0.29 Mcal kg^{-1} higher for pigs fed the 8%-glycerol diet than pigs fed the 0%-glycerol diet. Energy digestibility was 1.73% and DE content was 0.070 Mcal kg^{-1} higher on d 23 and 24 than d 9 and 10 ($P = 0.001$) and glycerol content of the diet did not interact with collection period ($P > 0.10$).

Glycerol forms the backbone of triglycerides and is involved in phospholipid synthesis in hepatic and adipose tissue (Mourot et al. 1994). In the small intestine, ingested fats are broken down into three compounds: two free fatty acids and a monoglyceride, followed by absorption. In the liver, the monoglyceride is broken down into glycerol and a third free fatty acid. Glycerol can be converted to glucose via gluconeogenesis or oxidized for energy via glycolysis and the citric acid cycle. Thus, dietary glycerol provides energy (Mourot et al. 1994), which might benefit weaned pigs that are commonly in a state of energy deficiency due to limited appetite.

Few studies have characterized the effects of dietary inclusion of crude glycerol on growth performance and

Table 2. Growth performance of weaned pigs fed diets containing 0, 4, or 8% crude glycerol

	Crude glycerol (%)			Pooled	*P* value for crude glycerol	
Variable[z]	0	4	8	SEM	Linear	Quadratic
Body weight (kg)						
Day 7	9.37	9.33	9.48	0.10	0.448	0.460
Day 14	12.71	12.82	13.23	0.16	0.038	0.479
Day 21	16.02	16.68	16.92	0.25	0.023	0.512
Day 28	21.85	22.55	22.96	0.36	0.044	0.754
ADG (kg d^{-1})						
Day 0 to 7	0.283	0.277	0.299	0.01	0.445	0.470
Day 8 to 14	0.476	0.499	0.536	0.02	0.042	0.751
Day 15 to 21	0.473	0.552	0.527	0.03	0.228	0.199
Day 22 to 28	0.832	0.838	0.863	0.04	0.613	0.861
Day 0 to 28	0.516	0.541	0.556	0.01	0.066	0.772
ADFI (kg d^{-1})						
Day 0 to 7	0.360	0.351	0.351	0.01	0.574	0.748
Day 8 to 14	0.611	0.635	0.669	0.02	0.065	0.874
Day 15 to 21	0.801	0.886	0.852	0.03	0.285	0.161
Day 22 to 28	1.105	1.264	1.143	0.05	0.620	0.055
Day 0 to 28	0.719	0.784	0.754	0.02	0.162	0.037
Feed efficiency						
Day 0 to 7	0.786	0.787	0.854	0.03	0.080	0.320
Day 8 to 14	0.781	0.784	0.804	0.02	0.513	0.788
Day 15 to 21	0.591	0.627	0.623	0.04	0.589	0.706
Day 22 to 28	0.758	0.664	0.759	0.04	0.995	0.056
Day 0 to 28	0.729	0.715	0.760	0.02	0.193	0.166

[z]Least-squares means based on 6 observations per diet.

Table 3. Apparent total tract energy digestibility and DE content of diets containing 0, 4, or 8% crude glycerol fed to weaned pigs measured in two collection periods

	Crude glycerol (%)			Pooled	*P* value for crude glycerol	
Variable[z]	0	4	8	SEM	Linear	Quadratic
Energy digestibility (%)[y]						
Day 9 and 10	83.65	84.78	85.27	0.35	0.005	0.469
Day 23 and 24	84.61	86.91	87.38	0.30	0.001	0.026
DE content (Mcal kg^{-1})[y]						
Day 9 and 10	3.24	3.36	3.48	0.01	0.001	0.898
Day 23 and 24	3.28	3.45	3.57	0.01	0.001	0.108

[z]Least-squares means based on 6 observations per diet.
[y]Collection period day 9 and 10 differed from day 23 and 24 ($P < 0.001$). A glycerol × collection period interaction did not occur ($P > 0.10$).

nutrient digestibility of weaned pigs. In the present study, BW of weaned pigs increased with increased glycerol inclusion, in contrast to the hypothesis that glycerol would not alter growth. The increase in BW or ADG due to glycerol inclusion in diets formulated to equal energy content is similar to previous work (Groesbeck et al. 2008) and contrasts the lack of a growth response in other studies (Lammers et al. 2007). The energy value of crude glycerol in the present study and Groesbeck et al. (2008) was likely underestimated; crude glycerol provided more energy than expected. A higher energy intake was achieved and pigs fed diets containing glycerol achieved a higher BW indicating that the growth response might not be due to crude glycerol per se. Crude glycerol may differ largely in quality among samples; crude glycerol may range in purity from 50 to 90%, and may contain residual fat, as reflected by the content of ether extract in the crude glycerol and increased content of ether extract in glycerol diets in the present study. Knowledge of the energy content of the specific batch of crude glycerol used prior to feed formulation may ensure a more predictable growth performance.

The inclusion of crude glycerol to a wheat-based diet increased ADFI quadratically in the present study. In contrast, inclusion of glycerol to a corn-based diet did not affect ADFI of nursery pigs (Lammers et al. 2007; Groesbeck et al. 2008). In the present study, glycerol inclusion may have improved palatability of the diet. The control diet did not contain added fat, and the resulting fat content was thus low (1.8% ether extract), whereas glycerol diets contained 2.1 and 3.7% ether extract. At 8% inclusion of crude glycerol, ADFI may have decreased relative to 4% due to increased energy supply. Likewise, 8% glycerol may have increased pellet durability (Groesbeck et al. 2008), causing less fines or wastage of the diets containing glycerol.

Glycerol inclusion did not affect feed efficiency in the present study, even though glycerol inclusion increased energy digestibility. The discrepancy might be due to a higher variability in feed efficiency than energy digestibility. In previous studies with nursery pigs, including up to 10% glycerol did not affect feed efficiency (Lammers et al. 2007; Groesbeck et al. 2008). The increased content of highly digestible fat in the glycerol diets may explain their increased energy digestibility. Energy digestibility and thus DE content increased during the time frame in the present study without interacting with diet indicating that older pigs were able to better digest all three diets, likely due to an increased digestive and absorptive capacity.

In the present study, feeding of crude glycerol to weaned pigs did not cause adverse effects; however, glycerol may present practical problems beyond an error in estimated energy content. For example, crude glycerol may contain impurities such as methanol and NaCl that remain as a residue after processing. Methanol content should not exceed 150 ppm in glycerol used as a feedstuff, because higher levels may cause metabolic acidosis, vomiting, blindness, or gastrointestinal problems (Kerr et al. 2007). Increased NaCl may limit dietary inclusion of glycerol to avoid dietary Na and Cl levels exceeding recommendations. Finally, glycerol is a viscous gel that may present problems for feed mixing and flow (Kerr et al. 2007). In the present study, glycerol inclusion was limited to 8% to prevent problems of feed flow prior to pelleting.

In the present study, glycerol inclusion up to 8% in late nursery diets was not detrimental to growth performance. However, gaps in knowledge remain. For instance, the impact of glycerol inclusion on the digestibility of energy and amino acids, carcass characteristics, and pork quality is not clear. Furthermore, the variation in glycerol quality has not been characterized. Still, using crude glycerol may provide cost benefits to producers and enhance the physical characteristics of nursery diets by reducing fines and improving pellet quality. Inclusion of 4% glycerol may save $10.50/tonne of feed (Kerr et al. 2007). These savings provide an opportunity for producers and create new market opportunities for co-products from the biofuel industry.

In conclusion, increased utilization of biofuel co-products, such as crude glycerol, will allow livestock producers to source alternative feedstuffs and mitigate high grain prices. Crude glycerol may play an important role in meeting the dietary energy needs of pigs as biodiesel production expands. The present study indicates that crude glycerol can be included up to 8% in replacement for wheat in diets for weaned pigs, without reducing growth and feed efficiency.

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