Evaluation of the Nutritional Value of Glycerol, a Byproduct of Biodiesel Production, for Swine

Final Report

N O R T H   C A R O L I N A   P O R K   C O U N C I L

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Introduction

The production of biodiesel involves the separation of glycerol from fat or oil, a process called transesterification. The end products of this process are methyl esters, or biodiesel, and glycerol. Typically, oils or fats are reacted with alcohols (usually methanol) in the presence of a catalyst (sodium or potassium hydroxide) and converted to ethyl esters and glycerin. The yield of this process is approximately 86% biodiesel, 9% glycerin, and 4% alcohol.

The co-product glycerin can be used in the manufacturing of soaps and other products. However, it also has potential value for the use in swine diets. Crude glycerol from biodiesel production contains approximately 85% glycerol, 10% water, and 3 to 7% salt. The gross energy value ranges from 3600 to 3750 depending on its purity (pure glycerol contains 4305 kcal/kg gross energy).

Studies in finisher pigs have shown that glycerol is highly palatable and improved feed intake was observed with 10% supplemental glycerol without effects on daily gain (Kijora, 1996; Kijora et al., 1995, 1997; Mourot et al., 1994). Kuhn (1996) reported that 10% technical rapeseed glycerol could be fed to finishing pigs without affecting growth performance. However, an increased proportion of saturated fatty acids in the body fat was observed in pigs fed glycerol. Kerr et al. (2007) reported an apparent digestible energy value (DE) of crude glycerol of 3772 kcal/kg in finishing pigs and 3386 kcal/kg in nursery pigs. These values were not different from the GE of the crude glycerol examined (3625 kcal/kg for the product they used).

Most studies have focused on the application of glycerol in diets for finishing pigs, but studies in weanling pigs are very limited. Considering the excellent palatability (sweetness) of glycerol and the relatively high digestibility, inclusion of glycerol in diets for weanling pigs has great potential value. Particularly with soaring costs of lactose, the potential value of glycerol as a replacement for lactose needs to be evaluated.

The objectives of this study were to:

1) Determine the value of glycerol in diets for newly weaned pigs relative to lactose.
2) Determine the value of glycerol in diets for nursery pigs when replacing lactose and corn.
3) Evaluate diet manufacturing characteristics and feed mill processing data when using glycerol.

We hypothesize that glycerol can successfully replace lactose in phase 1 diets for weaned pigs and that the maximum inclusion of glycerol will be less than 10%. We further hypothesize that glycerol can be included at least at 10% in diets for nursery pigs fed phase 2 diets.

Materials and Methods

Preliminary Experiments

We first conducted two preliminary trials to determine the possible inclusion level of glycerol when sprayed onto corn (preliminary experiment 1) or a complete prestarter diet containing plasma protein, fish meal, and whey (preliminary experiment 2). In the first experiment, spraying glycerol onto corn up to 10%, which was the highest level tested, did not appear to cause problems in terms of flowability of the end product. In experiment 2, spraying glycerol onto complete prestarter feeds (pelleted) appeared to make the pellets stickier, and a level of 6 to 8% seemed to result in a product that had good flow characteristics. In this experiment, we included 20% glycerol, which caused pellets to congeal and form a solid mass.

Based on these preliminary studies, we limited the inclusion of glycerol in subsequent studies to a maximum of 10%.

Experiment 1

A total of 126 pigs (body weight was 6.91 ± 0.18 kg) were weaned at approximately 21 days of age at the Swine Educational Unit, Raleigh, NC. Pigs were weighed and assigned within sex and weight block to one of 6 dietary treatments. Pigs were housed 3 pigs per pen using 42 pens and there were 7 replicates per treatment. Dietary treatments (Tables 1 and 2) were arranged in a 2 x 3 factorial randomized complete block design. Factors consisted of: 1) glycerol inclusion in phase 1 diets (0 or 5%), and 2) glycerol inclusion level in phase 2 diets (0, 5, or 10%). Glycerol supplementation in Phase 1 diets replaced lactose on a weight for weigh basis. Glycerol inclusion in phase 2 diets was made in replacement of corn and this replacement was made on a nutrient basis (thus accounting for the nutrient composition of corn).

Glycerol content of the crude glycerol product was determined prior to initiation of this experiment and diets were formulated based on analyzed glycerol content. In addition, Na and Cl can occur at high levels in crude glycerol products and was analyzed and accounted for in diet formulation. Further, methanol content of crude glycerol is a potential problem. FDA has suggested that methanol content in crude glycerol of greater than 150 ppm may be toxic to animals. Thus, we used a crude glycerol source with known methanol content, which was 280 ppm. We further determined the water content of the crude glycerol source we used and adjusted experimental diets by the addition of water. The crude glycerol used in this study contained 86.95% total glycerol, 9.22% moisture, 1.26% sodium, and 1.86% chloride.

Feed was manufactured at the North Carolina State University Feed Mill Educational Unit in accordance with current Good Manufacturing Processes. Corn was ground with a hammer mill (Model 1522, Roskamp Champion, Waterloo, IA) equipped with a 2.2 mm (#6) screen. Dry ingredients were blended in a double ribbon mixer and liquids were applied after dry mixing was complete. Pellets were manufactured using a pellet mill (Model PM1112-2, California Pellet Mill Co., Crawfordsville, IN) equipped with a 4.4 mm x 45 mm die (11/64 in x 1 3/4 in). Pellets were cooled with ambient air in a counter-flow cooler (Model VK09x09KL, Geelen Counterflow USA Inc., Orlando, Florida). Post-pelleting liquid application of glycerol was completed after the cooling process. Samples were collected immediately after the pellet die to determine hot pellet temperature and pellet durability index.

Diets were manufactured by creating a basal diet first that contained all ingredients, except lactose or glycerol. The basal was divided into 6 portions to which lactose (with additional salt and water to maintain the same level of salt and water as the glycerol diets) and glycerol were added to create the final dietary treatments. This ensured that diets were identical in their composition with the exception of lactose and glycerol content (Tables 1 and 2).

Pigs were fed a two-phase dietary program. The first phase diet was fed immediately following weaning for 14 days. Glycerol was included in these diets as indicated above in replacement of lactose. The second phase diet did not contain any lactose and, therefore, glycerol was included in replacement of corn on a least cost basis. The second phase diet was fed for 3 weeks. In industry practice, three and four phase feeding programs for nursery pigs are common, in which specialty ingredients, such as lactose, are gradually decreased. We specifically chose a two phase program strategy to be able to clearly evaluate the potential value of glycerol as a replacement for lactose. The variation in animal performance during the first week after weaning is typically large, and a 2 week period is likely required to be able to determine differences in performance.

Pigs were weighed weekly on an individual basis throughout the 5 week period. Feed added to the feeders was recorded and feeders with remaining feed were weighed weekly to determine feed disappearance.

Experiment 2

A total of 144 pigs (body weight was 6.68 ± 0.17 kg) were weaned at approximately 21 days of age at the Swine Educational Unit, Raleigh, NC. Pigs were weighed and assigned within sex and weight block to one of 6 dietary treatments. Pigs were housed 3 pigs per pen using 48 pens and there will be 8 replicates per treatment. Dietary treatments (Table 3) consisted of the following:

1) Control treatment containing 20% lactose and 0% glycerol
2) Diet with 17.5% lactose and 2.5% glycerol
3) Diet with 15% lactose and 5% glycerol
4) Diet with 12.5% lactose and 7.5% glycerol
5) Diet with 10% lactose and 10% glycerol
6) Diet with 10% lactose and 0% glycerol

The control diet contained 20% total lactose, therefore, glycerol replaced up to 10% of the lactose. A second control diet was included in the design, which contained 10% lactose and no added glycerol. Replacement of lactose with glycerol was conducted on a weight for weight basis because we expect the DE of lactose and glycerol to be similar.

The crude glycerol used in Experiment 2 was the same as what was used in Experiment 1. Thus, the glycerol content of the crude glycerol product was known and diets were formulated based on analyzed glycerol content. In addition, Na and Cl can occur at high levels in crude glycerol products and were accounted for in diet formulation. As in Experiment 1, we further adjusted for the water content of the crude glycerol source and adjusted experimental diets by the addition of water.

Feed was manufactured at the North Carolina State University Feed Mill Educational Unit in accordance with current Good Manufacturing Processes. Corn was ground with a hammer mill (Model 1522, Roskamp Champion, Waterloo, IA) equipped with a 2.2 mm (#6) screen. Dry ingredients were blended in a double ribbon mixer and liquids were applied after dry mixing was complete. Glycerol was added to the diets with the dry ingredients prior to pelleting (which is in contrast to Experiment 1 in which glycerol was applied post-pelleting). Pellets were manufactured using a pellet mill (Model PM1112-2, California Pellet Mill Co., Crawfordsville, IN) equipped with a 4.4 mm x 29 mm die (11/64 in x 1 1/8 in). Pellets were cooled with ambient air in a counter-flow cooler (Model VK09x09KL, Geelen Counterflow USA Inc., Orlando, Florida). Electrical consumption was recorded on the pellet mill main motor. Conditioning temperature was recorded during the pelleting process. Samples were collected immediately after the pellet die to determine hot pellet temperature and pellet durability index.

Diets were manufactured by creating a basal diet first that contained all ingredients, except lactose or glycerol. The basal was divided into 5 portions to which lactose (with additional salt and water) and glycerol were added to create the final dietary treatments (treatments 1 to 5). This ensured that diets were identical in their composition with the exception of lactose and glycerol content. Treatment 6 was made separately because it different in ingredient composition from the other diets.

Pigs were fed a two-phase dietary program. The first phase diet (Table 3) was fed immediately following weaning for 14 days. Glycerol was included in these diets as indicated above in replacement of lactose. The second phase diet (Table 4) did not contain any lactose and, therefore, no glycerol was included. However, potential carry-over effects of glycerol feeding in the first diet phase were determined. The second phase diet was fed for 2 weeks.

Pigs were weighed weekly on an individual basis throughout the 4 week period. Feed added to the feeders was recorded and feeders with remaining feed were weighed weekly to determine feed disappearance.

Statistical Analyses

All data were analyzed using the GLM procedure of SAS. The model for Experiment 1 included weight block, glycerol levels in phase 1 diets, glycerol levels in phase 2 diets and the interaction between level in phase 1 and phase 2 diets. Orthogonal contrast comparisons were made to determine linear and quadratic effects of glycerol inclusion in phase 2 diets. The model for Experiment 2 included weight block and dietary treatment. Orthogonal contrast comparisons were made to determine linear and quadratic effects of glycerol inclusion. In addition, single degree of freedom contrast comparisons were conducted to determine the effect of lactose (10 vs 20% lactose; treatment 1 vs 6) and the effect of glycerol (0 vs 10%; treatment 5 vs 6) in a basal diet containing 10% lactose).

Results and Discussion

Experiment 1. Glycerol in Experiment 1 was applied post-pelleting. Therefore, the feed mill production data presented for Phase 2 diets in Table 5 indicate differences prior to glycerol inclusion, with the exception of pellet durability index. The differences in the three basal diets (before glycerol application) were relatively minor, and thus, pellet production data are very similar. Pellet durability index measured in the final diets were also very similar indicating that glycerol supplementation did not negatively or positively impact pellet quality. Production data were measured on only one batch of feed for each of the treatments, so no statistical inferences can be made.

Inclusion of 5% glycerol in starter 1 diets had no effect ($P > 0.29$) on body weight, average daily gain (ADG), average daily feed intake (ADFI) or feed efficiency (gain/feed) (Table 6). An interactive effect between glycerol inclusion in starter 1 and starter 2 ($P = 0.04$) was noted for pig body weight on week 2 of the study, however, this interaction was not relevant because starter 2 diets had not been fed at that point. Final body weight after 5 weeks increased ($P = 0.03$) with the inclusion of glycerol and this effect appeared to be greater in pigs that were previously supplemented with glycerol in the starter 1 diets. This effect appeared to be mainly due to the low body weight of pigs fed the 5% glycerol diet during the Starter 1 and the 0% glycerol diet during the Starter 2. Average daily gain was greater in pigs fed glycerol in starter 2 diets during week 4 ($P = 0.01$), week 5 ($P = 0.007$), the starter 2 phase ($P = 0.002$) and overall ($P = 0.03$). Improvements in ADG appeared to be a related in part to increased ADFI when glycerol was added to phase 2 diets, which was observed in week 4 ($P = 0.04$), week 5 ($P=0.001$), starter phase 2 (0.003), and overall ($P = 0.02$). Feed efficiency was improved with glycerol supplementation to Phase 2 diets during the starter 2 phase ($P = 0.04$), but this was not observed when considering the entire trial period. This study indicates that glycerol supplementation at a level of 5% to diets immediately following weaning (starter 1 phase) had no effect on pig performance. However, supplementation of glycerol during the second phase improved ADFI, ADG, and gain/feed, with the level of 10% giving the greatest response.

Experiment 2. In Experiment 2, glycerol was applied to the mash diet before pelleting and pelleting data are presented in Table 7. The production rates were relatively similar for the different levels of glycerol; however, production rates relative to energy use by the pellet mill motor were greater as the level of glycerol in the diet increased. Figure 1 shows electrical consumption of the pellet mill motor as impacted by glycerol level in the diet. Electrical consumption was reduced by approximately 50% when 7.5 to 10% of glycerol was included compared to 0% glycerol. Pellet durability index and conditioning temperature did not appear to be different; however, hot pellet temperature was decreased as glycerol inclusion increased, which may indicate less friction through the die. Feed production was measured only on one batch of feed for each of the diets, so no statistical comparisons can be made. Nonetheless, these data provide some reasonable evidence that the pelleting process may be more efficient when glycerol is included in the diet. It should be noted, however, that the 10% glycerol mash diet (before pelleting) set up in the feed mill bins and had to be manually forced from the pellet mill mash bins. The 10% diet also created an overload condition on the mixer motor.

Supplementation of Starter 1 diets with glycerol linearly increased ($P < 0.05$) pig body weight when measured on week 2 and 3 of the study. Average daily gain increased linearly during week 2 and the starter 1 period with increasing levels of glycerol. This appeared to be directly related to feed intake, which followed the same pattern as ADG. Feed intake increased linearly during week 2 ($P = 0.05$) and the starter 1 phase ($P = 0.04$) as level of glycerol in the diet increased. Feed efficiency was not impacted by glycerol supplementation. The positive effects of glycerol supplementation in the starter 1 diet were not maintained when pigs were switched to a common starter 2 diet. We also included a second control diet in the experimental design with two objectives. First, this allowed us to determine the effect of lactose level in the diet (10 vs 20%) independent of glycerol. Second, it allowed for the comparison of 0 and 10% glycerol supplementation independent of the level of lactose in the diet. Supplementation of 20% lactose compared to 10% lactose in the starter 1 diet had no effect on ADG, ADFI, and gain/feed. This was surprising as lactose is traditionally included at high levels in the first diet after weaning to ease the transition from sow milk to a solid feed. It would also suggest that any effects of glycerol supplementation were due to glycerol, and not due to the reduction in lactose associated with increasing levels of glycerol. Glycerol supplementation (10%) to diets that had 10% lactose resulted in heavier pig body weights at week 2 ($P = 0.01$), greater ADG during week 1, 2, and the prestarter period ($P < 0.03$), and improved feed efficiency during week 1, 2, and the starter 1 period ($P < 0.04$).

Conclusions

Supplementation of glycerol to starter 2 diets in Experiment 1 improved pig performance when added at 5% and 10% and the greatest response was observed at 10%. Although no effect of 5% glycerol supplementation to Starter 1 diets on pig performance was observed in Experiment 1, clear effects were noted in Experiment 2. Pig performance was linearly improved with the supplementation of glycerol to Starter 2 diets, showing the best results for the highest level (10%) studied. This effect appeared to be independent from lactose levels that were replaced by the glycerol. Glycerol was added after pelleting in Experiment 1, but before pelleting in Experiment 2, which may be responsible, in part, for the differences between experiments.

Application of glycerol before pelleting may improve pelleting efficiency, resulting in a 50% reduction in energy use during the pelleting process. Although the 10% glycerol diet produced positive results in the animals, it set up in the feed mill bins and had to be manually forced from the pellet mill mash bins. The 10% diet also created an overload condition on the mixer motor.

Table 1. Composition of the experimental Phase 1 diets (Experiment 1), as fed basis

	Control	**Glycerol**
Ingredient		
Corn	41.25	41.25
Soybean meal (48.5% CP)	18.26	18.26
Lactose	20	15
Crude glycerol	0	5.75
Salt	0.28	0.10
Water	0.57	0
Fish meal, menhaden	5	5
Whey protein concentrate	5	5
Blood plasma	3	3
Poultry fat	2	2
Monocalcium phosphate, 21% P	1.58	1.58
Blood cells	1.50	1.50
Limestone	0.55	0.55
Vitamin-mineral mix	0.40	0.40
Zinc oxide	0.339	0.339
L-lysine HCl	0.139	0.139
DL-methionine	0.067	0.067
Threonine	0.066	0.066
Calculated nutrient composition, %		
Crude protein	21.21	21.21
Calcium	0.80	0.80
Total phosphorus	0.75	0.75
Available phosphorus	0.60	0.60
Lysine	1.50	1.50
Methionine	0.42	0.42
Threonine	0.97	0.97
Tryptophan	0.27	0.27

Table 2. Composition of the experimental Phase 2 diets (Experiment 1), as fed basis

	Glycerol, %		
	0	**5**	**10**
Ingredient, %			
Corn	64.66	58.48	52.28
Soybean meal (47.5% CP)	29.38	29.95	30.52
Crude glycerol	0	5.75	11.5
Poultry fat	2	2	2
Monocalcium phosphate, 21% P	1.65	1.71	1.76
Limestone	0.91	0.88	0.86
Salt	0.45	0.27	0.10
Vitamin-mineral premix	0.40	0.40	0.40
L-lysine	0.306	0.304	0.303
Threonine	0.110	0.117	0.125
DL-methionine	0.048	0.056	0.063
Copper sulfate	0.085	0.085	0.085
Calculated nutrient composition, %			
Crude protein	20.2	20.1	19.9
Calcium	0.75	0.75	0.75
Total phosphorus	0.70	0.70	0.70
Available phosphorus	0.47	0.47	0.48
Lysine	1.30	1.30	1.30
Methionine	0.37	0.37	0.37
Threonine	0.84	0.84	0.84
Tryptophan	0.23	0.23	0.23

Table 3. Composition of the experimental Phase 1 diets (Experiment 2), as fed basis.

	Glycerol, %					Negative
	0	**2.5**	**5**	**7.5**	**10**	**Control[1]**
Ingredient, %						
Corn	40.53	40.53	40.53	40.53	40.53	52.90
Soybean meal (47.5% CP)	21.28	21.28	21.28	21.28	21.28	20.13
Crude glycerol	0	2.88	5.75	8.63	11.5	0
Lactose	20	17.5	15	12.5	10	10
Salt	0.46	0.37	0.28	0.19	0.10	0.46
Water	1.14	0.85	0.57	0.28	0	0
Fish meal, menhaden	5	5	5	5	5	5
Blood plasma	3	3	3	3	3	3
Whey protein concentrate	2	2	2	2	2	2
Poultry fat	2	2	2	2	2	2
Blood cells	1.5	1.5	1.5	1.5	1.5	1.5
Monocalcium phosphate, 21% P	1.50	1.50	1.50	1.50	1.50	1.39
Limestone	0.56	0.56	0.56	0.56	0.56	0.61
Vitamin-mineral premix	0.40	0.40	0.40	0.40	0.40	0.40
Zinc oxide	0.34	0.34	0.34	0.34	0.34	0.34
L-lysine	0.145	0.145	0.145	0.145	0.145	0.148
Threonine	0.086	0.086	0.086	0.086	0.086	0.071
DL-methionine	0.067	0.067	0.067	0.067	0.067	0.053
Calculated nutrient composition, %						
Crude protein	21.6	21.6	21.6	21.6	21.6	22.0
Calcium	0.80	0.80	0.80	0.80	0.80	0.80
Total phosphorus	0.75	0.75	0.75	0.75	0.75	0.75
Available phosphorus	0.59	0.59	0.59	0.59	0.59	0.58
Lysine	1.50	1.50	1.50	1.50	1.50	1.50
Methionine	0.42	0.42	0.42	0.42	0.42	0.42
Threonine	0.97	0.97	0.97	0.97	0.97	0.97
Tryptophan	0.27	0.27	0.27	0.27	0.27	0.27

[1] The negative control diet was formulated to contain 10% lactose without glycerol

Table 4. Composition of the experimental Phase 2 diet (Experiment 2), as fed basis.

Ingredient, %	
Corn	64.66
Soybean meal (47.5% CP)	29.38
Crude glycerol	0
Poultry fat	2
Monocalcium phosphate, 21% P	1.65
Limestone	0.91
Salt	0.45
Vitamin-mineral premix	0.40
L-lysine	0.306
Threonine	0.110
DL-methionine	0.048
Copper sulfate	0.085
Calculated nutrient composition, %	
Crude protein	20.2
Calcium	0.75
Total phosphorus	0.70
Available phosphorus	0.47
Lysine	1.30
Methionine	0.37
Threonine	0.84
Tryptophan	0.23

Table 5. Effect of glycerol inclusion rate in Starter 2 nursery diets on pelleting characteristics (Experiment 1)

	Glycerol inclusion level		
	0%	**5%**	**10%**
Production rate, lbs/hr	1785	1814	1856
Pellet durability index	92	96	89
Conditioning temperature	180	179	180
Hot pellet temperature	187	186	189

Table 6. Growth performance of nursery pigs fed crude glycerol to supply 0 or 5% glycerol in starter phase 1 diets and 0, 5, or 10% glycerol in starter phase 2 diets[1]

	0% glycerol in starter 1			5% glycerol in starter 1						
	Glycerol in starter 2			Glycerol in starter 2				P values[2]		
	0%	**5%**	**10%**	**0%**	**5%**	**10%**	**SEM**	**Start 1**	**Start 2**	**S1 x S2**
Body weight, kg										
Initial	6.95	6.87	6.91	6.89	6.92	6.93	0.03	0.979	0.525	0.179
Week 1	8.08	7.59	7.91	7.85	7.90	8.08	0.17	0.559	0.267	0.256
Week 2	10.50	9.93	9.93	9.75	10.43	10.21	0.25	0.947	0.908	0.039
Week 3	13.31	12.73	12.75	12.43	12.75	13.32	0.33	0.727	0.681	0.107
Week 4	16.91	16.28	16.74	15.65	16.91	17.56	0.44	0.856	0.149	0.093
Week 5	20.32	20.05	20.32	18.50	20.66	21.50	0.53	0.980	0.027	0.020
Average daily gain, g/d										
Week 1	162	103	142	137	140	164	23	0.545	0.326	0.382
Week 2	346	334	288	272	363	305	29	0.687	0.188	0.166
Week 3	401	400	403	383	331	444	35	0.589	0.274	0.308
Week 4	513	508	570	460	594	606	31	0.369	0.010	0.091
Week 5	569	629	597	475	625	656	35	0.661	0.007	0.108
Starter 1	254	219	215	204	251	235	18	0.950	0.856	0.062
Starter 2	491	506	520	438	511	564	20	0.946	0.002	0.066
Overall	394	388	394	342	404	429	16	0.972	0.029	0.025
Average daily feed intake, g/d										
Week 1	226	184	192	209	207	220	13	0.299	0.251	0.184
Week 2	406	352	376	328	400	372	24	0.578	0.923	0.043
Week 3	630	611	622	561	595	649	27	0.384	0.305	0.223
Week 4	737	826	745	706	829	875	42	0.332	0.036	0.157
Week 5	921	1075	1081	821	1067	1078	58	0.444	0.001	0.645
Starter 1	316	268	284	268	304	296	15	0.996	0.911	0.029
Starter 2	751	826	806	690	819	857	32	0.831	0.003	0.241
Overall	571	596	591	516	606	626	23	0.879	0.019	0.169
Gain/feed, g/kg										
Week 1	716	537	746	643	662	721	81	0.892	0.261	0.449
Week 2	854	948	781	819	909	812	58	0.762	0.079	0.792
Week 3	637	651	646	673	557	690	48	0.900	0.381	0.282
Week 4	656	614	766	653	726	699	37	0.635	0.103	0.062
Week 5	617	590	589	578	583	612	34	0.791	0.905	0.664
Starter 1	804	810	766	760	824	788	31	0.910	0.386	0.522
Starter 2	656	613	652	634	626	664	14	0.913	0.044	0.400
Overall	693	652	674	661	668	689	13	0.973	0.244	0.133

[1] Each value represents the mean of 7 pens with 3 pigs per pen

[2] Probability values for the effects of glycerol in the phase 1 diets (Start 1), phase 2 diets (Start 2), and their interaction (S1 x S2).

Table 7. Effect of glycerol inclusion rate in Starter I nursery diets on pelleting characteristics (Experiment 2)

	Glycerol inclusion					Negative control
	0%	2.5%	5%	7.5%	10%	
Production Rate, lbs/hr	1334	1460	1437	1372	1434	1439
Production/energy, lbs/hr/hp	105.9	144.6	192.9	196	243	114
Pellet durability index	94	94	95	95	96	88
Conditioning temperature	145	145	145	144	145	146
Hot pellet temperature	166	163	157	155	154	172

Table 8. Effect of glycerol inclusion rate in Starter I nursery diets on pig performance (Experiment 2)[1]

	Glycerol inclusion, %							P values[2]			
	0	**2.5**	**5**	**7.5**	**10**	**NC[3]**	**SEM**	**Lin**	**Quad**	**C1**	**C2**
Body Weight, kg											
Initial	6.67	6.68	6.67	6.66	6.68	6.76	0.04	0.94	0.91	0.18	0.21
Week 1	7.71	7.81	7.88	7.80	8.06	7.74	0.12	0.07	0.72	0.85	0.08
Week 2	9.49	9.54	10.13	9.72	10.39	9.45	0.25	0.01	0.76	0.90	0.01
Week 3	11.95	11.93	12.71	12.17	12.74	11.96	0.30	0.05	0.90	0.98	0.07
Week 4	14.19	14.38	15.00	14.54	14.86	14.48	0.45	0.29	0.65	0.65	0.56
Average daily gain, kg/d											
Week 1	0.15	0.16	0.17	0.16	0.20	0.14	0.02	0.08	0.76	0.77	0.03
Week 2	0.25	0.25	0.32	0.27	0.33	0.24	0.02	0.02	0.87	0.76	0.02
Week 3	0.35	0.34	0.37	0.36	0.34	0.36	0.03	0.86	0.61	0.86	0.58
Week 4	0.32	0.35	0.33	0.34	0.30	0.36	0.04	0.71	0.54	0.46	0.30
Starter 1	0.20	0.20	0.25	0.22	0.27	0.19	0.02	0.01	0.79	0.73	0.01
Starter 2	0.34	0.35	0.35	0.35	0.32	0.36	0.03	0.72	0.47	0.53	0.28
Overall	0.27	0.27	0.30	0.28	0.29	0.28	0.02	0.30	0.62	0.75	0.51
Average daily feed intake, kg/d											
Week 1	0.20	0.20	0.20	0.21	0.23	0.21	0.02	0.35	0.44	0.85	0.48
Week 2	0.33	0.34	0.44	0.43	0.39	0.35	0.03	0.05	0.11	0.78	0.32
Week 3	0.49	0.47	0.56	0.51	0.51	0.49	0.03	0.40	0.46	0.95	0.58
Week 4	0.67	0.70	0.74	0.71	0.76	0.73	0.04	0.18	0.82	0.31	0.64
Starter 1	0.37	0.27	0.32	0.32	0.31	0.28	0.02	0.04	0.28	0.75	0.26
Starter 2	0.58	0.59	0.65	0.61	0.64	0.61	0.03	0.23	0.61	0.51	0.58
Overall	0.42	0.43	0.49	0.46	0.46	0.44	0.02	0.12	0.33	0.51	0.49
Gain/feed, kg/kg											
Week 1	0.73	0.81	0.83	0.77	0.87	0.65	0.05	0.16	0.68	0.29	0.01
Week 2	0.76	0.75	0.77	0.64	0.89	0.69	0.07	0.51	0.17	0.43	0.04
Week 3	0.72	0.73	0.67	0.69	0.66	0.74	0.05	0.29	0.98	0.72	0.19
Week 4	0.47	0.50	0.45	0.47	0.40	0.48	0.05	0.34	0.58	0.85	0.26
Starter 1	0.74	0.76	0.78	0.68	0.87	0.68	0.05	0.27	0.25	0.35	0.01
Starter 2	0.57	0.59	0.54	0.57	0.51	0.59	0.04	0.23	0.65	0.77	0.13
Overall	0.63	0.65	0.62	0.62	0.63	0.62	0.03	0.73	0.86	0.77	0.81

[1] Each value represents the mean of 8 pens with 3 pigs per pen

[2] Lin is the linear effect of glycerol supplementation; Quad is the quadratic effect of glycerol supplementation; C1 is the contrast between 20% lactose and 10% lactose in diets without glycerol (0% glycerol vs. NC); C2 is the contrast between 0 and 10% glycerol in diets with 10% lactose (10% glycerol vs. NC).

[3] NC is the negative control diet containing 10% lactose

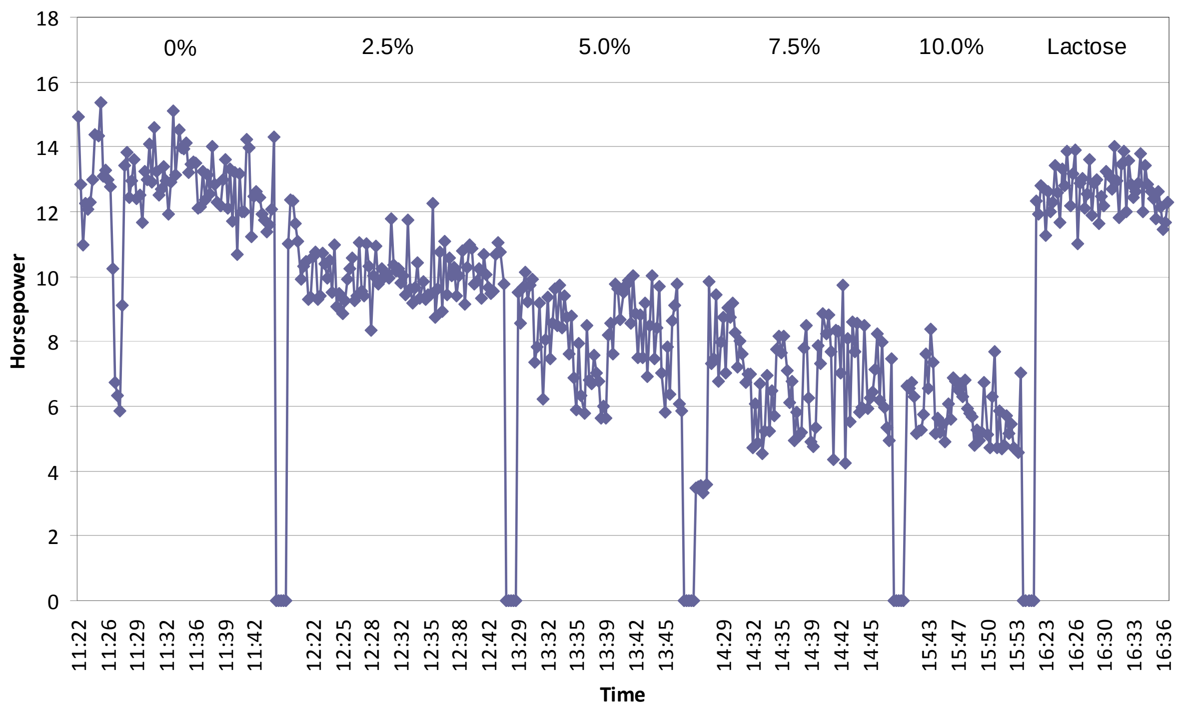

Figure 1. Effect of glycerol inclusion (0, 2.5, 5, 7.5, and 10%) in Starter I diets on electrical consumption (horsepower) of the main pellet mill motor.