Effects of adding liquid lactose or molasses to pelleted swine diets on pellet quality and pig performance

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ABSTRACT: Two experiments were conducted to evaluate the effects of including liquid lactose (LL) and molasses (M) in swine diets on pellet quality and pig performance. In experiment 1, a total of 194 nursery pigs (DNA 241 × 600, initially 6.7 ± 0.4 kg at 27 d of age) were used in a 33-d experiment evaluating the effects of LL (SweetLac 63; Westway Feed Products, Tomball, TX) or cane molasses on nursery pig performance and pellet quality. Pelleted experimental diets were fed from d 0 to 21, and a common pelleted diet fed from d 21 to 33. Dietary treatments consisted of a control diet containing 19.1% total sugars from whey powder and whey permeate and experimental diets with a percentage of whey permeate replaced by either 5% or 10% LL or 9.4% cane molasses (5 LL, 10 LL, and 9.4 M, respectively). Hot pellet temperature and production rate decreased ($P < 0.05$) from the control to 9.4 M treatments with 5 LL and 10 LL having intermediate effects. Pellet durability index (PDI) increased ($P < 0.05$) in 5 LL, 10 LL, and 9.4 M, respectively. From d 0 to 7, pigs fed the 10 LL and 9.4 M treatment had the best G:F followed by the control and 5 LL treatments. From d 0 to 21, ADFI had a marginally significant improvement ($P < 0.10$) in pigs fed up to 10 LL in the diet. Fecal consistency scores at d 7 were also firmer ($P < 0.05$) in pigs fed 9.4 M compared with pigs fed the control or 5 LL treatments with pigs fed the 10 LL treatment being intermediate. There was no evidence for differences in fecal consistency scores for d 14. In experiment 2, a total of 289 finishing pigs (DNA 241 × 600; initially 53.5 ± 0.5 kg BW) were used in a 53-d experiment evaluating the effects of LL on pellet quality and finishing pig performance. Experimental diets were fed in pelleted form from d 0 to 53 divided into three phases. Dietary treatments were a corn-soybean meal control diet with 0%, 2.5%, 5%, and 7.5% LL added in the place of corn. PDI improved (linear, $P < 0.01$) with increasing inclusion of LL. There were no differences in ADG, ADFI, final BW, or carcass characteristics. Pigs fed diets with increasing levels of LL tended to have improved (quadratic, $P = 0.070$) G:F.

Key words: liquid lactose, molasses, pelleting, pigs

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INTRODUCTION

Getting nursery pigs started on feed is key to success for swine producers. Milk and animal-based products are included in early nursery pig diets to help weaned pigs transition from a milk-based liquid diet to a plant-based solid diet. Dried whey powder and dried whey permeate (73% and 85% lactose, respectively) are milk-based products commonly used in nursery pig diets. Previous research has demonstrated that increasing the levels of lactose in nursery pig diets using dried whey resulted in an improvement in pig performance (Mahan et al., 2004). This can be explained by the increased level of lactase activity in a newly weaned pig which leads to lactose being more digestible than starch carbohydrates (Tokach et al., 1994). However, it has been demonstrated that a portion of whey may be replaced by non-lactose carbohydrate sources. These alternative carbohydrates include dextrose, sucrose, or by-products of candy manufacturers (Stephas and Miller, 1998). An additional source of sucrose is sugar cane molasses. Sugar cane molasses is a by-product of the cane sugar refining containing approximately 47.5% sucrose. Identifying alternative sources of lactose or non-lactose carbohydrates need to be evaluated for inclusion in nursery pig diets.

Finding the most affordable ingredient sources without sacrificing performance is a common goal among producers. Liquid lactose (LL) or molasses could serve as an alternative carbohydrate feed additive in swine diets, if pellet quality is maintained and pig performance is not negatively impacted. Thus, our objective was to determine the effects of adding LL or molasses to pelleted swine diets on pellet quality and pig performance.

MATERIALS AND METHODS

All experimental procedures were approved by Institutional Animal Care and Use Committee at Texas A&M University.

Experiment 1

A total of 194 nursery pigs (Line 241 × 600; DNA Genetics, Columbus, NE; initially 6.7 ± 0.4 kg) from two consecutive groups were used in a 33 d trial with treatments replicated equally in both groups. Pigs were weaned at 27 d, moved to the nursery, and started on dietary treatments. Pigs were housed in 16 pens per group (1.5 × 1.5m metal slatted pens). Pens were equipped with nipple waterers and four to five hole stainless steel feeders for *ad libitum* access to water and feed. At weaning, pigs were assigned to pens balanced by BW with four to seven pigs per pen. Group 1 pens contained seven total pigs with four gilts and three barrows or four barrows and three gilts. Group 2 pens contained five or six total pigs with three or four gilts, respectively, and two barrows. Pens of pigs were allotted to one of four dietary treatments balanced by initial BW, number of barrow and gilts per pen, and within group. Pens of pigs were also blocked by location within group. Overall, there were eight pens per treatment. Dietary treatments consisted of a control diet containing 19.1% total sugars from milk, whey powder and whey permeate, and the control diet with a percentage of whey permeate replaced by either 5% or 10% LL (SweetLac 63; Westway Feed Products, Houston, TX) or 9.4% cane molasses. All diets were balanced for SID Lys and total sugars and fed in pelleted form. Diets were formulated with consideration of increased moisture content provided by LL and molasses (Table 1). Therefore, diets were formulated under the assumption that additional moisture from LL would be removed during the pellet cooling process. After pelleting, expected levels of dietary components were achieved. Dietary treatments were split into two separate phases. Phase 1 was fed from day 0 to 7 and phase 2 from day 7 to 21. Phase 3 was a common pelleted diet fed across all pens from day 21 to 33.

Diets were mixed and pelleted at the Texas A&M University Poultry Science Teaching, Research, and Extension Center using a CPM Pellet Mill (Master Model HD, Series 2000). In order, to pellet the 10 LL and 9.4 M diets the process was done without the addition of steam. To remain consistent, no steam was added while pelleting any diets. Pellet mill throughput and hot pellet temperature were measured during pelleting. Four consecutive 60 s collections of pellets were weighed to measure production rate. Hot pellet temperature was measured at the center of the sample after all pellets were collected. A representative sample was used to determine percent fines and pellet durability index (PDI). Percent fines were established as the material that would pass through a number-6 screen (3.35 mm) sifter. A Seedburo Pellet Durability Tester with 4, 0.3 × 0.14 × 0.3 m tumble chambers was used to determine standard PDI. Pellet subsamples of 0.23 kg were collected from pellets fed into a one-gallon bag per treatment per phase. Each diet and phase had four 500 g samples sifted with a number-6 screen (3.35 mm) sifter.

Table 1. Chemical analysis of LL product (as-fed basis)[a]

Item, %	LL[b]
Crude protein	3.18
Amino acid content[c]	
Taurine	–
Hydroxyproline	0.01
Aspartic acid	0.16
Threonine	0.08
Serine	0.07
Glutamic acid	0.32
Proline	0.14
Glycine	0.08
Alanine	0.13
Cysteine	0.03
Valine	0.10
Methionine	0.02
Isoleucine	0.08
Leucine	0.17
Tyrosine	0.03
Phenylalanine	0.07
Hydroxylysine	0.01
Ornithine	0.01
Lysine	0.04
Histidine	0.03
Arginine	0.04
Tryptophan	<0.02
Moisture	31.7
Crude fat	7.40
Crude fiber	–
Ash	9.46

[a]Analyzed at University of Missouri Agricultural Experiment Station Chemical Laboratories (ESCL; Columbia, MO).

[b]SweetLac 63 (LL), LL product was obtained by Westway Feed Products (Tomball, TX).

[c]% of total amino acid in ingredient.

The sifted samples were tumbled for 10 min, simulating breakage from the time pellets are expelled until consumed by the animal. After tumble, pellets were re-sifted using the number-6 screen (3.35 mm) sifter and weighed. A modified pellet durability was measured with the Holmen NHP100 pellet durability tester as a more abrasive technique (Tekpro Limited, Norfolk, UK; Table 2). Pellet subsamples of 100 g were weighed, sifted then tested at 60 and 120 s under pressurized air flow to simulate breakage from mill to consumption. With all methods, PDI was calculated as weight of pellets after disturbance/weight of pellets before disturbance × 100 (ASAE S269.4; ASAE, 1997).

Pig weights and feed disappearance were measured on d 0, 7, 21, and 33 for calculation of ADG, ADFI, and G:F. Fecal samples were collected on d 7 and 14 to visually examine fecal consistency and to determine DM of fecal samples. Samples were collected using rectal massage from four randomly selected pigs per pen. Then, five individuals, blinded to treatments, scored samples based on a scale provided by Smiricky et al. (2002). The scale is as follows: 1 = hard, dry pellet; 2 = firm, formed stool; 3 = soft, moist stool that retains shape; 4 = soft, moist stool that assumes shape of container; and 5 = water liquid that can be poured. An average of individual scores was taken by sample and by pen. Fecal samples were then used for partial and laboratory DM (Undersander et al., 1993). Entire sample was then weighed and dried in a forced-air drying oven at 50°C for 24 h. Samples were air equilibrated for 24 h and weighed to complete partial DM. Laboratory DM was obtained by grinding samples in a Hamilton Beach coffee grinder. A 1-g sample from the original sample was then weighed and dried at 105°C for 24 h. DM samples were air equilibrated in a desiccator for 0.25 h and weighed to determine final percent DM.

Experiment 2

A total of 289 finishing pigs (Line 241 × 600; DNA Genetics, Columbus, NE; initially 53.5 ± 0.5 kg BW) from three groups of pigs were used in a 53 d trial. Treatment was replicated equally in all three groups of pigs. Pigs were housed on solid concrete pens in a fully open sided barn throughout the duration of the experiment. There were eight pens per group for a total of six pens per treatment. Pens were equipped with nipple waterers and stainless-steel feeders for ad libitum access to water and feed. Pigs were assigned to pens balanced by BW and gender with 8–14 pigs per pen. Pens of pigs were allotted to one of four dietary treatments balanced by BW, number of barrow and gilts per pen, and within group. Dietary treatments were blocked by location within each group. Dietary treatments consisted of a control diet with 0%, 2.5%, 5.0%, and 7.5% LL (SweetLac 63; Westway Feed Products, Tomball, TX), respectively. Pigs were fed dietary treatments for 53 days in three phases.

All diets were formulated and balanced for SID Lys and fed in pelleted form. The LL source used contained 31.7% moisture. Therefore, diets were formulated under the assumption that additional moisture from LL would be removed during the pellet cooling process (Tables 3–5). Concentration of diet components were initially decreased to allow for moisture loss during the pelleting process. After the pelleting process, components were returned to expected levels. Two batches of all diets were pelleted at a commercial feed mill and pelleted using a Sprout 26W pellet mill. Pellets were steam conditioned to a target of 85°C, however conditioning temperatures of approximately only 37.8°C were

Table 2. Formulated diet composition (as-fed) basis[a]

Item, %[b]	Phase 1				Phase 2				Phase 3
	Control	5 LL[c]	10 LL	9.4 M[d]	Control	5 LL	10 LL	9.4 M	Common diet
Corn	31.97	30.64	29.34	29.03	31.49	30.24	28.87	28.57	50.90
Soybean meal, 46.5%	29.33	28.93	28.48	28.88	30.07	29.60	29.19	29.55	25.84
Corn DDGS	5.00	4.93	4.85	4.92	20.00	19.72	19.42	19.67	20.00
Fish meal combined	5.00	4.93	4.85	4.92	–	–	–	–	–
Milk, whey powder	12.50	12.32	12.14	12.30	7.50	7.39	7.28	7.38	–
Milk, whey permeate, 85.0%	11.25	8.38	5.58	5.80	5.50	2.71	–	0.15	–
Liquid lactose[c]	–	5.0	10.0	–	–	5.00	10.00	–	–
Molasses cane	–	–	–	9.40	–	–	–	9.40	–
Soybean oil	2.00	1.97	1.94	1.97	2.00	1.97	1.94	1.97	–
Monocalcium phosphate, 21.0% P	0.50	0.44	0.36	0.57	0.95	0.89	0.83	1.03	0.95
Limestone, ground	0.85	0.86	0.87	0.62	1.00	0.99	1.00	0.76	1.15
Sodium chloride	0.30	0.30	0.30	0.30	0.35	0.35	0.34	0.34	0.35
L-Lys-HCL	0.33	0.33	0.33	0.33	0.40	0.40	0.40	0.41	0.40
DL-Met	0.18	0.18	0.18	0.18	0.13	0.12	0.13	0.13	0.06
L-Thr	0.14	0.14	0.14	0.14	0.12	0.11	0.11	0.12	0.09
L-Trp	–	–	–	–	–	–	0.01	0.01	–
VTM Premix[e]	0.25	0.25	0.25	0.25	0.25	0.25	0.24	0.25	0.25
Phytase[f]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Zinc oxide	0.39	0.39	0.39	0.39	0.25	0.25	0.24	0.25	–
Total	100	100	100	100	100	100	100	100	100
Calculated nutrient composition[g]									
Standard ileal digestible lysine, %	1.44	1.44	1.44	1.44	1.35	1.35	1.35	1.35	1.20
ME, kcal/kg	3,430	3,406	3,380	3,157	3,393	3,369	3,342	3,117	3,283
NE, kcal/kg	2,383	2,282	2,180	2,167	1,969	1,870	1,768	1,753	855
SID Lys: ME ratio, g/mcal	1.48	1.47	1.46	1.36	1.34	1.33	1.32	1.23	1.25
CP, %	23.5	23.4	23.4	23.6	24.0	23.9	23.9	24.1	22.5
Ca, %	0.82	0.82	0.82	0.82	0.70	0.70	0.70	0.70	0.64
P, %	0.70	0.70	0.70	0.70	0.69	0.69	0.69	0.69	0.64
Lactose, %	18.7	18.2	17.8	14.1	10.1	9.7	9.2	5.6	–
Sugar, %	18.7	18.7	18.7	18.7	10.1	10.1	10.1	10.1	–

[a]Treatment diets were fed during phase 1 from d 0 to 7 and phase 2 from d 7 to 21, with a common phase 3 diet fed from d 21 to 33. All diets were fed in pelleted form.

[b]Diets were formulated with consideration of increased moisture content provided by LL and molasses. Concentration of diet components were initially decreased to allow for moisture loss during the pellet cooling process. Item (%) represents the percentage of each ingredient that was added to the mixer.

[c]LL is SweetLac (SweetLac 63; Westway Feed Products, Tomball, TX).

[d]M = Sugar cane molasses.

[e]VTM = vitamin and trace mineral premix, which provide per kilogram premix: 725,747 IU vitamin A, 136,078 IU vitamin D, 3,629 IU vitamin E, 91 mg vitamin K, 3 mg B12, 2,722 mg Niacin, 1,814 mg pantothenic acid, 454 mg riboflavin, 18 mg biotin, 91 mg folic acid, 181 mg pyridoxine, 3,005ppm Zn phase 1, 1,925 ppm Zn phase 2, 125 ppm Zn phase 3, 125ppm Fe, 22 ppm Mg, 15ppm Cu, 0.6 ppm I, 0.3 ppm Se.

[f]RONOZYME HiPhos 2,700 provided 443 phytase units (FYT)/kg with a release of 0.05 % available P.

[g]The calculated nutrient composition is estimated on the diets after pelleting with 90% DM.

achieved because of additional moisture provided by LL ingredient. Samples were collected when feed was added to the feeder during each phase and then analyzed for percent of fines and PDI.

Percent of fines were determined before testing pellets for durability. Samples were sifted using a number-6 screen (3.35 mm) sifter. The accumulated fines were weighed, and percent of fines were calculated using the following formula: weight of fines/weight of sample × 100. PDI was determined using both the standard tumble box (ASAE S269.4; ASAE, 1998) and modified Holmen NHP100 methods as described in Experiment 1.

On d 53, pigs were shipped to a commercial abattoir for harvest and to determine carcass measurements. Pigs were killed on d 54 and hot carcass weights (HCW) were measured, including the head of the carcass. Carcasses chilled overnight, and fat thickness and loin eye area (LEA) were measured. Fat thickness

Table 3. Diet composition, phase 1 (as-is basis)[a]

Item	Control	2.5 LL[b]	5.0 LL	7.5 LL
Ingredient, %[c]				
Corn	61.36	60.54	59.69	58.81
Soybean meal, dehull, sol extr	16.32	16.72	17.14	17.57
Dried distillers grains with solubles	20.00	20.37	20.76	21.16
Limestone, ground	1.43	1.45	1.48	1.51
Sodium chloride	0.35	0.36	0.36	0.37
L-Lys-HCL	0.28	0.28	0.29	0.29
VTM Premix[d]	0.25	0.25	0.26	0.26
Phytase[e]	0.02	0.02	0.02	0.02
Liquid lactose	–	2.5	5.0	10.0
Total	100	1,000	1,000	1,000
Calculated nutrient analysis[f]				
Standardized ileal digestible lysine, %	0.87	0.87	0.87	0.87
ME, kcal/kg	3,311	3,303	3,292	3,280
NE, kcal/kg	2,458	2,445	2,429	2,416
CP, %	18.6	18.5	18.5	18.4
Ca, %	0.59	0.60	0.60	0.61
P, %	0.40	0.40	0.41	0.42
Available P, %	0.25	0.26	0.28	0.29
Lactose, %	–	0.90	1.90	2.80

[a]Phase 1 diet was fed from d 0 to 19 in pelleted form.

[b]LL= Liquid lactose (SweetLac63; Westway Feed Products, Tomball, TX).

[c]Diets were formulated with consideration of increased moisture content provided by LL and molasses. Concentration of diet components were initially decreased to allow for moisture loss during the pellet cooling process. Item (%) represents the percentage of each ingredient that was added to the mixer.

[d]VTM = vitamin and trace mineral premix, which provide per ton of premix: 8,000,000 IU vitamin A, 1,500,000 IU vitamin D, 40,000 IU vitamin E, 1,000 mg vitamin K, 30 mg B12, 30,000 mg Niacin, 20,000 mg pantothenic acid, 5,000 mg riboflavin, 200 mg biotin, 1,000 mg folic acid, 2,000 mg pyridoxine, 125 ppm Zn, 125 ppm Fe, 22 ppm Mn, 15 ppm Cu, 0.60 ppm I, 0.30 ppm Se. Vitamin concentrations are expressed on a per lb of product basis; whereas mineral concentrations are expressed on a total percentage of premix basis.

[e]RONOZYME HiPhos 2,700 provided 443 phytase units (FYT)/kg with a release of 0.11, 0.10, and 0.09 % of available P, respectively, for each phase.

[f]The calculated nutrient composition is estimated on the diets after pelleting with 90% DM.

measurements were measured using a backfat ruler at the ¾ point over the rib eye. LEA was measured using a grid. Carcass yield and percent fat free lean (FFL) were calculated (NPPC, 2001). Carcass yield was calculated by dividing the HCW at the plant by the live weight at the farm before transport to the plant. FFL equation was provided by National Pork Board/American Meat Science Association.

Statistical Analyses

For experiment 1, pellet data were analyzed as a randomize complete block design using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC) with batch of feed as the experimental unit. Dietary treatments were used as a fixed effect. Phase was used as a blocking factor and considered a random effect. Treatment means were separated using the PDIFFS option from the LSMEANS statement of SAS. Results from experiment were considered significant at $P < 0.05$ and a marginal significance between $P > 0.05$ and $P \leq 0.10$.

For experiment 1, growth data were analyzed as a generalized random complete block design using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC) with pen as experimental unit. Dietary treatments were used as a fixed effect. Pen location within group was used as a blocking factor and considered a random effect. Treatment means were separated using the PDIFFS option from the LSMEANS statement of SAS. Results from experiment were considered significant at $P < 0.05$ and a marginal significance between $P > 0.05$ and $P \leq 0.10$.

For experiment 2, pelleting data were analyzed as a generalized random complete block design with batch as experimental unit. Dietary treatments were fixed effects and phase was considered a random effect. Growth and carcass data were analyzed as a generalized random complete block design using PROC MIXED in SAS (SAS Institute, Inc.,

Table 4. Diet composition, phase 2 (as-is basis)[a]

Item	Control	2.5 LL[b]	5.0 LL	7.5 LL
Ingredient, %[c]				
Corn	66.26	65.54	64.79	64.00
Soybean meal, dehull, sol extr	11.57	11.98	12.21	12.55
Dried distillers grains with solubles	20.00	20.37	20.76	21.16
Limestone, ground	1.28	1.30	1.32	1.35
Sodium chloride	0.35	0.36	0.36	0.37
L-Lys-HCL	0.27	0.28	0.28	0.29
VTM Premix[d]	0.25	0.25	0.26	0.26
Phytase[e]	0.02	0.02	0.02	0.02
Liquid lactose[b]	–	2.50	5.00	10.00
Total	100	100	100	100
Calculated nutrient analysis[f]				
Standard ileal digestible lysine, %	0.75	0.75	0.75	0.75
ME, kcal/kg	3,322	3,311	3,300	3,292
NE, kcal/kg	2,490	2,476	2,462	2,448
CP, %	16.7	16.7	16.6	16.5
Ca, %	0.53	0.53	0.54	0.54
P, %	0.37	0.38	0.39	0.40
Available P, %	0.14	0.15	0.16	0.17
Lactose, %	–	0.90	1.90	2.80

[a]Phase 2 diet was fed from d 19 to 36 in pelleted form.

[b]LL= Liquid lactose (SweetLac63; Westway Feed Products, Tomball, TX).

[c]Diets were formulated with consideration of increased moisture content provided by LL and molasses. Concentration of diet components were initially decreased to allow for moisture loss during the pellet cooling process. Item (%) represents the percentage of each ingredient that was added to the mixer.

[d]VTM = vitamin and trace mineral premix, which provide per ton of premix: 8,000,000 IU vitamin A, 1,500,000 IU vitamin D, 40,000 IU vitamin E, 1,000 mg vitamin K, 30 mg B12, 30,000 mg Niacin, 20,000 mg pantothenic acid, 5,000 mg riboflavin, 200 mg biotin, 1,000 mg folic acid, 2,000 mg pyridoxine, 125 ppm Zn, 125 ppm Fe, 22 ppm Mn, 15 ppm Cu, 0.60 ppm I, 0.30 ppm Se. Vitamin concentrations are expressed on a per lb of product basis; whereas mineral concentrations are expressed on a total percentage of premix basis.

[e]RONOZYME HiPhos 2,700 provided 443 phytase units (FYT)/kg with a release of 0.11, 0.10, and 0.09 % of available P, respectively, for each phase.

[f]The calculated nutrient composition is estimated on the diets after pelleting with 90% DM.

Cary, NC) with pen as experimental unit. Dietary treatments were used as a fixed effect. Location block within group was used as a blocking factor and considered a random effect. Treatment means were separated using LSMEANS statement of SAS. In addition, data were analyzed for linear and quadratic effects of increasing LL concentrations. Results from experiment were considered significant at $P < 0.05$ and a marginal significance between $P > 0.05$ and $P \leq 0.10$.

RESULTS

Experiment 1

There was one batch of the experimental diets pelleted with each phase pelleted on a different day. Results of diet analysis were similar to formulated values with moisture content of the treatment diets corresponding with the ingredient inclusion (Table 6). Hot pellet temperature and production rate decreased ($P < 0.05$) when 10 LL was added to the diet when compared with the control, with 5 LL and 9.4 M treatments being intermediate (Table 7). Percent fines decreased ($P < 0.05$) from the control to 9.4 M added to the diet, with 5 LL and 10 LL being intermediate. Standard PDI increased ($P < 0.05$) with 9.4 M in the diets, when compared with the control, with 5 LL and 10 LL being intermediate. For the Holmen 60 s, PDI increased ($P < 0.05$) with 5 LL, 10 LL, and 9.4 M added to the diet with no differences among the 10 LL and 9.4 M treatments. For Holmen 120 s, PDI were least ($P < 0.05$) for control followed by 5 LL, 10 LL, and 9.4 M.

From d 0 to 7, there were no overall treatment effects on ADG or ADFI. Pigs fed the control and 5 LL had decreased ($P < 0.05$) G:F compared with pigs fed 10 LL and 9.4 M (Table 8). From d 7 to 21, there were no differences in ADG or G:F. Pigs fed 10 LL had increased ($P < 0.05$) ADFI compared with the control with the 5 LL and 9.4 M treatments having an intermediate effect. From d 21 to 33 (all

Table 5. Diet composition, phase 3 (as-is basis)[a]

Item	Control	2.5 LL[b]	5.0 LL	7.5 LL
Ingredient, %[c]				
Corn	69.20	68.53	67.83	67.11
Soybean meal, dehull, sol extr	8.85	9.11	9.38	9.67
Dried distillers grains with solubles	20.00	20.37	20.76	21.16
Limestone, ground	1.10	1.12	1.14	1.16
Sodium chloride	0.35	0.36	0.36	0.37
L-Lys-HCL	0.24	0.24	0.25	0.25
VTM Premix[d]	0.25	0.25	0.26	0.26
Phytase[e]	0.02	0.02	0.02	0.02
Liquid lactose[b]	–			
Total	100	100	100	100
Calculated analysis[f]				
Standard ileal digestible lysine, %	0.66	0.66	0.66	0.66
ME, kcal/kg	3,331	3,320	3,309	3,298
NE, kcal/kg	2,510	2,496	2,482	2,468
CP, %	15.60	15.60	15.50	15.40
Ca, %	0.45	0.46	0.46	0.47
P, %	0.36	0.37	0.38	0.39
Available P, %	0.13	0.14	0.15	0.17
Lactose, %	–	0.90	1.90	2.80

[a]Phase 3 diet was fed from d 36 to 53 in pelleted form.

[b]LL= Liquid lactose (SweetLac63; Westway Feed Products, Tomball, TX).

[c]Diets were formulated with consideration of increased moisture content provided by LL and molasses. Concentration of diet components were initially decreased to allow for moisture loss during the pellet cooling process. Item (%) represents the percentage of each ingredient that was added to the mixer.

[d]VTM = vitamin and trace mineral premix, which provide per ton of premix: 8,000,000 IU vitamin A, 1,500,000 IU vitamin D, 40,000 IU vitamin E, 1,000 mg vitamin K, 30 mg B12, 30,000 mg Niacin, 20,000 mg pantothenic acid, 5,000 mg riboflavin, 200 mg biotin, 1,000 mg folic acid, 2,000 mg pyridoxine, 125 ppm Zn, 125 ppm Fe, 22 ppm Mn, 15 ppm Cu, 0.60 ppm I, 0.30 ppm Se. Vitamin concentrations are expressed on a per lb of product basis; whereas mineral concentrations are expressed on a total percentage of premix basis.

[e]RONOZYME HiPhos 2,700 provided 443 phytase units (FYT)/kg with a release of 0.11, 0.10, and 0.09% of available P, respectively, for each phase.

[f]The calculated nutrient composition is estimated on the diets after pelleting with 90% DM.

pigs fed a common diet), pigs previously fed the 9.4 M treatment had decreased ($P < 0.05$) ADG compared with those fed control and the 10 LL diets.

From d 0 to 21, there were no treatment effects on ADG or G:F. Pigs fed the control diet had decreased ($P < 0.05$) ADFI compared with those fed 10 LL with 5 LL and 9.4 M being intermediate (Table 8). From d 0 to 33, ADFI increased ($P < 0.05$) for 10 LL inclusion when compared with all diets. Overall, there were no treatment effects on ADG or G:F.

Fecal consistency scores at d 7 were also firmer ($P < 0.05$) in pigs fed 9.4 M compared with pigs fed the control or 5 LL treatments with pigs fed the 10 LL treatment being intermediate. (Table 9). There were no treatment effects on d 14 fecal consistency scores.

Experiment 2

Two batches of the experimental diets were pelleted thus an average value was established for chemical analysis of experimental diets. Results of diet analysis were similar to formulated values with increasing moisture content higher inclusions of LL (Table 10). Increasing LL in the diet improved (linear, $P < 0.01$) pellet PDI for all methods (Table 11).

For d 0 to 53, there were no differences in ADG, ADFI, or final BW in pigs fed increasing levels of LL (Table 12). There was a tendency (quadratic, $P = 0.07$) for G:F to increase in pigs fed increasing levels of LL. Pigs fed 2.5 LL diet had the numerically greatest G:F. Additionally, there were no differences in HCW, yield, fat, or muscle measurements between pigs fed dietary treatments (Table 13).

In conclusion, pellet quality was improved by increasing LL in the diet. There was a tendency for improved feed efficiency, with pigs fed diets containing 2.5 LL having optimal feed efficiency.

DISCUSSION

Lactose is essential in post weaning pig diets for up to 3 weeks after weaning (Grieshop et al., 2001).

Table 6. Chemical analysis of experimental diets (as-fed)[a]

	Phase 1				Phase 2				Phase 3
Item, %	Control	50 LL[b]	100 LL	94 M[c]	Control	50 LL	100 LL	94 M	Common diet
Dry matter	90.1	89.7	88.1	88.5	91.2	89.6	88.2	88.6	88.3
Crude protein	236	232	233	238	235	249	23.9	23.4	22.2
Crude fiber	3.2	3.0	3.3	2.9	3.9	4.3	4.3	4.3	4.2
Sugar[d]	11.6	12.6	12.6	14.4	13.1	11.0	11.1	12.9	4.3
Crude fat	4.1	4.5	4.5	4.0	4.7	4.8	4.6	4.7	3.1
Ash	7.4	7.9	7.7	7.7	7.8	7.2	8.0	7.6	5.8
Calcium	0.9	1.0	0.9	0.9	1.2	1.0	1.0	0.9	0.7
Phosphorus	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7
Non-fiber carbohydrate	55.1	54.0	52.7	53.0	55.2	52.7	51.6	53.0	57.3
Non-structural carbohydrate	11.6	12.6	12.6	14.4	13.1	11.0	11.1	12.9	4.3

[a]LL product was obtained by Westway Feed Products (Tomball, TX).
[b]LL = liquid lactose (SweetLac 63; Westway Feed Products, Tomball, TX).
[c]M = Sugar cane molasses.
[d]Ethanol soluble.

Table 7. Pellet quality of experimental diets

Item	Control	5 LL[a]	10 LL	9.4 M[b]	SEM	Probability, $P<$
Hot pellet temperature, °C[c]	69.44[b]	62.6[ab]	59.36[a]	63.56[ab]	7.993	0.0417
Production rate, (metric tons/h)[d]	0.44[b]	0.43[ab]	0.39[a]	0.41[ab]	0.016	0.0300
Fines, %[e]	6.96[c]	3.93[b]	3.01[b]	1.84[a]	1.134	0.0128
PDI, %[f]	93.04[a]	96.08[bc]	96.99[cd]	98.17[d]	1.134	0.0128
Holmen 60, %[g]	87.10[a]	91.63[b]	94.80[cd]	96.43[d]	1.214	0.0012
Holmen 120, %	74.70[a]	83.45[b]	90.65[c]	93.65[d]	2.146	0.0003

[a]LL = liquid lactose (SweetLac 63; Westway Feed Products, Tomball, TX).
[b]M = Sugar cane molasses.
[c]Hot pellet temperatures were recorded with a single probe digital thermometer at the center of collected sample.
[d]Production rate was measured as the weight of the pellets collected divided by 60 s.
[e]Percentage fines were determined using a number 6 screen (3.35 mm).
[f]A Seedboro Pellet Durability Tester was used to determine PDI. Pellets were tumbled in 500-g samples of feed for 10 min, then, using a number-6 screen (3.35 mm) fines were sifted from the sample.
[g]Holmen NHP100 (Tekpro Limited, Norfolk, UK) process was run at 60 and 120 s as an additional PDI parameter, completed at Kansas State University.
[a–d]Means within a row with different superscripts differ ($P < 0.05$).

Table 8. Effects of LL and molasses in nursery pig diets on growth performance[a–c]

Item	Control[d]	5 LL[e]	10 LL[f]	9.4 M[g]	SEM	Probability, *P*<
d 0–7						
ADG, g	127	133	162	150	24.8	0.168
ADFI, g	196	202	207	193	18.7	0.656
G:F	0.604[a]	0.622[a]	0.736[b]	0.753[b]	0.067	0.022
d 7–21						
ADG, g	243	270	264	262	17.8	0.718
ADFI, g	371[a]	417[ab]	454[b]	405[ab]	19.5	0.046
G:F	0.652	0.645	0.584	0.649	0.036	0.390
d 21–33						
ADG, g	460[a]	449[ab]	476[a]	410[b]	25.6	0.062
ADFI, g	674	692	704	633	32.8	0.192
G:F	0.683	0.652	0.675	0.643	0.017	0.296
d 0–21						
ADG, g	204	224	230	225	17.1	0.577
ADFI, g	312[a]	345[ab]	372[b]	334[ab]	17.0	0.064
G:F	0.645	0.646	0.617	0.671	0.034	0.600
d 0–33						
ADG, g	297	306	320	292	13.2	0.499
ADFI, g	444[a]	471[ab]	492[b]	443[a]	15.8	0.109
G:F	0.667	0.649	0.650	0.660	0.017	0.807
BW, kg						
d 7	7.62	7.64	7.85	7.79	0.089	0.148
d 21	11.02	11.42	11.55	11.46	0.300	0.588
d 33	16.54	16.81	17.26	16.38	0.461	0.535

[a]A total of 194 nursery pigs (DNA 241 × 600; initially 6.7 ± 0.4 kg at 27 d of age) were used with 8 replicate pens per treatment and 4–7 pig per pen. Research was conducted at Texas A&M University, O.D. Butler Animal Science Teaching and Research Center, Nutrition and Physiology Center (College Station, TX).

[b]Experimental diets were fed from d 0 to 21 followed by a common diet d 21–33.

[c]LL product was obtained by Westway Feed Products (Tomball, TX).

[d]Control Diet with 19.1% total sugars from whey powder and whey permeate (85% lactose).

[e]5% SweetLac; 12% of the total sugars replaced by 5% LL (44.7% total sugars).

[f]10% SweetLac; 24% total sugars replaced by 10% LL (44.7% total sugars).

[g]94 Molasses; 24% total sugars with 94 molasses.

[h]Sugar cane molasses.

[a–c]Means within a row with different superscripts differ ($P < 0.05$).

Table 9. Fecal consistency and DM, % on d 7 and 14 of experimental diets[a]

Item	Control	5 LL[b]	10 LL	9.4 M[c]	SEM	Probability, *P*<
Score						
d7	3.86[a]	4.00[a]	3.51[ab]	3.15[b]	0.213	0.030
d14	3.88	4.05	3.95	3.72	0.123	0.297
DM, %						
d7	16.74	16.87	19.04	20.35	2.120	0.482
d14	15.49	13.99	14.89	16.89	0.997	0.246

[a]Smiricky (2002); 1 = hard, dry pellet; 2 = firm, formed stool; 3 = soft, moist stool that retains shape; 4 = soft, moist stool that assumes shape of container, and 5 = water liquid that can be poured.

[b]LL = SweetLac (SweetLac 63; Westway Feed Products, Tomball, TX).

[c]M = Sugar cane molasses.

[a–c]Means within a row with different superscripts differ ($P < 0.05$).

Nessmith et al. (1997) found that the lactose fraction of dried whey can be replaced by crystalline lactose and deproteinized whey in nursery pig diets; however, these replacements must be of equal quality to the dried whey. Touchette et al. (1995) also observed that crystalline lactose was an acceptable

Table 10. Chemical analysis of experimental diets (as-fed)[a]

Item, %	Phase 1				Phase 2				Phase 3			
	Control	25 LL[b]	50 LL	75 LL	Control	25 LL	50 LL	75 LL	Control	25 LL	50 LL	75 LL
Moisture	11.40	11.70	11.93	12.23	10.23	10.97	11.33	11.17	10.90	11.37	11.77	12.07
Dry matter	88.60	88.30	88.07	87.77	89.77	89.03	88.67	88.83	89.10	88.63	88.23	87.97
Crude protein	17.60	18.19	18.67	19.10	16.76	16.65	17.63	17.42	15.15	15.07	15.35	15.45
Crude fiber	3.57	3.89	3.96	3.69	4.13	3.68	3.46	3.20	3.39	3.46	3.15	3.23
Sugar[c]	4.61	5.30	5.61	6.14	4.31	4.25	4.64	5.33	3.47	4.05	4.73	5.31
Crude fat	3.02	3.19	3.51	3.34	3.58	3.68	3.43	3.43	3.73	3.42	3.32	3.34
Ash	4.47	4.46	5.02	5.29	4.28	4.14	4.60	4.79	3.50	3.79	3.77	3.80
Calcium	0.66	0.64	0.74	0.65	0.62	0.50	0.49	0.57	0.42	0.38	0.36	0.40
Phosphorus	0.44	0.46	0.48	0.49	0.41	0.41	0.42	0.44	0.40	0.41	0.42	0.42
Non-fiber carbohydrate	63.50	62.45	60.85	60.04	65.17	64.58	63.03	63.24	66.73	66.33	65.76	65.36
Non-structural carbohydrate	4.61	5.30	5.61	6.14	4.31	4.25	4.64	5.33	3.47	4.05	4.73	5.31

[a]Samples were analyzed at Cumberland Valley Analytical Services (Hagerstown, MD).

[b]LL = Liquid lactose (SweetLac 63; Westway Feed Products, Tomball, TX.

[c]Ethanol soluble.

alternative to dried whey in nursery pig diets. Most common sources of lactose include whey, whey permeate, deproteinized whey, and crystalline lactose (Dritz et al., 1993; Nessmith et al., 1997; Owen et al., 1993; Touchette et al., 1995). In the experiment conducted herein, LL was evaluated to be a replacement to dried whey and whey permeate. The control diets were formulated to have 18.7% and 10.1% lactose or total sugars for phase 1 and 2 diets, respectively. In our experiment, 12.8% and 25.1% of the total sugar in phase 1 diets and 22.8% and 44.5% of the total sugar in phase 2 diets were replaced using 5 LL and 10 LL, respectively. Because LL is a majority lactose with a minority of other sugars, this resulted in the final 5 LL and 10 LL diets having 97.3% lactose with 2.7% other sugars and 95.2% lactose with 4.8% other sugars for phase 1 and 96.0% lactose with 4% other sugars and 91.1% lactose with 8.9% other sugars for phase 2, respectively. In this experiment it was demonstrated that up to 10 LL could be added to the diet without negatively influencing growth performance.

Alternate sugar sources have been proven to partially replace up to 45% of dietary lactose in nursery pig diets using candy co-products (Guo et al., 2015). In previous experiments, candy co-products increased intakes due to added sweetness from sucrose compared with lactose. Mavromichalis et al. (2001) found that diets with molasses composed of sucrose can effectively replace the lactose portion of nursery pig diets. When pigs were fed the 9.4 M treatment growth performance was intermediate compared with all other diets with firmer fecal consistency at d 0–7. When pigs were fed the common diet after being fed the 9.4 M treatment, ADG decreased. This decrease in ADG can potentially be explained by the numerical decrease in ADFI for pigs previously fed 9.4 M. This response differs from previous research (Mavromichalis et al., 2001) and it is inconclusive what led to the response in the experiment conducted herein.

To pellet the current experimental diets with 10 LL and 9.4 M, the process was done without the addition of steam due to mill limitations of die plugging. Therefore, no steam was added while pelleting any diets to remain consistent. This could potentially lead to concerns with scorching or pellet hardness with the control pellets. Pellet hardness was not directly measured in this experiment. However, the control diets had decreased PDI compared with LL and 9.4M. Further research is needed to determine the response to these treatments when conditioned to a common moisture content prior to pelleting.

Table 11. Pellet quality of experimental diets

Item, %	Control	2.5 LL[b]	5 LL[c]	7.5 LL[d]	SEM	Contrast P-value[a] Linear	Quadratic
Fines[e,f]	3.96	2.57	3.22	1.83	1.481	0.251	0.997
PDI[g]	93.18	94.74	95.83	96.72	0.817	0.005	0.687
Holmen, 60 s[h]	85.65	89.96	91.94	92.40	1.357	0.002	0.173
Holmen, 120 s[i]	67.17	77.06	81.84	83.32	2.771	0.001	0.146

[a]Results from experiment were considered significant at $P < 0.05$ and a marginal significance between $P > 0.05$ and $P \leq 0.10$.

[b–d]Phases contain increasing amounts of SweetLac (SweetLac 63; Westway Feed Products, Tomball, TX).

[e]Percentage fines were determined using a number 6 screen (3.35 mm).

[f]Percentage Fines = (Weight of tumbled and sifted pellet (g)-Weight of sifted pellet (g)) / Weight of sifted pellet (g).

[g]PDI was determined by tumbling 500-g samples of feed for 10 min and then using a number-6 screen (3.35 mm) to sift off the fines.

[h]Holmen NHP pellet durability tester (Tekpro Limited, Norfolk, UK) at 60 s.

[i]Holmen NHP pellet durability tester (Tekpro Limited, Norfolk, UK) at 120 s.

Pellet quality is affected by where moisture is added during processing in the form of steam conditioning or directly to the mixer. Pellet quality, as measured by percent fines and PDI, was improved when LL or molasses were added to the diet compared with the control. Mash moisture in the form of steam conditioning involves using steam to raise temperature and moisture levels prior to the mash reaching the pellet die. It is well known that high quality steam is needed to achieve desired pellet quality (Skoch et al., 1981). Wet steam has less sensible heat and requires a larger amount of steam to achieve target conditioning temperature (Gilpin et al., 2002). Previous research explored the effects of adding water to the mixer to create a mash moisture between 12% and 15% which showed a positive relationship with mash moisture in the mixer and PDI (Greer and Fairchild, 1999). Gilpin et al. (2002) found that 14% mash moisture allows feed manufacturers to maximize pellet quality. In the experiment herein, the addition of moisture from adding 5 LL, 10 LL, and 9.4 M treatments to the mixer were 1.59%, 3.17%, and 2.43%, respectively. In addition to added moisture, binding properties of sugars might occur via recrystallization of sugars or the formation of a glass after cooling (Thomas et al., 1998). Prolonged exposure to heat in the pellet die has been suggested to increase “cook” and pellet durability (Fahrenholz, 2012). The combinations of heat, hydration, and shear during pelleting disrupts starch molecules causing gelatinization, improving pellet durability, and digestibility (Grieshop et al., 2001). In the experiment herein, increasing LL in the diet improved pellet quality with all measures of PDI. Inclusion of sugar increases the resistance at the feed-die interface (Thomas et al., 1998). To pellet the current experimental diets with 10 LL and 9.4 M, the process was done without the addition of steam due to mill limitations of die plugging. Therefore, no steam was added while pelleting any diets to remain consistent. However, in this experiment, adding liquid ingredients in the mash provided lubrication to the die keeping hot pellet temperature from increasing.

Advantages to pelleting swine diets include improved animal performance through increased bulk density, and reduced selective feeding, reduced feed waste, and decreases in harmful pathogens present (Behnke, 1994). This comes with reduced production rate and increased cost associated with pelleting diets. Previous research demonstrated that pigs fed the pelleted diets had a 3% greater ADG and 5% improvement in G:F compared with those fed mash diets (Stark et al., 1994). However, these improvements diminished as pellet quality decreased. Literature suggests that pelleting diets improves G:F but there has been varying effects on ADFI and ADG in nursery pigs (Johnston et al. 1999; Paulk et al., 2015; Traylor et al., 1996). Researchers attribute growth performance improvements to increased nutrient digestibility and decreased feed wastage (Wondra et al., 1995). However, pellet quality is also a contributing factor. Stark et al. (1994) conducted an experiment to determine pellet quality effects on finishing pig growth performance. Compared with those fed the meal diet, pigs fed the pelleted diet had improved ADG of 3% and G:F of 5%. Feed efficiency improvements for pigs fed pelleted diets were lost as the pellet fines increased. In the experiment herein, ADG was not effected with only a marginal significance for G:F improvement.

Pelleting swine diets has been shown to improve growth performance and decrease feed wastage (Stark, 1994). Stark (1994) observed that nursery pigs fed pelleted diets had a 10% and 14% improvement in ADG and G:F, respectively, compared with

Table 12. Effects of increasing LL in finishing pig diets on growth performance[a,b]

						Contrast *P*-value[c]	
Item	Control	2.5 LL[d]	5 LL[e]	7.5 LL[f]	SEM	Linear	Quadratic
BW, kg							
d 0	53.9	53.8	53.9	54.2	1.04	0.831	0.817
d 53	120.0	118.5	120.0	118.7	2.031	0.697	0.958
d 0–53							
ADG, kg	1.21	1.22	1.23	1.21	0.029	0.852	0.517
ADFI, kg	3.31	3.18	3.26	3.27	0.104	0.694	0.231
G: F	0.367	0.385	0.379	0.372	0.011	0.791	0.070

[a]A total of 289 finishing pigs (DNA 241 × 600; initially 54 kg) were used with 6 replicate pens per treatment and 8 to 14 pigs per pen. Research was conducted at Texas A&M University, O.D. Butler Animal Science Teaching and Research Center, Nutrition and Physiology Center (College Station, TX).

[b]Three phases of experimental diets were fed from d 0 to 19, d 19 to 36 and d 36 to 53 for Phases 1, 2 and 3, respectively.

[c]Results from experiment were considered significant at $P < 0.05$ and a marginal significance between $P > 0.05$ and $P \leq 0.10$.

[d–f]Phases contain increasing amounts of LL (SweetLac 63; Westway Feed Products, Tomball, TX).

Table 13. Carcass composition characteristics of pigs fed LL[a]

						Contrast *P*-value[b]	
Item	Control	2.5 LL[c]	5 LL[d]	7.5 LL[e]	SEM	Linear	Quadratic
Hot carcass Wt, kg[f]	91.46	90.90	92.18	90.37	1.855	0.737	0.640
Yield, %[g]	75.31	75.77	75.68	74.99	0.662	0.616	0.241
Fat, cm							
First rib	1.53	1.53	1.53	1.52	0.070	0.832	0.817
Last rib	0.93	0.89	0.90	0.89	0.050	0.500	0.658
Last lumbar vertebra	0.90	0.85	0.91	0.87	0.042	0.755	0.889
10th rib fat thickness	0.74	0.72	0.72	0.71	0.028	0.408	0.871
Muscle							
Loin eye area, cm^2	49.94	49.94	49.81	49.35	1.355	0.656	0.809
Fat free lean, %	53.68	53.90	53.70	53.99	0.464	0.630	0.910
Muscle score	2.32	2.34	2.34	2.33	0.057	0.935	0.730

[a]Pigs were shipped on d 53 to Union Slaughter (Del Rio, Texas) to determine carcass measurements and characteristics.

[b]Results from experiment were considered significant at $P < 0.05$ and a marginal significance between $P > 0.05$ and $P \leq 0.10$.

[c–e]LL = SweetLac (SweetLac 63; Westway Feed Products, Tomball, TX).

[f]Yield percentage = HCW/live weight × 100.

[g]Percent of Fat Free Lean (%FFL) = (8.558+ [0.456 × HCW] – [21.896×10th RFT] + [3.005×LEA]/HCW) × 100.

pigs fed mash diets. De Jong et al. (2012) found that pigs fed pelleted diets had improved ($P < 0.03$) ADG, F/G, and caloric efficiency on an ME or NE basis. Nemechek et al. (2015a) observed nursery pigs fed mash diets tended to have decreased ADG and G:F compared with pigs fed pellets, with an intermediate response in ADG and G:F in those fed poor-quality pellets. However, the benefits of pelleting come with an increase in diet cost. Although pellet quality as measured by PDI was improved in the current experiment and the amount of fines at the feeder were reduced, it did not result in improved growth performance. It is hypothesized that no difference in performance was observed because all treatments had less than 10% fines at the feeder.

Many researchers have not found differences in carcass characteristics when compared with pigs fed mash diets (De Jong et al., 2016; Nemechek et al., 2016; Paulk and Hancock, 2015). There were no differences in HCW, fat, and muscle measurements between pigs fed dietary treatments in the current study.

CONCLUSION

Hot pellet temperature and production rate decreased when 10 LL was added to the diet, with 5 LL and 9.4 M treatments having intermediate effects. The addition molasses to nursery pig diets had an improvement on PDI and decrease in percent fines without negatively impacting pig performance with LL at 5 LL and 10 LL, respectively, having intermediate effects.

Growth performance and fecal consistency of nursery pigs was not negatively affected with inclusion of LL or molasses in the diet. However, the current study would suggest that increasing LL to up to 10% of the diet would increase nursery pig feed intake from d 0 to 21 post weaning. The data suggests that ADFI may contribute to ADG improvements. Although, pigs fed up to 10% LL had numerically the heaviest BW, these differences were not significant. Therefore, ingredient and diet cost should be considered when selecting the appropriate sugar combination in the diet formula.

In conclusion, pellet quality was improved with addition of LL in the diet. There was a marginal significance for improved feed efficiency, with pigs fed diets containing 2.5% LL. Optimal LL inclusion should be determined with the economic consideration.

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