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THE EFFECT OF FEED INGREDIENTS ON FEED MANUFACTURING AND GROWTH PERFORMANCE OF PIGS

by

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B.S., California State University, Fresno, 2002
M.S., Kansas State University, 2004

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Animal Science and Industry
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2007

Abstract

Two experiments evaluated effects of glycerol on pellet mill production and pig performance. In Exp. 1, increasing glycerol increased (quadratic; $P < 0.01$) pellet durability index through 9% added glycerol. Adding glycerol decreased (linear; $P > 0.01$) production energy (kWh/t). In Exp. 2, pigs were fed one of seven diets with no added soy oil or glycerol (control); the control diet with 3 or 6% added soy oil, 3 or 6% added glycerol, and 6 or 12% additions of a 50:50 soy oil/glycerol blend in a 26-d growth assay. Adding glycerol improved ($P < 0.01$) pellet durability compared to soy oil and the soy oil/glycerol blend treatments. Pigs fed glycerol had increased (linear, $P < 0.03$) ADG. Adding soy oil, glycerol, or the soy oil/glycerol blend resulted in similar final BW. Two experiments evaluated the effects of glycerol as a replacement for lactose on pellet mill production and nursery pig performance. In Exp. 1, pigs were fed one of ten treatments that included 0, 3.6, or 7.2% lactose or 0, 3.6, or 7.2 % glycerol and fed in either meal or pelleted form. Pellet durability index increased (linear; $P < 0.01$) with added lactose and glycerol. Glycerol decreased (linear; $P < 0.01$) production energy (kWh/t). There was a tendency ($P < 0.06$) for an inclusion level × diet form (meal or pellet) interaction observed for ADG. Pigs fed the pelleted diets containing the 7.2% glycerol inclusion had decreased ADG compared to all other treatments. In Exp. 2, pigs were fed one of fourteen diets that included 0, 3.6, 7.2, or 10.8% lactose or 0, 3.6, 7.2, or 10.8 % glycerol and fed in either meal or pelleted form. There was no effect ($P < 0.27$) of diet form, inclusion level, or source on ADG or ADFI. Eight experiments evaluated the effect of ingredients on the flow ability of ground corn. Flow ability of feed improved with added glycerol, especially when added to meal diets containing hammer mill ground corn. Specialty protein ingredients in powder form reduce flow

ability, while fine lactose sources improved flow ability. Granulated ingredients improved flow ability.

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Dedication

Mom and Dad, thank you for believing in me, supporting me, letting me take risks, and following my passion. Kansas has come and gone, can you believe it. It's now time for Pennsylvania. I just keep getting farther and farther away from home. Know that I love you, miss you, and appreciate all you have done for me. I have accomplished my goals because you have helped to make me the person I am. You are my foundation. Thank you.

Preface

Chapters have been written in several different journal formats for publication purposes.

CHAPTER 1 - Effect of glycerol on pellet mill production and nursery pig growth performance

ABSTRACT: The objective of this study was to determine the effects of diets containing glycerol on pellet mill production efficiency and nursery pig growth performance. In a pilot study, increasing glycerol (0, 3, 6, 9, 12, and 15%) in a corn-soybean meal diet was evaluated for pellet mill production efficiency and pellet quality. All experimental diets were steam conditioned to 65.5°C and pelleted through pellet mill equipment with a die that had an effective thickness of 31.8 mm and holes 3.96 mm in diameter. Each diet was replicated by manufacturing a new batch of feed 3 times. Increasing glycerol increased (quadratic; $P < 0.01$) pellet durability index through 9% with no further benefit thereafter. The addition of glycerol decreased (linear; $P > 0.01$) production rate (t/h) and production energy (kWh/t). Next, 182 pigs (initial BW 10.9 kg) were fed one of seven corn-soybean meal-based diets with no added soy oil or glycerol (control), the control diet with 3 or 6% added soy oil, 3 or 6% added glycerol, and 6 or 12% additions of a 50:50 soy oil/glycerol blend in a 26-d growth assay. Pigs were blocked by initial BW and randomly allotted to treatment with five or six pigs/pen and five pens/treatment. Pellet mill production data and pig growth performance data were collected. The addition of glycerol lowered ($P < 0.01$) delta temperature, amperage, motor load, and production efficiency (kWh/t). The addition of glycerol improved ($P < 0.01$) pellet durability compared with soy oil and the soy oil/glycerol blend treatments. Pigs fed increasing glycerol had increased (linear, $P < 0.03$) ADG. Average daily gain tended to increase with increasing soy oil (quadratic; $P < 0.07$) or the soy oil/glycerol blend (linear; $P < 0.06$), but there were no differences in final BW. Adding glycerol to the diet did not influence G:F compared with the control. Gain:feed tended to increase with

increasing soy oil (quadratic, $P < 0.06$) or the soy oil/glycerol blend (linear, $P < 0.01$). Nitrogen digestibility tended ($P < 0.07$) to decrease in pigs fed glycerol compared with pigs fed the soy oil treatments. Apparent digestibility of GE tended ($P < 0.08$) to be greater in the pigs fed soy oil compared with pigs fed the soy oil/glycerol blends. These data indicate that up to 6% glycerol can be included in a diet alone or in combination with soy oil. Adding glycerol before pelleting improved pellet quality and decreased energy cost in processing. Adding glycerol resulted in an increase in ADFI, while adding soy oil or the soy oil/glycerol blend resulted in improved G:F.
Key words: Feed manufacturing, glycerol, pelleting, pig

INTRODUCTION

The Renewable Fuel Standards Program, which is part of the Energy Policy Act of 2005, mandates that a minimum level of renewable fuels be consumed in the United States each year. In 2006, the minimum biofuels consumption level was set at four billion gallons, with expectations of doubling consumption by 2012. Biodiesel is an alternative to petroleum-based diesel fuel and consists of monoalkyl esters formed through an alcohol-based catalyzed reaction of triglycerides in oils and fats. According to the National Biodiesel Board, there are currently 105 biodiesel production facilities operating in the United States, and 77 facilities are in the planning or construction stage. If all of these facilities are realized, the estimated U.S. biodiesel production capacity will exceed 2.5 billon gallons (USEPA, 2007). This level of production will yield nearly 1.3 million tons of glycerol, the primary co-product of the biodiesel production process. Glycerol constitutes approximately 10 to 11% of a typical triglyceride. Purification of crude glycerol to a chemically pure substance results in a valuable industrial chemical. However, it is costly, and the glycerol market is already saturated, thus the price of glycerol continues to

decline. This trend will continue as more and more biodiesel production facilities begin production. Consequently, there has been much interest in using crude glycerol as a feed ingredient in animal diets to reduce diet costs. Lammers et al. (2007a) fed 10% crude glycerol to pigs with little to no adverse effects on ADG, carcass composition, or meat quality. However, little is known about glycerol's nutritional value or how it affects feed quality and feed processing efficiency. Therefore, the objective of these trials was to evaluate the effects of glycerol on pelleting efficiency and growth performance of nursery pigs.

MATERIALS AND METHODS

Exp. 1 Pilot Study

Experiment 1 included six treatments that were corn-soybean meal-based swine grower diets formulated to contain 0, 3, 6, 9, 12, and 15% crude glycerol (Table 1).

Diets were manufactured and pelleted, and data were collected at the KSU Grain Science Feed Mill. All diets were steam conditioned to 65.5°C by adjusting the steam flow rate and pelleted using a California Pellet Mill (Master Model HD, Series 2000 Crawfordsville, IN) equipped with a die that had an effective thickness of 31.8 mm and holes 3.96 mm in diameter. Pellets were cooled using a double-pass perforated deck cooler (Wenger Manufacturing, Sabetha, KS). All experimental runs were performed using a warm die. Samples of corn, soybean meal (SBM), diet mash (before conditioning), and pellets were collected for each experimental run. Particle size of corn and SBM used in the diets was determined, 667 and 1,025 μm respectively (ASAE Standard 319.1; 1983).

Pellet mill production data was collected on all diets. Each diet run was replicated by manufacturing a new batch of feed three times. Pellet mill electrical consumption, production rate, hot-pellet temperature, motor load, feeder rate, conditioning rate, and pellet durability were

measured. Conditioning temperature was measured through a stiff thermocouple placed in the steam of the conditioned mash as it moved from the conditioner to the pellet die. To measure hot pellet temperature, pellets were collected in a foam insulated pail, and the temperature was taken using a stiff thermocouple after the temperature reading reached equilibrium. Conditioning temperature and production rate were held constant. Pelleting efficiency, expressed as kilowatthours per metric ton (kWh/t), was determined from changes voltage and amperage meter readings. Standard and modified pellet durability index (PDI) was evaluated for each experimental run using 500 g of cold pellets (ASAE Standard S269.3; 2003).

Exp. 2

The experimental protocol used in this study was approved by the Kansas State University Institutional Animal Care and Use Committee. Prior to starting the trial, pigs were fed standard SEW and transition diets (DeRouchey et al, 2007). A total of 182 nursery pigs (21 ± 3 d of age and initial BW 11.0 ± 1.3 kg) were used in a 26-d growth assay. Pigs were blocked by initial weight and randomly allotted to one of seven dietary treatments with five or six pigs/pen and five pens/treatment. Experimental diets included a control with no added soy oil or glycerol, the control diet with 3 or 6% added soy oil, the control diet with 3 or 6% added glycerol, and the control with 6 or 12% of a 50:50 soy oil glycerol blend (Table 2). All diets were formulated to the same lysine to ME ratio. All diets were formulated using the ME energy value of corn (3420 kcal/kg) as the ME value for glycerol. Similar to Exp. 1, pellet mill production data was collected during diet manufacturing.

Pigs were housed in an environmentally controlled nursery at the KSU Segregated Early-Weaning Facility. Each pen was 1.2 × 1.2-m and contained one self-feeder and one cup waterer to provide ad libitum access to feed and water. Pigs were weighed and feed disappearance was

determined on d 0, 8, 19, and 26 to determine ADG, ADFI, and G:F. From d 14 to 21, an indigestible marker (Cr_2O_3) was added at 0.5% to all treatment diets. On d 19, grab samples of feces were collected from a minimum of two pigs/pen. Concentrations of Cr (Kimura and Miller, 1957; Williams et al., 1962), DM and N (AOAC, 1995; method 930.15 and 990.03) and GE using adiabatic bomb calorimetry (Parr Instruments, Moline, IL) in the feces and diet were determined to calculate apparent digestibility of DM, N, and GE.

Statistical Analysis

Statistical analysis was performed using MIXED procedures (SAS Inst. Inc., Cary, NC.). Data from Exp. 1 were analyzed as a completely randomized block design, with batch as the experimental unit. Contrasts for linear, quadratic, and cubic polynomial effects of glycerol were conducted. In Exp. 2, pellet mill production data were analyzed as a completely randomized block design, with batch as the experimental unit. Contrasts included linear and quadratic effects of soy oil, glycerol, and the blend of soy oil and glycerol. Contrasts between soy oil, glycerol, and the soy oil/glycerol blend production data were conducted. Pig growth data were analyzed as a completely randomized block, with initial weight as the blocking factor. Pen was the experimental unit for growth and digestibility data analyses. Contrasts included linear and quadratic effects of soy oil, glycerol, and the blend of soy oil and glycerol. In addition, contrasts between the mean of pigs fed soy oil, glycerol, and the soy oil/glycerol blend were conducted.

RESULTS AND DISCUSSION

Exp. 1 Pilot Study

There was no difference ($P = 0.11$) in conditioning temperature, indicating that conditioning temperature was indeed held constant at 65.5 °C (Table 3). Hot pellet temperature decreased (linear; $P < 0.03$). Delta temperature also decreased (linear; $P < 0.02$). Delta

temperature should follow a similar pattern to hot pellet temperature, as delta temperature is calculated as the difference between hot pellet temperature and conditioning temperature. There was no difference ($P > 0.84$) in voltage (V) with increasing glycerol. Amperage (Amps) decreased (linear; $P < 0.01$) with the addition of glycerol. The greatest decreases occurred with the addition of 3% glycerol and again at the 12% glycerol additions; however, all diets with glycerol had lower amps than the control. Motor load also decreased (linear; $P < 0.01$) with the addition of glycerol. Voltage, amps, and motor load are measures of energy usage by the pellet mill. Amperage and motor load values follow similar trends. Amperage measures the electrical current pulled by the pellet mill, and motor load measures energy required by the pellet mill to rotate the pellet die. Motor load will increase with increased friction in the die and decrease as friction is decreased in the die. The decrease in motor load when glycerol was added to the diet indicated a decrease in pellet die friction.

Pellet durability index also increased (quadratic; $P < 0.01$) through 9% added glycerol for both the standard and modified PDI, resulting in a 2 to 6% improvement in PDI compared with the control. These results differ from previous research reporting broiler diets pelleted with 10% glycerol had visibly poorer pellet quality; however, PDI was not measured in that study (Cerrate et al., 2006). The addition of glycerol decreased (linear; $P > 0.01$) production rate (t/h). An attempt was made to hold production rate constant. Due to the lack of information available with glycerol on pellet quality, adjustments were continuously made to steam pressure to hold conditioning temperature constant. These slight adjustments may have caused a decreased in production rate. However, the steam pressure was determined in the pilot study to ensure fewer adjustments in the following studies. The total production energy (kWh/t) also decreased (linear; $P < 0.01$) with added glycerol. A reduction or improvement in production efficiency (kWh/t)

will result in a direct economical savings for the feed mill by reducing total energy usage of the pellet mill.

Exp. 2

Similar to Exp. 1, a conditioning temperature of 65.5 °C was targeted for pelleting. There was a tendency ($P < 0.08$) for the 3% soy oil, 3% glycerol, and the 6% blend treatments to have a higher conditioning temperature of 66.2 °C compared to all other treatments at 65.9 °C (Table 4). Although statistically significant, this small difference is of little practical importance. Hot pellet temperature and delta temperature decreased (linear; $P < 0.01$) with the addition of soy oil and both decreased (quadratic; $P < 0.03$) with the addition of glycerol or the soy oil/glycerol blend. A lower delta temperature is an indication of reduced die friction. As die friction increases, delta temperature would be expected to increase. The greatest improvement occurred with the initial liquid addition of glycerol or the soy oil/glycerol blend, only slightly decreasing further with the addition of either the 6% glycerol or the 12% blend addition. Hot pellet temperature and delta temperature had a greater decreased ($P < 0.01$) for the soy oil/glycerol blend when compared with soy oil and glycerol additions. The 6% soy oil/glycerol blend had a greater decrease in hot pellet temperature than either the addition of 6% soy oil or 6% glycerol, indicating that glycerol and soy oil combined can reduce die friction more than when either ingredient is added to the diet individually. There was no difference ($P > 0.10$) in hot pellet temperature and delta temperature between the soy oil and glycerol treatments, indicating that glycerol had a lubrication effect on the pellet die similar to that of soy oil.

There was no difference ($P > 0.11$) in V among any of the treatments. Amperage and motor load decreased (linear; $P < 0.01$) with the addition of soy oil and the soy oil/glycerol blend. Adding glycerol decreased (quadratic; $P < 0.05$) amperage and motor load with the

greatest decrease occurring with the addition of 3% glycerol to the diet, with little to no additional improvement with the 6% glycerol addition. The addition of the soy oil/glycerol blend had the greatest decrease in motor load (linear; $P < 0.01$) and amperage (quadratic; $P < 0.03$), with the greatest decrease occurring with the 12% soy oil/glycerol blend. The addition of soy oil and glycerol resulted in increased ($P < 0.01$) amperage and motor load compared with the blend, indicating that the soy oil/glycerol blend had greatest reduction in pellet die friction.

Pellet quality was not affected ($P > 0.26$) with the addition glycerol; however, 6% added glycerol diet had the highest PDI compared with all other treatments. Soybean oil is typically added to nursery diets to aid in pelleting and reduced diet friction; however, the addition of soy oil results in poor quality pellets (Briggs et al., 1999). As expected, the addition of soy oil decreased (quadratic; $P < 0.01$) PDI. The soy oil/glycerol blend decreased (linear; $P < 0.01$) PDI; however, PDI of the blend was greater ($P < 0.01$) than the PDI of soybean oil alone. The addition of the 6% and 12%, soy oil/glycerol blends resulted in a 5 to 37% improvement in PDI compared with the addition of 3 or 6% soy oil alone. Similar to Exp. 1, the addition of glycerol improved PDI. The addition of glycerol improved ($P < 0.01$) PDI by an average of 15% when compared with the soy oil/glycerol blends when compared with the soy oil treatments. These data indicate that glycerol added to a diet before pelleting, with or without added soy oil, will result in an improved PDI.

Diets containing soy oil to the diet had increased ($P > 0.01$) production rate compared with diets containing the addition of glycerol. Production rate (t/h) was not different between glycerol and the soy oil/glycerol blend or the control, and the soy oil/glycerol blend was not different from any of the other treatments. Total production energy, (kWh/t) improved (quadratic; $P < 0.01$) with the addition of soy oil, glycerol, or the soy oil/glycerol blend.

However, the greatest benefit occurred with the initial addition of any of the liquid sources. The control diet used the greatest ($P < 0.01$) total production energy (kWh/t), and the soy oil/glycerol blend had the largest improvement, requiring the least total production energy. Added dietary glycerol had poorer ($P < 0.01$) total production energy (kWh/t) compared with soy oil but was intermediate to the control and the soy oil/glycerol blend. The potential energy savings by the feed mill results from an improvement in total production efficiency (kWh/t), demonstrating the importance of liquid addition to meal diets before pelleting.

Several studies have evaluated the use of glycerol in swine and poultry diets (Bernal et al., 1978; Kijora et al., 1995; Simon et al., 1996). However, the majority of these studies used a glycerol by-product of biodiesel production from rapeseed oil. The glycerol used in these studies should be similar to the glycerol used in our studies; however, the impurities will vary between sources. In our study pigs were fed a glycerol source containing 90.7% glycerol and 136 ppm methanol, from a Midwestern USA biodiesel plant (Minnesota Soybean Processors, Brewster, MN).

For overall (d 0 to 26) pig growth performance, pigs fed diets containing soy oil had a tendency for increased (quadratic, $P = 0.07$) ADG, with the greatest improvement occurring with the addition of 3% soy oil and no additional improvement observed with the addition of 6% soy oil (Table 5). Pigs fed diets with increasing glycerol had increased (linear, $P = 0.03$) ADG. In addition, pigs fed increasing soy oil/glycerol blend had a tendency for increased (linear, $P = 0.06$) ADG. Pigs fed increasing soy oil had increased ($P < 0.03$) ADFI compared to pigs fed the soy oil/glycerol blend treatments. The ADFI of pigs fed the soy oil treatments were intermediate between the pigs fed glycerol and the pigs fed the soy oil/glycerol blends. Pigs fed diets with increasing glycerol had a tendency for increased ($P < 0.08$) ADFI compared with pigs fed diets

containing soy oil. The pigs fed diets with increasing soy oil had increased (linear, $P < 0.01$) G:F. The greatest improvement occurring with the 3% added soy oil, with no additional improvement with the addition of 6% soy oil. Increasing glycerol had no effect on G:F, but pigs fed the soy oil/glycerol blend had increased (linear, $P < 0.01$) G:F. Pigs fed the diets containing soy oil had greater ($P < 0.03$) G:F compared with pigs fed diets containing glycerol. Pigs fed the soy oil/glycerol blends had improved ($P < 0.03$) G:F compared with pigs fed the soy oil diets. The G:F of pigs fed soy oil was intermediate to the pigs fed glycerol and pigs fed the soy oil/glycerol blends. Pigs fed diets with increasing soy oil had a tendency for increased (quadratic, $P < 0.07$) final BW. Pigs fed increasing glycerol had increased (linear, $P < 0.03$) final BW and the pigs fed the soy oil/glycerol blend had a tendency for increased (linear, $P < 0.06$) final BW.

Fecal excretion of DM tended ($P < 0.07$) to increase in pigs fed glycerol compared with pigs fed soy oil or pigs fed the soy oil/glycerol blends (Table 6). Percentage of N digestion tended ($P < 0.07$) to decrease in pigs fed diets containing glycerol compared with pigs fed diets containing soy oil. Previous research by Simon et al. (1997) showed N retention in broilers increased as glycerol inclusion increased up to 20%. However, subsequent work reported no effect on N retention when glycerol is increased in a diet (Simon et al., 1997). Gross energy intake tended ($P < 0.10$) to decrease in pigs fed the soy oil/glycerol blends compared with pigs fed glycerol. This was expected, as pigs fed the soy oil/glycerol blend had decreased ADFI compared with pigs fed glycerol. Fecal excretion of GE tended ($P < 0.10$) to decrease in pigs fed the soy oil/glycerol blend compared with pigs fed glycerol. Gross energy retention tended ($P < 0.08$) to increase in pigs fed soy oil compared with pigs fed the soy oil/glycerol blends. Pigs fed the added soy oil treatments tended ($P < 0.07$) to have increased GE digestibility compared with pigs fed glycerol.

Previous research conducted by Lammers et al. (2007a) showed the addition of glycerol to swine diets did not affect growth performance. Our data differ slightly from these previous data, as glycerol tended to increase ADFI compared with pigs fed the control diets. Lammers et al. (2007a) demonstrated no difference in ADG, ADFI, G:F, or carcass composition in pigs fed glycerol at 5 or 10% inclusions. Lammers et al. (2007b) estimates that the apparent DE of crude glycerol in a nursery pigs diet is 3,386 ± 149 kcal/kg. This energy value of crude glycerol for nursery pigs is approximately 96% of the DE value for corn (3525 kcal/kg; NRC, 1998). Additional research also shows glycerol can be used as a feed ingredient without altering growth performance criteria in both swine and poultry (Bernal et al., 1978; Kijora et al., 1995; Simon et al., 1996). All of these studies focused on using glycerol as an energy source for replacing cereal grains in the diet. It appears that glycerol can replace cereal grains in swine diets without negatively affecting ADG. These studies indicate that adding glycerol may have positive implications on ADFI. Additional research is needed to further evaluate glycerol in swine diets, glycerol storage and oxidation. Further evaluation of glycerol product variability, storage of feed manufactured with glycerol also needs to be conducted.

Adding glycerol to a corn-soybean meal diet prior to pelleting appears to be a management strategy that can enhance the overall pelleting process by improving total production efficiency (kWh/t) and pellet quality without compromising growth performance. These data indicate that glycerol can be included in a swine diet up to 6% to improve the pelleting process without reducing pig performance.

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Table 1.1 Composition of diets (Exp. 1; as-fed basis)

Table 1. Composition of diets (Exp. 1; as-fed basis)

	Added glycerol, %					
Item	0	3	6	9	12	15
Corn	63.54	60.30	57.06	53.82	50.57	47.33
Soybean meal, 46.5% CP	32.57	32.81	33.06	33.30	33.54	33.78
Crude glycerol[1]	---	3.00	6.00	9.00	12.00	15.00
Monocalcium phosphate, 21% P	1.65	1.65	1.65	1.65	1.65	1.65
Limestone	0.95	0.95	0.95	0.95	0.95	0.95
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[2]	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.30	0.30	0.30	0.30	0.30	0.30
DL-methionine	0.12	0.12	0.12	0.12	0.12	0.12
L-threonine	0.12	0.12	0.12	0.12	0.12	0.12
Total	100.0	100.0	100.0	100.00	100.0	100.0
Calculated analysis						
Total lysine, %	1.38	1.38	1.38	1.38	1.38	1.38
ME, kcal/kg	3,299	3,299	3,299	3,299	3,299	3,299
CP, %	21.0	20.8	20.7	20.5	20.3	20.2
Ca, %	0.80	0.80	0.80	0.80	0.80	0.80
P, %	0.75	0.74	0.73	0.73	0.72	0.71
Available P, %	0.42	0.42	0.42	0.42	0.42	0.42
Lysine:calorie ratio, g/Mcal	3.79	3.79	3.79	3.79	3.79	3.79

[1]Contained 90.7% glycerin and 136 ppm methanol. Diets were formulated using an ME value of 3,420 kcal/kg for glycerol.

[2]Provided (per kilogram of complete diet): 11,025 IU of vitamin A; 1,654 IU of vitamin D; 44 IU of vitamin E; 4.4 mg of vitamin K (as menadione dimethylpyrimidinol bisulfate); 55.1 mg of niacin; 33.1 mg of pantothenic acid (as d-calcium pantothenate); 9.9 mg of riboflavin; 0.044 mg of vitamin B_{12}; 16.5 mg of Cu; 165.4 mg of Fe; 39.7 mg of Mn; 0.30 mg of Se; 165.4 mg of Zn; and 0.30 mg of I.

Table 1.2 Composition of diets (Exp. 2; as fed basis)

Table 2. Composition of diets (Exp. 2; as-fed basis)

		Soy oil, %		Glycerol, %		Blend, %[1]	
Item	Control	3	6	3	6	6	12
Corn	53.71	47.92	42.55	50.44	47.18	44.67	35.91
Soybean meal, 46.5% CP	41.98	44.62	46.86	42.23	42.47	44.86	47.54
Crude glycerol[2]	---	---	---	3.00	6.00	3.00	6.00
Soybean oil	---	3.00	6.00	---	---	3.00	6.00
Monocalcium phosphate, 21% P	1.60	1.71	1.81	1.61	1.61	1.71	1.77
Limestone	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.30	0.30	0.30	0.30	0.30	0.30	0.30
DL-methionine	0.11	0.13	0.15	0.12	0.13	0.14	0.16
L-threonine	0.10	0.12	0.13	0.11	0.11	0.12	0.13
Antibiotic[4]	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis							
Total lysine, %	1.38	1.45	1.50	1.38	1.38	1.45	1.51
ME, kcal/kg	3,283	3,429	3,574	3,283	3,283	3,429	3,574
CP, %	20.9	21.7	22.3	20.8	20.6	21.6	22.1
Analyzed CP, %[5]	19.5	21.7	22.2	20.5	19.8	20.4	21.7
Ca, %	0.79	0.81	0.84	0.79	0.79	0.81	0.83
P, %	0.74	0.76	0.78	0.73	0.72	0.76	0.76
Available P, %	0.41	0.44	0.46	0.41	0.41	0.44	0.45
Lysine:calorie ratio, g/Mcal	3.81	3.82	3.81	3.81	3.81	3.82	3.82

[1]Contained a 50:50 blend of soy oil and glycerol.
[2]Provided 90.7 % glycerin and contained 136 ppm methanol. Diets were formulated using an ME value of 3,420 kcal/kg for glycerol.
[3]Provided (per kilogram of complete diet): 11,025 IU of vitamin A; 1,654 IU of vitamin D; 44 IU of vitamin E; 4.4 mg of vitamin K (as menadione dimethylpyrimidinol bisulfate); 55.1 mg of niacin; 33.1 mg of pantothenic acid (as d-calcium pantothenate); 9.9 mg of riboflavin; 0.044 mg of vitamin B_{12}; 16.5 mg of Cu; 165.4 mg of Fe; 39.7 mg of Mn; 0.30 mg of Se; 165.4 mg of Zn; and 0.30 mg of I.
[4]Provided 140 g of Neomycin sulfate and 140 g Oxytetracycline HCl per ton of complete feed.
[5]Analyzed CP content (AOAC, 1995; method 990.03).

Table 1.3 Effects of added glycerol on production efficiency, Exp. 1

Table 3. Effects of added glycerol on production efficiency, Exp. 1[1,2]

	Added glycerol, %							Contrast, *P* <	
Item	0	3	6	9	12	15	SE	Linear	Quadratic
Conditioning temperature, °C	65.4	65.6	65.7	65.7	65.4	65.5	0.20	0.97	0.16
Hot pellet temperature, °C	76.1	75.4	74.5	76.6	72.2	72.8	1.20	0.03	0.50
Delta temperature, °C	10.5	9.6	8.6	10.6	6.4	7.0	1.14	0.02	0.60
Voltage, V	250.4	250.0	248.9	252.3	250.1	250.3	1.94	0.84	0.95
Amperage, amps	29.3	25.2	23.6	22.9	19.5	18.1	0.85	0.01	0.45
Motor load, %	54.7	45.7	41.7	41.0	33.3	30.3	2.00	0.01	0.42
Pellet durability									
Standard, %	90.1	92.1	93.5	95.7	94.9	94.7	0.73	0.01	0.01
Modified, %	87.5	89.4	91.2	93.9	92.3	91.6	1.14	0.01	0.02
Production rate, t/hr	1.20	1.15	1.13	1.00	0.99	1.00	0.04	0.01	0.25
Total energy, kWh/t	8.41	7.51	7.12	7.81	6.72	6.12	0.28	0.01	0.63

[1]All diets were corn-soybean meal-based swine grower diets.
[2]Each experimental diet was replicated by manufacturing a new batch of feed three times.

Table 1.4 Effects of added soy oil and glycerol on production efficiency, Exp. 2

Table 4. Effects of added soy oil and glycerol on production efficiency, Exp. 2[1,2]

									Contrasts, $P <$[4]					
		Soy oil,%		Glycerol, %		Blend[3], %			Soy oil		Glycerol		Blend	
Item	Control	3	6	3	6	6	12	SE	L	Q	L	Q	L	Q
Conditioning temperature, °C	65.8	66.3	65.9	66.3	65.9	66.2	65.8	0.20	0.71	0.07	0.82	0.06	0.94	0.07
Hot pellet temperature, °C[5,6]	77.3	74.2	71.6	74.1	73.4	71.1	69.3	0.72	0.01	0.71	0.01	0.11	0.01	0.01
Delta temperature, °C[5,6]	11.3	7.7	5.5	7.6	7.3	4.7	3.3	0.71	0.01	0.33	0.01	0.03	0.01	0.01
Voltage, V	247.7	249.9	245.8	248.4	250.1	249.4	249.3	1.53	0.40	0.11	0.28	0.82	0.45	0.62
Amperage, amps[5,6]	28.3	23.0	19.6	23.7	22.8	20.9	16.0	0.52	0.01	0.10	0.01	0.01	0.01	0.03
Motor load, %[5,6]	53.6	45.9	34.6	42.9	41.6	36.3	26.9	2.22	0.01	0.41	0.01	0.05	0.01	0.09
Pellet durability														
Standard, %[5,6,7]	92.6	81.6	58.3	94.7	95.5	85.4	80.3	1.84	0.01	0.01	0.26	0.79	0.01	0.52
Modified, %[5,6,7]	89.9	74.7	40.0	91.9	92.2	78.3	65.8	1.80	0.01	0.01	0.39	0.69	0.01	0.82
Production rate, t/hr[7]	1.25	1.28	1.27	1.23	1.25	1.27	1.24	0.02	0.29	0.19	0.95	0.16	0.44	0.16
Total energy, kWh/t[5,6,7]	8.36	6.71	5.69	7.17	6.81	6.01	4.89	0.16	0.01	0.04	0.01	0.01	0.01	0.01

[1]All diets were formulated to the same lysine to ME ratio.
[2]Each experimental diet was replicated by manufacturing a new batch of feed three times; each run consisted of 340 kg batches.
[3]Addition of 50% soy oil and 50% glycerol.
[4]Linear (L) and quadratic (Q) contrasts.
[5]Contrast soy oil vs. blend, $P < 0.01$.
[6]Contrast glycerol vs. blend, $P < 0.01$.
[7]Contrast soy oil vs. glycerol, $P < 0.01$.

Table 1.5 Effects of soy oil and glycerol on growth performance of nursery pigs

Table 5. Effects of soy oil and glycerol on growth performance of nursery pigs[1]

									Contrasts, P <[3]					
		Soy oil, %		Glycerol, %		Blend, %[2]			Soy oil		Glycerol		Blend	
Item	Control	3	6	3	6	6	12	SE	L	Q	L	Q	L	Q
D 0 to 26														
ADG, g	528	571	554	568	570	555	564	18.2	0.18	0.07	0.03	0.23	0.06	0.58
ADFI, g[4,5]	782	782	761	809	814	757	762	33.9	0.52	0.72	0.32	0.69	0.55	0.60
G:F[5,6]	0.68	0.73	0.73	0.70	0.70	0.73	0.74	0.01	0.01	0.06	0.12	0.31	0.01	0.09
Final wt, kg	24.7	25.8	25.4	25.8	25.8	25.4	25.7	0.97	0.17	0.07	0.03	0.23	0.06	0.61

[1]A total of 182 pigs (initial BW 11.0 ± 1.3 kg) were used in a 26 d growth assay. Pigs were blocked by initial weight and randomly allotted to one of seven dietary treatments with five or six pigs/pen and five pens/treatment.
[2]Contained a 50:50 blend of soy oil and glycerol.
[3]Linear (L) and quadratic (Q) contrasts.
[4]Contrast soy oil vs. glycerol, $P < 0.08$.
[5]Contrast glycerol vs. blend , $P < 0.03$.
[6]Contrast soy oil vs. glycerol, $P < 0.03$.

Table 1.6 Effects of soy oil and glycerol on apparent digestibility in nursery pigs

Table 6. Effects of soy oil and glycerol on apparent digestibility in nursery pigs[1]

									Contrasts, P <[3]					
		Soy oil, %		Glycerol, %		Blend, %[2]			Soy oil		Glycerol		Blend	
Item	Control	3	6	3	6	6	12	SE	L	Q	L	Q	L	Q
DM intake, g/d	689	700	677	711	709	670	671	30.0	0.78	0.63	0.62	0.74	0.69	0.79
Fecal excretion of DM, g/d[4,5]	102	100	98	110	110	93	101	6.09	0.68	1.00	0.30	0.63	0.91	0.31
DM retention, g/d	586	600	580	601	600	576	572	25.4	0.86	0.59	0.71	0.78	0.69	0.93
DM digestibility, %	85.1	85.7	85.5	84.4	84.4	86.0	85.0	0.46	0.50	0.41	0.35	0.58	0.99	0.12
N intake, g/d	26.8	28.3	26.6	27.3	27.4	25.2	27.3	1.43	0.92	0.36	0.76	0.89	0.79	0.31
Fecal excretion of N, g/d	4.8	4.6	4.2	4.8	5.0	3.8	4.6	0.47	0.35	0.82	0.79	0.88	0.79	0.13
N retention, g/d	22.0	23.9	22.4	22.5	22.4	21.4	22.6	1.04	0.81	0.21	0.81	0.83	0.71	0.48
N digestibility, %[5]	82.2	84.0	84.5	82.8	82.2	84.5	83.0	0.93	0.10	0.60	0.97	0.64	0.56	0.11
GE intake, mcal/d[6]	2.85	2.97	2.96	2.98	2.98	2.76	2.77	0.12	0.58	0.66	0.51	0.69	0.64	0.72
Fecal excretion of GE, mcal/d[5]	0.42	0.42	0.40	0.45	0.45	0.39	0.42	0.03	0.66	0.80	0.39	0.62	1.00	0.35
GE retention, mcal/d[7]	2.44	2.56	2.56	2.52	2.53	2.37	2.36	0.11	0.44	0.67	0.55	0.74	0.58	0.86
GE digestibility, %[5]	85.3	86.0	86.5	85.0	85.0	86.0	85.0	0.56	0.16	0.83	0.71	0.81	0.64	0.21

[1]Fecal collections occurred on d 19 and minimum of two pigs/pen were collected for apparent digestibility assays.
[2]Contained a 50:50 blend of soy oil and glycerol.
[3]Linear (L) and quadratic (Q) contrasts.
[4]Contrast glycerol vs. blend, $P < 0.05$.
[5]Contrast soy oil vs. glycerol, $P < 0.07$.
[6]Contrast glycerol vs. blend, $P < 0.10$.
[7]Contrast soy oil vs. blend, $P < 0.08$.

CHAPTER 2 - Influence of glycerol as a substitute for lactose on pellet mill production and nursery pig growth performance

ABSTRACT: The objective of these trials was to evaluate glycerol as a replacement for lactose in nursery pigs. In Exp. 1, a total of 350 weanling pigs (8-d after weaning with initial BW of 6.3 ± 0.9 kg) were used in a 14-d growth assay. Pigs were fed one of ten diets that included 0, 3.6, or 7.2% lactose or 3.6, or 7.2 % crude glycerol and either meal or pelleted form. Pellet mill production data was collected for all pelleted diets. Hot pellet temperature increased (linear; $P < 0.01$) with increasing dietary lactose, and decreased (linear; $P < 0.01$) with increasing glycerol. Delta temperature increased (linear; $P < 0.01$) with increasing lactose and decreased (linear; $P < 0.01$) with increasing glycerol. Pellet durability index increased (linear; $P < 0.01$) with the addition of either lactose or glycerol. The addition of lactose increased (linear; $P > 0.01$) production rate (t/h), and the addition of glycerol had no effect on production rate compared to the control. Increasing glycerol improved (linear; $P < 0.01$) total production efficiency (kWh/t). From d 0 to 14, there was a tendency ($P < 0.06$) for an inclusion level × diet form (meal or pellet) interaction for ADG and an inclusion level × diet form and diet form × source (lactose or glycerol) interaction ($P < 0.03$) observed for ADFI. Pigs fed the pelleted diets containing 7.2% glycerol had decreased ADG and ADFI compared to all other treatments. Pigs fed the pelleted glycerol diets had reduced ADFI compared to pigs fed the pelleted lactose diets and pigs fed diets containing either lactose or glycerol fed in meal form. In Exp. 2, 375 weanling pigs (initial BW 6.7 ± 1.1 kg) were used in a 14-d growth assay. Pigs were fed one of fourteen diets that included 0, 3.6, 7.2, or 10.8% lactose or 3.6, 7.2, or 10.8 % crude glycerol and fed in either meal

or pelleted form. From d 0 to 14, there was no effect ($P > 0.27$) of diet form (meal or pellet), inclusion level (0, 3.6, 7.2, or 10.8%), or ingredient source (lactose or glycerol) on ADG or ADFI. Adding glycerol to a corn-soybean meal based diet before pelleting improved pellet durability index, and decreased energy cost. However, due to the lack of lactose response, it is unknown if glycerol can replace lactose in weanling pig diets.

Key words: Feed manufacturing, glycerol, lactose, pelleting, pig

INTRODUCTION

Crude glycerol is a by-product of the biofuels industry, and it is currently being evaluated as a feed ingredient is swine diets. Lammers et al. (2007b) fed wean-to-finish pigs 10% crude glycerol with no adverse effects on ADG, carcass composition, or meat quality. Lammers (2007b) estimated that the apparent DE of crude glycerol for nursery pig diet is 3,386 ± 149 kcal/kg. Groesbeck et al. (2007) showed that adding glycerol to a corn-soybean meal diet prior to pelleting appears to be a management strategy to enhance the overall pellet process by improving total production efficiency (kWh/t) and improving pellet quality without compromising growth in nursery pig performance. While the majority of glycerol research has focused on its use as a replacement for cereal grains or fat in the diet, it is believed that it can replace lactose in nursery pig diets. Lactose is a simple carbohydrate that is easily digested by nursery pigs and utilized as an energy source; therefore, included in starter diets. The increased variability and cost of lactose sources has stimulated the evaluation of less expensive ingredients. Previous research has demonstrated that glycerol added in nursery pig diets could stimulate ADFI similar to pig fed diets containing lactose (Groesbeck, 2007). Glycerol is also converted to dihydroxyacetone phosphate and used as an intermediate in two of the fundamental metabolic pathways, glycolsis and gluconeogensis. Dihydroxyacetone phosphate is coverted into a

pyruvate molecules and utilized to yield energy in the Kreb's cycle. This indicated that glycerol could potential be utilized by the pig as an energy source, and may be a replacement for lactose in nursery pig diets. Therefore, the objective of these trials was to evaluate the effects of glycerol on pelleting efficiency and growth performance of nursery pigs.

MATERIALS AND METHODS

General

The experimental protocol used in this study was approved by the Kansas State University Institutional Animal Care and Use Committee. Pigs were housed in an environmentally controlled nursery at the Kansas State University Segregated Early-Weaning Facility. Each pen was 1.2 × 1.2-m and contained one self-feeder and one cup waterer to provide ad libitum access to feed and water. Initial temperature of the nursery was maintained at 32°C for the first week and decreased approximately 2°C each week thereafter. All pigs used in these experiments were 21 ± 3 days of age at weaning and randomly allotted to dietary treatments in a complete randomized design. All diets were formulated to meet or exceed the NRC (1998) nutrient requirements, and diets were formulated using an ME value of 3,420 kcal/kg for glycerol. Pigs were fed a glycerol source containing 90.7% glycerol and 136 ppm methanol, from a Midwestern USA biodiesel plant (Minnesota Soybean Processors, Brewster, MN).

Exp. 1

A total of 350 weanling pigs (8 d post weaning, initial average BW of 6.3 ± 0.9 kg) were used in a 14-d growth assay. Prior to starting on trial, pigs were fed standard SEW and transition diets. On d 8 post-weaning, pigs were weighed and pens were alloted to one of seven dietary treatments with five pigs/pen and seven pens/treatment. Experimental diets included ten treatments that were corn-soybean meal-based diets formulated to contain 0, 3.6, or 7.2% lactose

or 3.6, or 7.2 % crude glycerol and fed in either meal or pelleted form (Table 1). Diets were manufactured, pelleted, and pellet mill production data collected at the Kansas State University Grain Science Feed Mill. Pelleted diets were steam conditioned to 65.5°C by adjusting the steam flow rate and pelleted using a California Pellet Mill (Master Model HD, Series 2000 Crawfordsville, IN) equipped with a die that had an effective thickness of 31.8 mm and holes 3.96 mm in diameter. Pellets were cooled using a double-pass perforated deck cooler (Wenger Manufacturing, Sabetha, KS). All experimental runs were performed using a warm die. Samples of corn, soybean meal (SBM), diet mash (before conditioning), and pellets were collected for each experimental run. Particle size was determined for the corn and SBM used, 786 μm and 1,045 μm respectively (ASAE Standard 319.1; 1983).

Pellet mill production data was collected on all diets, and each diet run was replicated by manufacturing a new batch of feed three times. Pellet mill electrical consumption, production rate, hot-pellet temperature, motor load, feeder rate, conditioning rate, and pellet durability index (PDI) were measured. Conditioning temperature was measured through a stiff thermocouple that was placed in the steam of the conditioned mash as it moved from the conditioner to the pellet die. To measure hot pellet temperature, pellets were collected in a foam insulated pail, and the temperature was taken using a stiff thermocouple after the temperature reading reached equilibrium. Attempts were made to hold conditioning temperature and production rate constant. Pelleting efficiency, expressed as kilo-watt hours per metric ton (kWh/t), was determined from voltage and amperage meter readings and production rate. Standard and modified PDI was evaluated for each experimental run using 500 g of cooled pellets (ASAE Standard S269.3; 2003). Pigs were weighed and feed disappearance was determined on d 0, 7, and 14 to determine ADG, ADFI, and G:F. All diets contained 0.4% Cr_2O_3, an indigestible marker. On d 12, grab

samples of feces were collected from a minimum of two pigs/pen. Concentrations of Cr (Kimura and Miller, 1957; Williams et al., 1962), DM and N (AOAC, 1995; method 930.15 and 990.03) and GE using adiabatic bomb calorimetry (Parr Instruments, Moline, IL) in the feces and diet were determined to calculate apparent digestibility of DM, N, and GE.

Exp. 2

A total of 375 weanling pigs (7-d post weaning, initial average BW of 6.7 ± 1.1 kg) were used in a 14-d growth assay. Prior to starting on trial, pigs were fed standard SEW and transition diets (DeRouchey et al., 2007). On d 7 post weaning, pigs were weighed and allotted to one of 14 dietary treatments with five pigs/pen and five or six pens/treatment. Experimental diets were corn-soybean meal-based diets formulated to contain 0, 3.6, 7.2, or 10.8% lactose or 3.6, 7.2, or 10.8 % crude glycerol and fed in either meal or pelleted form (Table 2). Seven diets were manufactured at the Kansas State University Animal Science Feed Mill, with one half of each diet separated and then pelleted at the Kansas State University Grain Science Feed Mill with similar procedures and equipment described as in Exp. 1.

Pigs were weighed and feed disappearance was determined on d 0, 7, and 14 to determine ADG, ADFI, and G:F. All diets included 0.4% Cr_2O_3, an indigestible marker. On d 12, grab samples of feces were collected from a minimum of two pigs/pen. Concentrations of Cr (Kimura and Miller, 1957; Williams et al., 1962), DM and N (AOAC, 1995; method 930.15 and 990.03) and GE using adiabatic bomb calorimetry (Parr Instruments, Moline, IL) in the feces and diet were determined to calculate apparent digestibility of DM, N, and GE.

Statistical Analysis

Statistical analysis was performed using MIXED procedures (SAS Inst. Inc., Cary, NC.). In Exp. 1, pellet mill production data was analyzed as completely randomized block, with batch

as the experimental unit. Linear and quadratic polynomial contrasts were used to determine the effects of increasing lactose and glycerol. For Exp. 1 and 2, pig growth data was analyzed with pen as the experimental unit. Interactions between diet form (meal or pellet), inclusion level (0, 3.6, 7.2, and 10.8%), and ingredient source (lactose or glycerol) were evaluated. For pellet mill production and growth data; contrasts were used to evaluate differences between meal and pelleted treatments, as well as, between lactose and glycerol.

RESULTS

Exp. 1 pellet mill production data

There was no difference ($P > 0.12$) in conditioning temperature, indicating that conditioning temperature was indeed held constant between treatments (Table 3). However, hot pellet temperature increased (linear; $P < 0.01$) with increasing lactose. Delta temperature increased (linear; $P < 0.01$) with increasing lactose. Hot pellet temperature decreased (linear; $P < 0.01$) with increasing glycerol. Delta temperature also decreased (linear; $P < 0.01$) with increasing glycerol. There was no difference ($P = 0.19$) in voltage (V) with increasing lactose or glycerol. Amperage and motor load increased (linear; $P < 0.01$) with increasing lactose, and decreased (linear; $P < 0.01$) with increasing glycerol. Pellet durability index increased (linear; $P < 0.01$) with the addition of both lactose and glycerol for both the standard and modified PDI, with 7.2% glycerol having the highest PDI. The addition of lactose increased (linear; $P > 0.01$) production rate (t/h), while the addition of glycerol had no effect on production rate compared to the control. The addition of lactose had no effect on total production efficiency (kWh/t) compared to the control, while the addition of glycerol decreased (linear; $P < 0.01$) production efficiency.

Exp. 1 growth performance data

Overall (d 0 to 14), there was a tendency ($P = 0.06$) for an inclusion level × diet form (meal or pellet) interaction for ADG (Table 4 and 5). Pigs fed the pelleted diets containing 7.2% glycerol had reduced ADG compared to all other treatments. There was also an inclusion level × diet form and diet form × ingredient source (lactose or glycerol) interaction ($P < 0.03$) observed for ADFI. Pigs fed the pelleted diets containing 7.2% glycerol had reduced ADFI compared to all other treatments. Pigs fed the pelleted glycerol (338 g) diets had decreased ADFI compared to pigs fed the pelleted lactose (397 g) diets and pigs fed diets containing either lactose (395 g) or glycerol (391 g) fed in meal form. All of these interactions were due to the decreased performance of the pigs fed the pelleted diet with 7.2% glycerol. There was no effect ($P > 0.15$) of diet form, inclusion level or ingredient source on G:F.

Apparent digestibility demonstrated a diet form × ingredient source interaction ($P < 0.04$) for DM intake (Table 6 and 7). Pigs fed diets containing glycerol had decreased DM intake and pigs fed pelleted diets with glycerol had lower DM intakes compared to pigs fed glycerol in meal form. This response is primarily a result of the decreased ADFI of the pigs fed 7.2% glycerol in pelleted form. There was an inclusion level × ingredient source interaction ($P < 0.04$) observed for fecal excretion of DM. Pigs fed diets with increasing glycerol had decreased fecal excretion of DM compared to pigs fed increasing lactose. There was a diet form × source, and inclusion level × source ($P < 0.05$) interaction observed for DM retention (g/d). Pigs fed the diets containing lactose in pellet form had increased DM retention compared to the pigs fed diets containing lactose in meal form. Also, pigs fed the diets containing glycerol in meal form had increased DM retention compared to pigs fed the diets with glycerol in pelleted form, and increasing glycerol in pelleted diets decrease DM retention. Overall, DM digestion was greatest

($P < 0.02$) in the pigs fed the diets containing lactose in pelleted form compared to the pigs fed diets with glycerol, and increasing glycerol increased percent DM retained.

Nitrogen intake (g/d) was greater ($P < 0.04$) for the pigs fed the lactose diets compared to the pigs fed the glycerol diets. There was a inclusion level × source × diet form interaction ($P < 0.03$) for N fecal excretion (g/d). Pigs fed the diets with increasing lactose in meal form had increased N fecal excretion, while pigs fed lactose in pelleted form had decreased N fecal excretion. Pigs fed diets with increasing glycerol had decreased N fecal excretion. Overall, N retention (%) increased ($P < 0.01$) in pigs fed pelleted diets. Nitrogen digestibility also increased ($P < 0.04$) in pigs fed diets containing lactose compared with pigs fed diets containing glycerol.

Gross energy intake increased ($P < 0.02$) for pigs fed pelleted diets compared to pigs fed meal diets. Also, GE intake increased ($P < 0.04$) for pigs fed diets containing lactose compared to pigs fed diets with glycerol. Fecal excretion decreased ($P < 0.01$) in pigs fed pelleted diets compared to pigs fed meal diets. Furthermore, there was an inclusion level × source interaction ($P < 0.02$) for GE digestibility. Gross energy digestibility increased as pigs were fed increasing glycerol, but pigs fed diets containing lactose had an increased GE digestibility compared to pigs fed diets containing glycerol.

Exp. 2

From d 0 to 14, there was no effect ($P < 0.27$) of diet form (meal or pellet), inclusion level (0, 3.6, 7.2, or 10.8%), or source (lactose or glycerol) on ADG or ADFI. The was a tendency ($P < 0.06$) for an inclusion level × diet form × source interaction for G:F. The interaction occurred because pigs had the lowest G:F when fed 3.6% lactose in meal diets but 10.8% lactose in the pelleted diets. For pigs fed glycerol, the lowest G:F occurred for pigs fed 10.8% glycerol in the meal diet.

DISCUSSION

Similar to previous studies conducted by Groesbeck et al. (2007), the addition of glycerol to a corn-soybean meal diet prior to pelleting appears to be a management strategy to enhance the overall pellet process, by reducing energy used in pelleting and improving pellet durability index. It appears that the addition of glycerol helps reduce the friction created in the pelleting process resulting in a reduction in energy usage for the pellet mill. Delta temperature should follow a similar pattern to hot pellet temperature as delta temperature is calculated as the difference between hot pellet temperature and conditioning temperature. Voltage, amps, and motor load are measures of energy usage by the pellet mill. Amperage and motor load values follow similar trends. Amperage measures the electrical current pulled from the pellet mill, and motor load energy needed to rotate the pellet die. Motor load will increase with increased friction in the die, and decrease as friction is decreased in the die. The decrease in motor load when glycerol is added to the diet indicates a decrease pellet die friction. A reduction or improvement in production efficiency (kWh/t) will result in a direct economical savings for the feed mill by reducing total energy usage of the pellet mill. Regardless, the use of glycerol in swine diets will depend on its impact on the growth performance of the pigs.

Previous research conducted by Lammers et al. (2007a) supports the addition of glycerol to swine diets, without altering growth performance. Lammers et al. (2007a) demonstrated no difference in ADG, ADFI, G:F or carcass composition in pigs fed glycerol at 5 or 10% inclusions. Lammers (2007b) estimated that the apparent DE of crude glycerol for nursery pig diet is 3,386 ± 149 kcal/kg. Additional research also supports the use of glycerol as a feed ingredient without altering growth performance criteria in both swine and poultry (Bernal et al., 1978; Kijora et al., 1995; Simon et al., 1996). Groesbeck et al. (2007) also demonstrated that glycerol can replace cereal grains or fat at an energy value greater then corn. All of these studies

focused on using glycerol as an energy source for replacing cereal grains in the diet, and have not evaluated if glycerol could replace other ingredients such as lactose.

Lactose is an energy source for the weanling pig. Studies have consistently demonstrated that the addition of lactose results in increased feed intake and growth in early-weaned pigs (Tokach et al., 1989; Nessmith et al 1997), and a study conducted across several universities indicated that the inclusion of up to 7.5% lactose in a late nursery diets results in increased feed intake and growth (Cromwell et al., 2007). While apparent digestibility did improve when lactose was added into the diet, a growth response was not observed. Improvements in growth performance were expected with the inclusion of lactose; however, the lack of response can not be explained. Mahan et al. (2004) indicated that as weanling pigs mature, the positive response to lactose decreases. The pigs in both experiments were weaned onto complex starter diets, by the time the pigs were placed on test (d 7 or 8 post weaning) the response to lactose may have already started to diminish.

Adding glycerol to a corn-soybean meal based diet prior to pelleting is beneficial to the pelleting process by improving pellet quality, and decreasing energy costs. In addition, pigs fed increasing levels of glycerol had equal performance to that of the pigs fed the control, but no improvements were seen.

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Table 2.1 Composition of diets (Exp. 1; as fed basis)

Table 1. Composition of diets (Exp. 1; as fed basis)

		Lactose, %		Glycerol, %	
Item	0	3.6	7.2	3.6	7.2
Corn	63.25	59.36	55.47	59.36	55.47
Soybean meal, 46.5% CP	26.87	27.16	27.45	27.16	27.45
Fish meal	4.50	4.50	4.50	4.50	4.50
Lactose	---	3.60	7.20	---	---
Crude glycerol[1]	---	---	---	3.60	7.20
Soybean oil	1.40	1.40	1.40	1.40	1.40
Monocalcium phosphate, 21% P	0.70	0.70	0.70	0.70	0.70
Limestone	0.35	0.35	0.35	0.35	0.35
Sal	0.25	0.25	0.25	0.25	0.25
Zinc oxide	0.25	0.25	0.25	0.25	0.25
Vitamin premix[2]	0.15	0.15	0.15	0.15	0.15
Trace mineral premix[2]	0.30	0.30	0.30	0.30	0.30
L-lysine HCl	0.14	0.14	0.14	0.14	0.14
DL-methionine	0.14	0.14	0.14	0.14	0.14
L-threonine	0.70	0.70	0.70	0.70	0.70
Antibiotic	1.00	1.00	1.00	1.00	1.00
TOTAL	100.0	100.0	100.0	100.0	100.0
Calculated analysis					
Total lysine, %	1.43	1.43	1.43	1.43	1.43
ME, kcal/kg	3,333	3,333	3,333	3,333	3,333
CP, %	21.2	21.0	20.8	21.0	20.8
Ca, %	0.87	0.87	0.87	0.87	0.87
P, %	0.79	0.78	0.78	0.78	0.78
Available P, %	0.49	0.49	0.49	0.49	0.49
Lysine:calorie ratio, g/Mcal	3.90	3.90	3.90	3.90	3.90

[1]Contained 90.7% glycerin and 136 ppm methanol.

[2]Provided (per kilogram of complete diet): 11,025 IU of vitamin A; 1,654 IU of vitamin D; 44 IU of vitamin E; 4.4 mg of vitamin K (as menadione dimethylpyrimidinol bisulfate); 55.1 mg of niacin; 33.1 mg of pantothenic acid (as d-calcium pantothenate); 9.9 mg of riboflavin; 0.044 mg of vitamin B_{12}; 16.5 mg of Cu; 165.4 mg of Fe; 39.7 mg of Mn; 0.30 mg of Se; 165.4 mg of Zn; and 0.30 mg of I.

Table 2.2 Composition of diets (Exp. 2; as fed basis)

Table 2. Composition of diets (Exp. 2; as fed basis)[1]

		Lactose, %			Glycerol, %		
Item	0	3.6	7.2	10.8	3.6	7.2	10.8
Corn	62.46	58.83	55.21	51.57	58.83	55.21	51.57
Soybean meal, 46.5% CP	27.75	27.75	27.74	27.74	27.75	27.74	27.74
Fish meal	4.50	4.50	4.50	4.50	4.50	4.50	4.50
Lactose	---	3.60	7.20	10.80	---	---	---
Crude glycerol	---	---	---	---	3.60	7.20	10.80
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Monocalcium phosphate, 21% P	1.40	1.40	1.40	1.40	1.40	1.40	1.40
Limestone	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[2]	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.27	0.28	0.29	0.30	0.28	0.29	0.30
DL-methionine	0.11	0.12	0.13	0.15	0.12	0.13	0.15
L-threonine	0.11	0.12	0.13	0.14	0.12	0.13	0.14
Antibiotic	0.70	0.70	0.70	0.70	0.70	0.70	0.70
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis							
Total lysine, %	1.43	1.43	1.43	1.42	1.43	1.43	1.42
ME, kcal/kg	3,332	3,333	3,333	3,333	3,332	3,333	3,333
CP, %	21.4	21.2	20.9	20.6	21.2	20.9	20.6
Ca, %	0.87	0.87	0.87	0.87	0.87	0.87	0.87
P, %	0.80	0.79	0.78	0.77	0.79	0.78	0.77
Available P, %	0.49	0.49	0.49	0.49	0.49	0.49	0.49
Lysine:calorie ratio, g/Mcal	3.90	3.90	3.90	3.90	3.90	3.90	3.90

[1]One half of each batch of feed was pelleted to result in the 14 treatments.

[2]Provided (per kilogram of complete diet): 11,025 IU of vitamin A; 1,654 IU of vitamin D; 44 IU of vitamin E; 4.4 mg of vitamin K (as menadione dimethylpyrimidinol bisulfate); 55.1 mg of niacin; 33.1 mg of pantothenic acid (as d-calcium pantothenate); 9.9 mg of riboflavin; 0.044 mg of vitamin B_{12}; 16.5 mg of Cu; 165.4 mg of Fe; 39.7 mg of Mn; 0.30 mg of Se; 165.4 mg of Zn; and 0.30 mg of I.

Table 2.3 Effects of added lactose or glycerol on pellet mill efficiency

Table 3. Effects of added lactose or glycerol on pellet mill efficiency[1]

							Probability, P <			
		Lactose, %		Glycerol, %			Lactose		Glycerol	
Item	Control	3.6	7.2	3.6	7.2	SE	Linear	Quadratic	Linear	Quadratic
Conditioning temperature, °C	65.7	65.6	65.7	65.4	65.7	0.15	1.00	0.64	0.93	0.12
Hot pellet temperature, °C	74.9	75.7	77.4	73.6	70.2	0.56	0.01	0.56	0.01	0.17
Delta temperature, °C	9.2	10.1	11.6	8.2	4.5	0.52	0.01	0.63	0.01	0.06
Volts	252.2	251.9	248.0	251.7	252.3	2.10	0.19	0.51	0.97	0.82
Amps	21.6	22.2	23.0	19.3	17.2	0.34	0.01	0.79	0.01	0.64
Motor Load, %	33.8	37.1	38.4	30.1	27.1	1.32	0.01	0.40	0.01	0.78
Pellet durability										
Standard, %	86.1	88.5	90.1	89.9	91.8	1.15	0.01	0.75	0.01	0.39
Modified, %	87.0	89.2	90.8	89.8	92.0	1.17	0.01	0.81	0.01	0.80
Production rate, t/hr	0.89	0.93	0.93	0.90	0.88	0.01	0.01	0.04	0.19	0.10
KWH/ton	8.95	8.86	9.04	7.93	7.29	0.20	0.65	0.42	0.01	0.28

[1]Each experimental diet was replicated by manufacturing a new batch of feed three times.

Table 2.4 Effects of lactose or glycerol on growth performance of nursery pigs

Table 4. Effects of lactose or glycerol on growth performance of nursery pigs[1,2]

	Meal					Pellet					
		Lactose, %		Glycerol, %			Lactose, %		Glycerol, %		SE
Item	0	3.6	7.2	3.6	7.2	0	3.6	7.2	3.6	7.2	
D 0 to 14											
ADG, g	281	271	296	262	269	253	281	254	248	212	23.5
ADFI, g	409	383	408	390	392	367	417	377	359	316	23.8
G:F	0.68	0.71	0.72	0.67	0.68	0.68	0.67	0.67	0.69	0.66	0.02

[1]P-values are listed in Table 5.

[2]A total of 350 weanling pigs (8 d post weaning, initial average BW of 6.3 ± 0.9 kg) were used in a 14-d growth assay. Pigs were weighed and pens were allotted in a completely random design to one of seven dietary treatments with five pigs/pen and seven pens/treatment.

Table 2.5 Effects of lactose or glycerol on growth performance of nursery pigs, P values

Table 5. Effects of lactose or glycerol on growth performance of nursery pigs, P values

	Probability, P <										
	Lactose		Glycerol			Meal vs	Lactose vs	Level ×	Level x diet	Diet form x	Level x source x
Item	Linear	Quadratic	Linear	Quadratic	Level	Pellet	glycerol	Source	form	source	diet form
D 0 to 14											
ADG, g	0.64	0.72	0.13	0.93	0.52	0.02	0.02	0.59	0.06	0.42	0.86
ADFI, g	0.80	0.81	0.05	0.01	0.24	0.79	0.01	0.60	0.02	0.03	0.65
G:F	0.63	0.99	0.70	0.93	0.93	0.28	0.32	0.81	0.41	0.15	0.63

Table 2.6 Effects of lactose and glycerol on apparent digestibility in nursery pigs

Table 6. Effects of lactose and glycerol on apparent digestibility in nursery pigs[1,2]

	Meal					Pellet					
		Lactose, %		Glycerol, %			Lactose, %		Glycerol, %		SE
Item	0	3.6	7.2	3.6	7.2	0	3.6	7.2	3.6	7.2	
DM intake, g/d	376	347	371	360	351	339	384	342	324	290	17.9
Fecal excretion of DM, g/d	106	72	78	88	71	59	65	58	62	51	4.32
DM retention, g/d	270	275	293	272	279	280	320	284	262	238	14.9
DM retention, %	71.6	79.6	78.8	75.4	80	82.3	83.1	83.2	81.1	82.6	0.87
N intake, g/d	13.0	11.7	13.0	12.3	11.0	11.7	13.6	11.7	10.4	9.1	1.20
Fecal excretion of N, g/d	5.2	3.9	4.5	4.5	3.2	3.9	4.5	1.9	3.9	3.2	0.63
N retention, g/d	7.8	8.4	9.7	8.4	9.1	9.1	10.4	9.7	9.1	7.1	0.94
N retention, %	61.8	72.3	74.2	69.5	73.2	75.6	76.0	76.6	72.2	74.3	1.63
GE intake, mcal/d	3.58	3.30	3.50	3.42	3.33	3.19	3.57	3.18	3.02	2.71	0.18
Fecal excretion of GE, mcal/d	1.07	0.73	0.78	0.89	0.70	0.57	0.60	0.52	0.58	0.48	0.05
GE retention, mcal/d	2.51	2.56	2.73	2.52	2.63	2.62	2.98	2.66	2.45	2.24	0.15
GE retention, %	70.0	78.0	77.8	73.7	79.1	82.0	83.2	83.6	81.0	82.4	1.00

[1]P-values are listed in Table 7

[2]Fecal collections occurred on d 12 and minimum of two pigs/pen were collected for apparent digestibility assays.

Table 2.7 Effects of lactose and glycerol on apparent digestibility in nursery pigs, P values

Table 7. Effects of lactose and glycerol on apparent digestibility in nursery pigs, P-values

	Probability, P <										
	Lactose		Glycerol								
Item	Linear	Quadratic	Linear	Quadratic	Level	Meal vs Pellet	Lactose vs glycerol	Level x Source	Level x diet form	Diet form x source	Level x source x diet form
DM intake, g/d	0.96	0.58	0.04	0.84	0.23	0.03	0.02	0.61	0.07	0.04	0.41
Fecal excretion of DM, g/d	0.01	0.08	0.01	0.41	0.02	0.01	0.99	0.04	0.60	0.11	0.12
DM retention, g/d	0.36	0.23	0.28	0.98	0.44	0.93	0.01	0.96	0.05	0.04	0.59
DM retention, %	0.01	0.01	0.01	0.24	0.03	0.01	0.02	0.01	0.35	0.88	0.11
N intake, g/d	0.99	0.76	0.06	0.88	0.34	0.24	0.04	0.57	0.34	0.19	0.34
Fecal excretion of N, g/d	0.04	0.55	0.04	0.55	0.03	0.05	0.99	0.99	0.14	0.47	0.03
N retention, g/d	0.17	0.69	0.73	0.55	0.80	0.52	0.09	0.47	0.09	0.23	0.80
N retention, %	0.01	0.14	0.03	0.77	0.07	0.01	0.04	0.46	0.55	0.62	0.94
GE intake, mcal/d	0.81	0.65	0.05	0.91	0.27	0.02	0.04	0.68	0.12	0.07	0.47
Fecal excretion of GE, mcal/d	0.01	0.11	0.01	0.48	0.03	0.01	0.88	0.07	0.90	0.28	0.13
GE retention, mcal/d	0.38	0.29	0.39	0.90	0.56	0.98	0.01	0.90	0.07	0.05	0.69
GE retention, %	0.01	0.01	0.01	0.23	0.01	0.01	0.03	0.02	0.24	0.87	0.10

Table 2.8 Effects of glycerol on growth performance of nursery pigs

Table 8. Effects of glycerol on growth performance of nursery pigs[1]

	Meal							Pellet							
		Lactose, %			Glycerol, %				Lactose, %			Glycerol, %			SE
Item	0	3.6	7.2	10.8	3.6	7.2	10.8	0	3.6	7.2	10.8	3.6	7.2	10.8	
D 0 to 14															
ADG, g	342	296	337	320	323	332	317	335	312	318	325	322	318	331	18.8
ADFI, g	437	416	436	429	425	441	431	427	408	425	450	420	417	413	19.0
G:F	0.78	0.71	0.77	0.75	0.76	0.75	0.73	0.79	0.76	0.75	0.73	0.77	0.76	0.80	0.03

[1]P-vlaues are listed in Table 9.

[2]A total of 375 weanling pigs (7-d post weaning, initial BW 6.7 ± 1.1 kg) were used in a 14-d growth assay. Pigs were allotted completely random to one of 14 dietary treatments with five pigs/pen and five or 5 or 6 pens/treatment

Table 2.9 Effects of glycerol on growth performance of nursery pigs, P values

Table 9. Effects glycerol on growth performance of nursery pigs, P values[1]

	Probability, P <										
	Lactose		Glycerol			Meal vs Pellet	Lactose vs glycerol	Level × Source	Level × diet form	Diet form × source	Level × source × diet form
Item	Linear	Quadratic	Linear	Quadratic	Level						
D 0 to 14											
ADG, g	0.35	0.50	0.35	0.92	0.62	0.92	0.56	0.52	0.52	0.85	0.73
ADFI, g	0.75	0.27	0.58	0.94	0.55	0.42	0.79	0.47	0.76	0.37	0.78
G:F	0.03	0.43	0.35	0.23	0.89	0.17	0.15	0.41	0.46	0.30	0.06

CHAPTER 3 - Effect of glycerol on flow ability of maize based swine diets

Abstract: Four experiments were conducted to determine the effect of glycerol on the flow ability of ground maize. In Exp. 1, the effects of added soy oil, glycerol, or a 50:50 soy oil/glycerol blend on the flow ability of ground maize (645 μm) were evaluated. Soy oil, glycerol, or a 50:50 blend of soy oil/glycerol was added to either hammer mill (HM) or roller mill (RM) ground maize at 0, 20, 40, 60, or 80 g/kg. There was a mill type × liquid ingredient source × percent liquid ingredient added interaction ($P < 0.05$) observed. Roller mill ground grain decreased angle of repose (AOR), improving flow ability compared with HM ground grain. Increasing soy oil increased AOR and increasing glycerol or the 50:50 soy oil/glycerol blend decreased AOR when added to HM, but not RM ground maize. In Exp. 2, the effects of coarse HM ground maize (1,081 μm) with 0, 30 or 60 g/kg added glycerol or soy oil on flow ability were evaluated. There was a percent added × ingredient source interaction ($P < 0.05$) observed. Increasing glycerol decreased AOR, while increasing soy oil increased AOR. In Exp. 3, the effects of added soy oil, glycerol, or a 50:50 soy oil/glycerol blend on the flow ability of HM ground maize (645 μm) diets containing 150 or 300 g/kg added spray-dried whey were evaluated. Soy oil, glycerol, or a 50:50 blend of soy oil/glycerol was added to the ground maize and spray-dried whey-based diets at 0, 40, or 80 g/kg. There was a spray-dried whey level × percent liquid added × liquid source interaction ($P < 0.05$) observed. The addition of glycerol or the 50:50 soy oil/glycerol blend decreased AOR, improving flow ability. Increasing soy oil increased AOR regardless of spray-dried whey concentration.

In Exp. 4, the flow ability effects of HM ground grain (1,081 μm) with 0, 40, or 80 g/kg added glycerol and 0, 150, and 300 g/kg added whey permeate were evaluated. There was a percent glycerol × percent whey interaction ($P < 0.05$) observed. Adding whey permeate or glycerol decreased AOR. Added glycerol had the greatest impact on decreasing AOR in the samples with no added whey permeate. Samples containing 150 or 300 g/kg added whey permeate and increasing glycerol had decreased AOR compared with the samples containing no added whey, and both levels of added whey resulted in similar flow ability. These data indicate that soy oil increased AOR and the addition of whey decreases AOR. These data also indicate that the addition of glycerol to a meal diet containing both medium (645 μm) or coarse (1,081μm) HM ground maize will improve flow ability.

Key words: Angle of repose, flow ability, glycerol, humidity

1. Introduction

Decreasing particle size and adding fat to a swine diet, can improve pig performance and profitability (De La Llata, et al., 2001a,b). Interactions between added fat and diet particle size effect feed flow ability. Previous research has demonstrated that adding increasing levels of fat to a diet will decrease flow ability and increase feed handling problems (Groesbeck et al., 2006). Glycerol, a liquid ingredient, is currently being evaluated for use as a feed ingredient in swine diets (Lammers et al., 2007). It is expected that glycerol will be added to swine diets similar to the application of liquid fat. When glycerol is added to swine diets it may impact feed handling similar to the impact demonstrate with added fat. Therefore, the objective of these studies were to evaluate the

effects of added glycerol on the flow ability of medium (645 μm) or coarse (1,081μm) ground maize or a ground maize diet containing either 150 or 300 g/kg spray-dried whey.

2. Materials and Methods

2.1 General

Experiments were conducted using maize ground by either a full circle, teardrop hammer mill (HM; P-240D Pulverator, Jacobsen Machine Works, Minneapolis, MN) or a three high roller mill (RM; Model TP 012, Roskamp Manufacturing, Cedar Falls, IA) at the Kansas State University Grain Science Feed Mill. Particle size and standard deviation were determined with a Ro-Tap tester (W. S. Tyler, Mentor, OH) with a stack of 13 screens, as outlined in the American Society of Agricultural Engineers (publication S319). Angle of repose was defined as the maximum angle measured in degrees at which a pile of grain retains its slope (Appel, 1994). A large angle of repose represents a steeper slope and poorer flow ability. An angle of repose tester was constructed from 4 pieces of poly vinyl chloride (PVC, Groesbeck et al., 2006). In brief the tester is 76-mm in diameter and 914-mm tall and attached to a 76-mm PVC floor mounting. A 76-mm diameter plate was mounted to the top of the machine, which allowed two 76" PVC couplers to slide up and down the long axis of the tester. To conduct the angle of repose test, a 500 g sample was placed inside the couplers at a specified height at the top of the tester. The base of the angle of repose tester was held stationary and the PVC couplers were lifted vertically, allowing the test ingredient to flow downward resulting in a pile on top of the plate. The height of the pile was measured, and angle of repose was calculated by the following equation, Angle of repose = $\tan^{-1}$ (the height of the pile divided by one

half the diameter of the plate). A larger angle of repose represents a steeper slope and poorly flowing product; a low angle of repose would represent a freer flowing product.

2.2 Experiment 1.

The objective of this study was to evaluate the effects of added soy oil, glycerol, or a 50:50 soy oil/glycerol blend on the flow ability of ground maize. Maize samples were ground through a RM (rollermill) or HM (hammer mill). After processing, corn was dried for 12 h to equalize moisture content, resulting in a DM of 96%. The maize contained 101 g/kg CP and 30 g/kg fat on an as-fed basis. Particle size mean and standard deviations were 645 μm and 1.97 for maize ground through the RM and 674 μm and 2.31 for maize ground through the HM. Soy oil, glycerol, or a 50:50 blend of soy oil/glycerol was added to the ground maize at 0, 20, 40, 60, or 80 g/kg for a total of 30 samples (2 mill types, 3 liquid ingredient sources, and 5 levels of added liquid ingredient source). Angle of repose was measured, and replicated 4 times on each sample.

2.3 Experiment 2.

The objective of this study was to further evaluate the effects of added glycerol on the flow ability of HM ground maize. Glycerol or soy oil was added to the coarse ground maize at 0, 30 or 60 g/kg. Particle size mean and standard deviations of the HM ground maize were 1,081 μm and 2.52. The maize contained 85.4 g/kg CP, 33 g/kg fat, and 12% moisture on an as-fed basis. Angle of repose was then measured, and replicated 4 times on each sample.

2.4 Experiment 3.

The objective of this study was to evaluate the effects of added soy oil, glycerol, or a 50:50 soy oil/glycerol blend on the flow ability of a HM ground maize diet with

either 150 or 300 g/kg spray-dried whey (Land-O-Lakes, Saint Paul, MN). The HM maize sample used in Exp.1 was the same sample used in this study. Soy oil, glycerol, or a 50:50 blend of soy oil/glycerol was added to the ground grain and spray-dried whey-based diets at 0, 40, or 80 g/kg for a total of 18 samples (2 levels of added whey, 3 liquid ingredient sources, and 3 levels of added liquid ingredient source). Angle of repose was then measured, and replicated 4 times on each sample.

2.5 Experiment 4

The objective of this study was to further evaluate the effects of adding glycerol and whey permeate on flow ability of HM ground whey. Glycerol was added at 0, 40, or 80 g/kg added glycerol and whey permeate (Davisco Food International, Eden Prairie, MN) was added at 0, 150, and 300 g/kg to the base HM ground maize. The HM maize sample used in this study was the same sample used in Exp. 2. Angle of repose was then measured, and replicated 4 times on each sample.

2.6 Statistical analysis

All data was analyzed using PROC MIXED in SAS (SAS Institute, Cary, NC). Experiment 1 was analyzed as a 2 × 3 × 5 factorial (2 mill types, 3 liquid ingredient sources, and 5 levels of added liquid ingredients). Experiment 2 was analyzed as a 3 × 2 factorial (2 liquid sources and 3 levels of added liquid). Experiment 3 was analyzed as a 2 × 3 × 3 factorial (2 levels of added whey, 3 liquid sources, and 3 levels of added liquid). Experiment 4 was analyzed as a 3 × 2 factorial (3 levels of added glycerol and 2 whey permeate levels). All interactions were evaluated. Graphs were generated to show the experimental interactions (Figures 1, 2, 3 and 4).

3. Results

3.1 Experiment 1.

In Exp. 1, a mill type × liquid ingredient source × percent liquid ingredient added interaction ($P < 0.05$; Figure 1) was observed. Roller mill ground grain decreased angle of repose, improving flow ability compared with HM ground grain. The addition of soy oil increased angle of repose, decreasing flow ability. The addition of glycerol or a 50:50 soy oil/glycerol blend decreased angle of repose, improving flow ability when added to the sample containing HM ground maize. Adding glycerol or the 50:50 soy oil/glycerol blend to the sample containing RM ground maize did not influence angle of repose.

3.2 Experiment 2.

In Exp. 2, a liquid source × level interaction ($P < 0.05$; Figure 3) was observed. Increasing glycerol decreased angle of repose, improving flow ability, while increasing soy oil increased angle of repose.

3.3 Experiment 3.

In Exp. 3, a spray-dried whey level × liquid ingredient source × percent liquid ingredient added interaction was ($P < 0.05$; Figure 2) was observed. The addition of 300g/kg whey increased angle of repose compared with the 150 g/kg whey sample. The addition of soy oil increased angle of repose regardless of spray-dried whey concentration. The addition of the 50:50 soy oil/glycerol blend decreased angle of repose. Regardless of whey concentration, adding the soy oil/glycerol blend at 40 and 80 g/kg resulted in similar flow ability. The decrease in angle of repose was greater as the 50:50 soy oil/glycerol blend was increased from 0 to 40g/kg in the samples containing 300 g/kg when compared to samples containing 150g'kg added whey. The addition of glycerol

decreased angle of repose, with the decrease in angle of repose being greater with 150g/kg added whey compared with 300g/kg added whey.

3.4 Experiment 4.

In Exp. 4, a percent glycerol × percent whey permeate interaction ($P < 0.03$; Figure 4) was observed. Adding whey permeate or glycerol decreased angle of repose. Added glycerol had the greatest impact on decreasing angle of repose in the samples with no added whey permeate. Samples containing 150 or 300 g/kg added whey permeate had similar angle of repose with the flow ability improving similarly for both permeate levels as glycerol was added.

4. Discussion

Hammermill and RM grinding are both methods used by the swine industry in particle size reduction. Previous work has demonstrated that RM ground grain with 60g/kg added fat will result in similar flow ability to HM ground grain with no added fat (Groesbeck et al., 2006). In Exp. 1, the addition of glycerol to the HM ground grain diet improved flow ability, while adding glycerol to the RM ground grain diet did not. This response could be due to the increased particle size standard deviation in HM ground grain compared to RM ground grain (Groesbeck et al., 2006). The glycerol could be encapsulating the smaller particles reducing cohesion or friction between particles, improving flow ability in HM ground grain. These data, similar to Groesbeck et al. (2006), indicate that RM ground grain will flow better than HM ground grain, but these data indicate the addition of glycerol to HM ground grain can improve flow ability.

A particle size of 700 μm for maize is often recommended to producers (DeRouchey et al., 2007); however, a larger particle size of 1,000 μm is often used in

gestation and lactation diets. Regardless of particle size, the addition of glycerol improved flow ability. Similar to previous work, adding soy oil decreased flow ability (Groesbeck, et al., 2006). It would be expected that as particle size decreased and fat was increased that flow ability would further decrease (Groesbeck, et al., 2006).

Soy oil and other fat sources are often added to diets to help control dust. It is not clear if glycerol would reduce dustiness, but these data show that glycerol can be added to swine diets in a blend with soy oil and result in improved flow ability compared with the addition of soy oil alone. Liquid fat is often added to nursery diets to reduce dust, but may adversely affect flow ability when mixed with powered specialty protein ingredients (Carney et al. 2005, 2007).

The addition of lactose ingredients has been shown to improve flow ability (Carney et al., 2005); however, lactose was not evaluated in the presence of added fat in those trials. It is also not expected that adding lactose sources to diets would improve feed handling. However, similar to Carney et al. (2005) these trials suggest that adding whey permeate to maize-based diets will result in improved feed handling. When lactose is incorporated in a diet with added glycerol, flow ability further improves.

These experiments suggest that flow ability of feed will be improved by the addition of glycerol, especially when added to meal diets containing maize ground through a HM. These data also confirm previous research that the addition of whey sources to swine diets improves flow ability with diets containing 150 g/kg or 300g/kg added whey resulting in similar flow ability. Adding glycerol to diets with whey will further improve flow ability. Glycerol added to meal diets should not create feed handling

issues commonly found when fat is added to diets. These data suggest that the addition of glycerol to a meal diet will improve flow ability and therefore feed handling.

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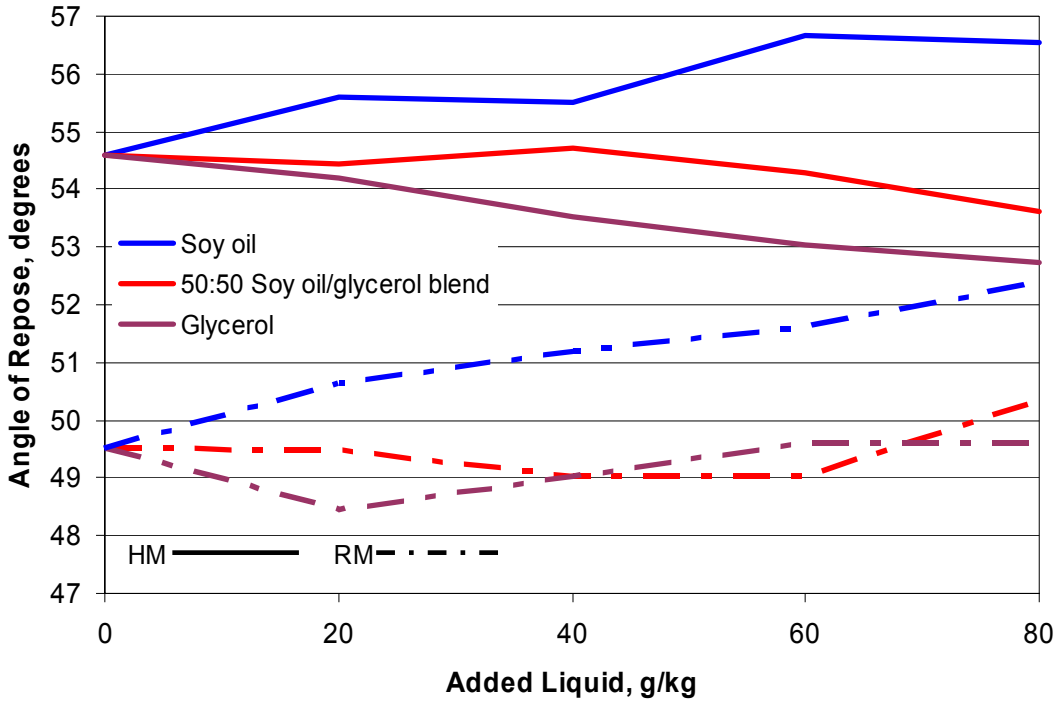

Figure 3.1 Influence of maize ground through a hammer (HM) or roller (RM) mill, liquid ingredient source, and liquid ingredient level on angle of repose.

Figure 1. A mill type x liquid ingredient source x percent liquid ingredient added interaction ($P < 0.05$) was observed. Roller mill ground grain decreased angle of repose compared with HM ground grain. The addition of soy oil increased angle of repose in both HM and RM ground grain. The addition of the 50:50 soy oil/glycerol blend and the addition of glycerol decreased angle of repose when added to HM ground grain.

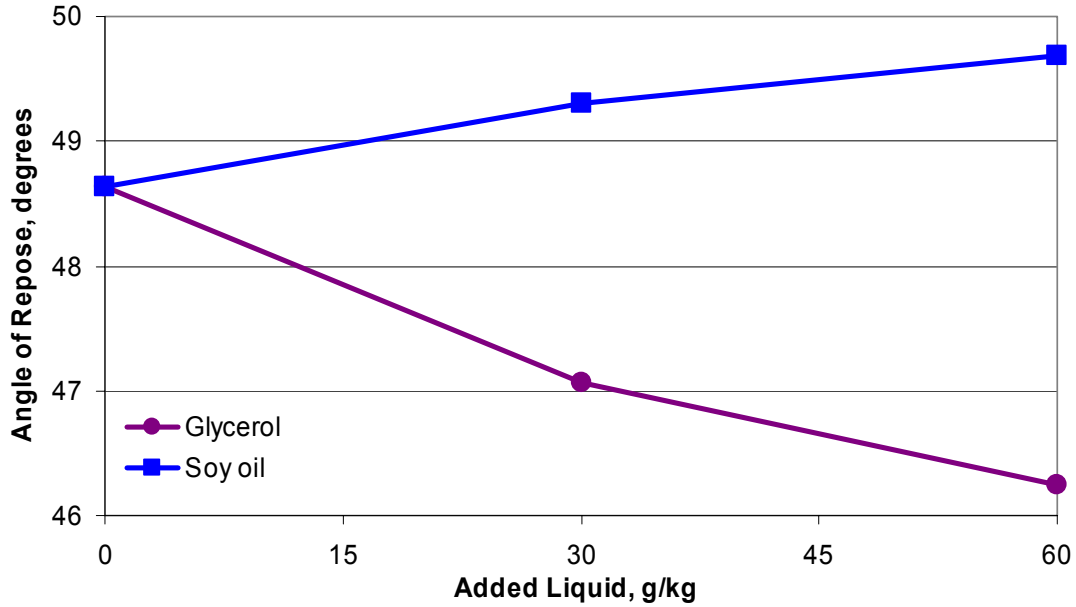

Figure 3.2 Influence of coarse HM ground maize with 0, 30, or 60 g/kg added glycerol.

Figure 2.There was a percent liquid ingredient added × ingredient source interaction ($P < 0.05$) observed. Increasing glycerol decreased angle of repose, while increasing soy oil decreased flow ability.

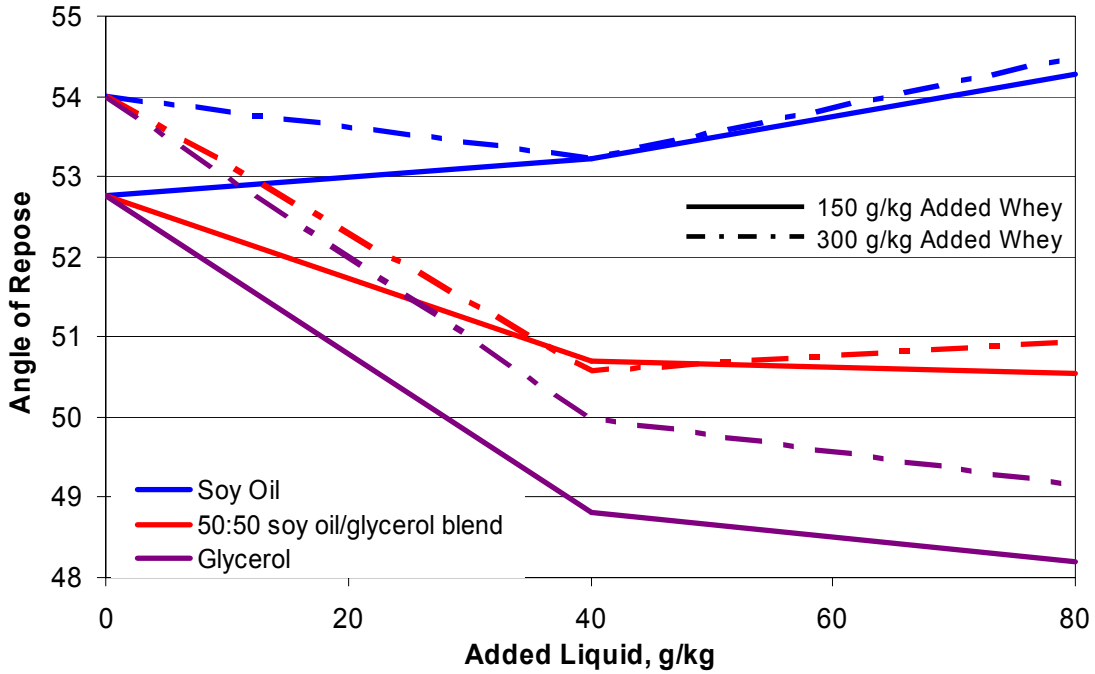

Figure 3.3 Influence of spray-dried whey, liquid ingredient source, and percent liquid ingredient added on angle of repose.

Figure 3. There was a spray-dried whey level × liquid ingredient source, × percent liquid ingredient interaction ($P<0.05$) observed. The addition of glycerol or the 50:50 soy oil/glycerol blend decreased angle of repose, improving flow ability. The addition of soy oil increased angle of repose regardless of spray-dried whey concentration.

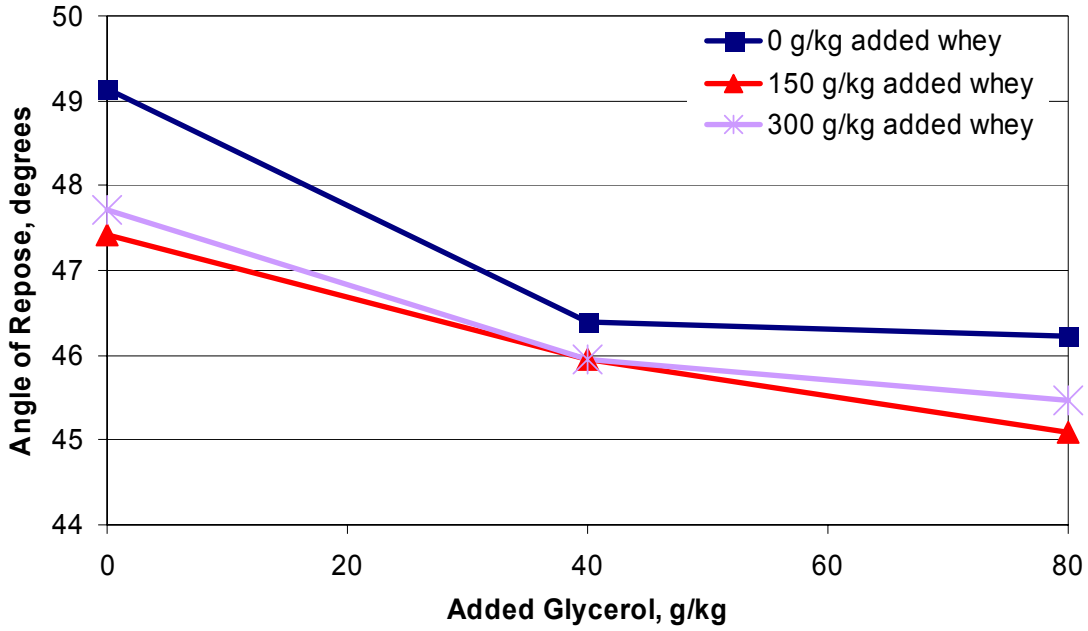

Figure 3.4 Influence of temperature and humidity on flow ability of HM ground maize with 0, 40, or 80 g/kg added glycerol and 0, 150, and 300 g/kg added whey permeate.

Figure 4. There was a percent glycerol × percent whey interaction ($P < 0.03$) observed. Adding whey permeate or glycerol decreased angle of repose. Added glycerol had the greatest impact on decreasing angle of repose in the samples with no added. Samples containing 150 or 300 g/kg added whey permeate and increasing glycerol had decreased angle of repose compared with the samples containing no added whey, and both levels of added whey resulted in similar flow ability

CHAPTER 4 - Lactose and specialty protein sources influence flow ability of nursery pig diets

Abstract: Four experiments were conducted to determine the effects of lactose and specialty protein sources on angle of repose, an indicator of feed flow ability. In Exp. 1, six lactose sources were evaluated; three powdered whey permeates, a coarse whey permeate, spray-dried whey, and crystalline lactose. Lactose sources were added at 0, 50, 100, 200, and 300 g/kg to a 70:30 maize-soybean meal blend. There was a lactose source × level interaction ($P < 0.01$) for angle of repose. Increasing lactose sources improved flow ability with the coarse whey permeate having a greater improvement in flow ability then other lactose sources. In Exp. 2, five specialty protein sources were evaluated; spray-dried animal plasma (powdered or granulated), spray-dried blood cells (powdered or granulated), and fish meal. Specialty protein sources were added at 0, 25, 50, 75, and 100 g/kg to a 70:30 maize-soybean meal blend. There was a specialty protein source × level interaction ($P < 0.01$). Increasing powdered animal plasma and blood cells increased angle of repose, resulting in poorer flow ability. Increasing granulated animal plasma and blood cells decreased angle of repose. Increasing fish meal did not influence angle of repose. In Exp. 3, four lactose sources (a powdered whey permeate, coarse whey permeate, spray-dried whey, and crystalline lactose) were evaluated at two relative humidity levels (40 and 67%). Lactose sources were added at 0, 50, 100, 200, and 300 g/kg to a 70:30 maize-soybean meal blend. There was a lactose source × inclusion level × humidity interaction ($P < 0.01$). As crystalline lactose increased, angle of repose decreased, decreasing faster at 67% humidity compared to 40% humidity. As dried whey

and the whey permeates increased, angle of repose decreased. The coarse whey permeate had little change in angle of repose as inclusion rate increased. As relative humidity increased, angle of repose increased for all ingredients. In Exp. 4, five specialty protein sources were evaluated; spray-dried animal plasma (powdered or granulated), spray-dried blood cells (powdered or granulated), and fish meal at two relative humidity levels (34 and 64%). Specialty protein sources were added at 0, 25, 50, 75, and 100 g/kg to a 70:30 maize-soybean meal blend. There was a specialty protein source × inclusion level × humidity interaction ($P < 0.01$). As powdered spray-dried animal plasma and fish meal increased, angle of repose increased, increasing faster for fish meal at 34% humidity compared with 64% humidity. Angle of repose decreased as granular spray-dried blood cells and animal plasma inclusion increased, decreasing faster at 34% humidity compared with 64% humidity. Although there was an interaction, angle of repose responded similarly for all ingredients as humidity level increased; however, all ingredients had increased angle of repose as relative humidity increased. These data confirm that the humidity, inclusion rate, and ingredient form (powder or granulated) affect flow ability of diets fed in meal form.

Key words: Angle of repose; humidity, lactose, spray-dried animal plasma

1. Introduction

Lactose and specialty protein sources are often included in nursery pig diets to stimulate feed intake (Mahan et al., 2004; Pierce et al., 2005) and improve growth performance (Steidinger et al., 2000). High concentrations of these ingredients, unless pelleted, are frequently speculated to increase the incidence of bridging in bins and feeders. However, there is little research data available about how these ingredients

affect flow ability of the diet. If these ingredients would flow more consistently in a meal diet, producers and nutritionist would have more options in diet formulation. This would also mean fewer "out of feed" occurrences and a reduction in on-farm feed handling problems. Quantifying the differences in flow ability among different ingredients could also justify the selection of one ingredient over another. Humidity is also an additional factor that could contribute to feed handling issues when lactose sources and specialty ingredients are added to nursery diets. The increase in barn humidity could result in increased water absorption by specialty ingredients included in the diet, causing increased feed bridging and handling problems. Therefore, we conducted four experiments to determine the effects of lactose sources and specialty protein sources on flow characteristics of a 70:30 maize-soybean meal-based diet.

2. Materials and methods

2.1 General

All experiments were conducted using maize ground through a full-circle teardrop hammer mill (P-240D Pulverator, Jacobsen Machine Works) at the Kansas State University Grain Science Feed Mill. Particle size and particle size standard deviation (PSSD) were determined with a ro-tap tester (W. S. Tyler, Mentor, OH) with a stack of 13 screens, as outlined in ASAE procedures (ASAE, 1983). Particle size and PSSD of maize used in Exp. 1 and 2 was 709 and 2.41, respectively and contained 10.4 % CP and 3.3% fat on an as-fed basis. Particle size and PSSD of maize used in Exp. 3 and 4 was 937 and 2.74, respectively and contained 7.54% CP and 2.6% fat on an as fed basis. Particle sizes for all lactose and specialty protein ingredients were determined (Table 1).

Angle of repose is defined as the maximum angle measured in degrees at which a pile of grain retains its slope. A devise to test angle of repose was constructed from 4 pieces of polyvinyl chloride plastic (PVC; Groesbeck et al. 2006). In brief the tester was 76 mm in diameter and 914 mm tall and attached to a 98 mm PVC base. A 76 mm diameter plate was mounted to the top of the machine; this allowed 2, 76 mm PVC couplers to slide up and down the long axis of the tester. To conduct the angle of repose test, a 500 g sample was placed inside the couplers at 140 mm above the top of the tester. The base of the angle of repose tester was held stationary and the PVC couplers were lifted vertically to allow the test ingredient to flow downward, resulting in a cone-shaped pile on top of the plate. The height of the pile was measured, and angle of repose was calculated by the equation: Angle of repose = $\tan^{-1}$ (the height of the pile divided by the radius of the plate; Appel, 1994). A larger angle of repose represents a steeper slope and poorly flowing test ingredient; a low angle of repose represents a more freely flowing product.

A 70:30 maize-soybean meal blend served as the base mixture to which all lactose sources and specialty ingredients were added.

2.2 Experiment 1

The objective of this study was to evaluate the effects of lactose sources on angle of repose. Six different lactose sources were evaluated. These included three sources of fine powdered whey permeates (Adell Whey, Adell, WI, Davisco Food International, Eden Prairie, MN, and Lynn Dairy Inc., Granton, WI), coarse ground whey permeate (Dairy Lac 80; International Ingredients Corporation, St Louis, Mo), edible grade spray-dried whey (Land-O-Lakes, Saint Paul, MN), and crystalline lactose. The

lactose sources were added at 0, 50, 100, 200, and 300 g/kg to the 70:30 maize-soybean meal blend.

The maize and soybean meal used in the 70:30 maize-soybean meal blend were dried at 40°C to 96% DM to ensure moisture would not be a variable affecting results. After mixing the lactose sources with the maize-soybean meal blend, angle of repose was measured on the blends and the individual lactose ingredients. Angle of repose was replicated four times with each sample.

2.3 Experiment 2

The objective of this study was to evaluate the effects of specialty protein ingredients on angle of repose. Five different specialty protein sources were evaluated. These included fish meal (Select Menhaden, Omega Proteins, Houston, TX), powdered (AP920; American Proteins Cooperation, Ankeny, IA) or granulated (Appetein, American Proteins Cooperation, Ankeny, IA) spray-dried animal plasma, powdered (AP301; American Proteins Cooperation, Ankeny, IA) or granulated spray-dried blood cells (AP301G; American Proteins Cooperation, Ankeny, IA). The specialty protein sources were added at 0, 25, 50, 75 and 100 g/kg to a maize-soybean meal blend.

The maize and soybean meal and the 70:30 maize-soybean meal blend used were identical to Exp. 1. After mixing the specialty protein ingredient with the maize-soybean meal blend, angle of repose was measured on the blends and individual protein ingredients. Angle of repose was replicated four times with each sample.

2.4 Experiment 3

The objective of this study was to evaluate the effects of humidity on the angle of repose of lactose sources. Four different lactose sources were evaluated. These included

a fine powdered whey permeate, coarse ground whey permeate (Dairy Lac 80; International Ingredients Corporation, St Louis, Mo), edible grade spray-dried whey (Land-O-Lakes,Saint Paul, MN), and a crystalline lactose source. The lactose sources were added at 0, 50, 100, 200, and 300 g/kg to a 70:30 maize-soybean meal blend.

The experiment was conducted at two relative humidity levels of 40 and 67%. This experiment was conducted in an environmentally-controlled facility to minimize temperature and humidity fluctuations. All samples were placed into the environmentally-controlled facility 24 h before the experiment was conducted to allow for acclamation of the ingredients to the environmental conditions. Temperature was held constant at 32°C. Temperature and humidity were monitored throughout the acclimation period. Digital humidity and temperature readers were used to measure minimum and maximum temperature and humidity. Flow ability was determined by measuring angle of repose. Angle of repose was replicated four times with each sample.

2.5 Experiment 4

The objective of this study was to evaluate the effects of humidity on the angle of repose of specialty protein ingredients. Five specialty protein sources were evaluated. These included Menhaden fish meal, powdered (AP920) or granulated (Appetein) spray-dried animal plasma, powdered (AP301) or granulated spray-dried blood cells (AP301G). The specialty protein sources were added at 0, 25, 50, 75, and 100 g/kg to a 70:30 maize-soybean meal blend.

Relative humidity levels of 34 and 64% and the environmentally-controlled facility was used to minimize temperature and humidity fluctuations. Experimental procedures were identical to Exp. 3.

2.6 Statistical analysis

All data was analyzed using PROC MIXED in SAS 8.1 (SAS Institute, Cary, NC). In Exp. 1 and 2 ingredient source and inclusion level were modeled and parameter estimates were then outputted to develop regression equations (Tables 2 and 3). In Exp. 3 and 4, ingredient source, inclusion level, and humidity were modeled and parameter estimates were then outputted to develop the regression equations (Tables 4 and 5).

Results

In Exp. 1 and 3, the coarse whey permeate (Dairy lac 80) had the greatest particle size and PSSD compared with the other lactose sources (Table 1). All the powdered lactose sources had similar particle size and PSSD values. As expected, the spray-dried animal plasma and spray-dried blood cells had the greatest particle size compared with the other specialty protein sources. The granular spray-dried blood cells the greatest PSSD when compared with the other specialty protein sources.

In Exp. 1, a lactose source × level interaction (Figure 1, $P < 0.01$) was observed. Increasing lactose regardless of source decreased angle of repose, indicating improved flow ability. The actual decrease in angle of repose for each of the lactose sources at increasing levels is calculated using the parameter estimate in Table 2. The coarse ground whey permeate source had the greatest decrease in angle of repose as inclusion rate increased, therefore, having the best flow ability and resulting in the observed interaction.

In Exp. 2, a specialty protein source × level interaction (Figure 2, $P < 0.01$) was observed. The actual angle of repose for each of the specialty protein sources at increasing levels is calculated using the parameter estimate in Table 3. Angle of repose increased with powdered animal plasma and blood cells indicating poorer flow ability.

The angle of repose decreased as granulated animal plasma and blood cells increased, indicating better flow ability. Increasing fish meal did not influence angle of repose.

In Exp. 3 a lactose source × inclusion level × humidity interaction (Figure 3, $P < 0.01$) was observed. Although the increase in humidity initially caused an increased in angle of repose, increasing the inclusion of crystalline lactose decreased angle of repose at a greater rate at 67% humidity compared to 40% humidity, with both humidity levels at 250 g/kg inclusion having similar angle of repose values. As dried whey and the whey permeates increased, angle of repose decreased. The actual decrease in angle of repose for each of these lactose sources at increasing levels is calculated using the parameter estimate in Table 4. The decreased angle of repose for crystalline lactose is due to crystalline lactose having the largest and most negative source parameter estimate of -1.7023. The coarse whey permeate had little change in angle of repose as inclusion rate increased. As relative humidity increased, angle of repose increased for all ingredients. All lactose ingredients, except crystalline lactose, followed a similar trend at both humidity levels.

In Exp. 4, a protein source × inclusion level × humidity interaction (Figure 4, $P < 0.01$) was observed. The actual angle of repose values are calculated using the parameter estimates in Table 5. As powdered spray-dried animal plasma and fish meal increased, angle of repose increased, increasing faster for fish meal at 34% humidity compared with 64% humidity. The decrease in flow ability is a result of powdered spray-dried animal plasma having the largest source parameter estimate compared with the other specialty protein ingredients. There was no change in angle of repose for the powdered spray-dried blood cells as inclusion level increased. Angle of repose decreased as granular spray-

dried blood cells and animal plasma inclusion increased, decreasing faster at 34% humidity compared with 64% humidity. This decrease in angle of repose is demonstrated by the percent added × source estimate of -0.1843 for granular spray dried animal plasma and -.1646 for spray-dried blood cells. Although there was an interaction, changes in the angle of repose slope for ingredient source was minimal between humidity levels; however, increasing relative humidity increased angle of repose for all ingredients.

Discussion

Nursery pig diets contain various lactose sources and specialty protein ingredients designed to stimulate feed intake and maximize performance (Dritz et al., 1996). The addition of specialty ingredients to diets fed in meal form may result in feed handling problems. To avoid the handling problems with additions of lactose products and specialty protein ingredients, the majority of these diets are fed in pelleted form. Pelleting increases diet cost, and could potentially denature or alter the bioavailability of the specialty ingredients added to these diets (Fairfield, 2005). Therefore it is important to understand the flow characteristics of varying inclusions of lactose sources and specialty protein ingredients included in nursery pigs diets, and to determine which ingredients would improve flow ability when added to a maize-soybean meal diet and fed in meal form.

The improvement in flow ability observed in Exp. 1 and 3 with the additions of fine lactose sources was not expected. Lactose was expected to inhibit or significantly decrease flow ability. Lactose ingredients held in bags often become compressed and compacted, and are therefore associated with increased feed handling problems. The particle size of fine powdered lactose is also less than 200 μm. Previous research has

indicated that as maize particle size decreases, flow ability decreases (Groesbeck et al., 2006). Regardless, these data indicate that fine powdered lactose sources alone in a maize-soybean meal blend do not inhibit flow ability, and the addition of crystalline lactose may improve feed handling. Diets that include lactose and other specialty ingredients together were not evaluated, and could result in an interaction and increase feed handling issues.

Coarse whey permeates improved flow ability in Exp 1, while it had little effect in Exp. 2. The coarse ground whey permeate used in Exp 1 and 3 were not from the same lot, but had similar particle size values. The particle size of the course ground whey permeate ranged from 1,919-202 μm in Exp. 1 and 1,834-150 μm in Exp.3. The lack of flow ability improvement when coarse whey permeate was added to the blend in Exp. 3 could be a result of adding a coarse ingredient to a blend with similar particle size as the ingredient. The particle size of the ground corn was 709 μm in Exp. 1 and 937 μm in Exp 3. Thus, the particle size of the course whey permeate was much greater than the particle size of the corn in experiment 1, but not in Exp. 3. When ingredients of similar sizes are added together an improvement in flow ability would not be expected. However, the fine lactose ingredients all improved flow ability regardless of blend. This indicates that fine lactose ingredients may not be the contributing ingredient affecting flow ability of diets and that other ingredients such as the powdered specialty proteins are responsible for decreased flow ability. As evidenced in our trials, adding increasing levels of fine powdered specialty protein sources had a much greater impact on angle of repose than lactose sources.

Similar to the results with coarse whey permeate in Exp. 1, granular specialty protein ingredients decreased angle of repose. The PSSD of spray-dried blood cells was greater then the PSSD of spray-dried animal plasma. However, the particle size of the spray-dried animal plasma was greater when compared to the spray-dried blood cells. Both the spray-dried blood cells and spray-dried animal plasma had greater then 60% of its particles above 1,100 μm. This indicates that regardless of particle size and PSSD, majority of the particles are large, and large particles would be expected to improve flow ability.

Humidity and the overall environment of commercial barns may be a contributing factor in the flow ability of diets, especially diets containing high percentages of lactose sources. Swine diets and ingredients have the potential to be exposed to a wide variety of environmental conditions. Barn temperature and humidity vary within the barn with size of pig, number of pigs, ventilation, and season. As ingredients are exposed to higher humidity it would be expected that flow ability would decrease, increasing feed handling problems. Therefore, further understanding the effects of humidity may help us understand the potential feed handling issues on farm with diets containing lactose and specialty protein ingredients.

Increasing humidity with either lactose or specialty protein ingredients increases angle of repose. It was expected that the increased humidity would cause an increase in water uptake by the ingredients, decreasing flow ability to a larger extent, especially for lactose sources. Increasing humidity had the predicted impact on flow ability; however all ingredients were impacted similarly as humidity increased.

In conclusion, these data confirm that lactose and specialty ingredients influence the flow ability of swine diets when fed in meal form. These data indicate that increasing humidity will decrease flow ability. Specialty protein ingredients in powder form reduce flow ability compared with those in granular form, while lactose sources improve flow ability. Our data indicates that lactose added to swine diets should not increase feed handling issues. It appears that other ingredients, such as, powdered specialty ingredients will cause more issues with bridging when added to swine diets then fine lactose ingredients.

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Table 4.1 Particle size and standard deviations of ingredients

Table 1. Particle size and standard deviation of ingredients[a]

Ingredient	Particle size, μm	PSSD
Exp. 1		
Whey permeate 1	141	1.84
Whey permeate 2	147	1.83
Whey permeate 3	143	1.83
Spray-dried edible whey	150	1.85
Crystalline lactose	157	1.57
Course ground whey permeate	623	3.08
Exp. 2		
Spray-dried animal plasma, powered	82	1.68
Spray-dried animal plasma, granular	1,505	1.40
Spray-dried blood cells, powder	293	2.24
Spray-dried blood cells, granular	688	2.95
Fish meal	304	2.58
Exp. 3		
Whey permeate	159	2.30
Spray-dried edible whey	162	1.89
Crystalline lactose	206	1.58
Course ground whey permeate	524	3.50
Exp. 4		
Spray-dried animal plasma, powder	82	1.68
Spray-dried animal plasma, granular	972	2.04
Spray-dried blood cells, powder	293	2.24
Spray-dried blood cells, granular	545	2.92
Fish meal	268	2.57

[a]Particle size and particle size standard deviation (PSSD) were determined with a ro-tap tester (W. S. Tyler, Mentor, OH) with a stack of 13 screens, as outlined in ASAE procedures (ASAE, 1983).

Table 4.2 Parameter estimates for effects of lactose sources, Exp. 1

Table 2. Parameter estimates for effects of lactose sources, Exp. 1[a]

Effect	Lactose source	Estimate
Intercept		54.4966
Source	Whey permeate 1	-0.07821
Source	Whey permeate 2	0
Source	Whey permeate 3	-0.04966
Source	Spray-dried edible whey	0.1064
Source	Crystalline lactose	0.4665
Source	Course ground whey permeate	-0.5359
Percent added		-0.02266
Percent added × source	Whey permeate 1	-0.0051
Percent added × source	Whey permeate 2	0
Percent added × source	Whey permeate 3	0.003897
Percent added × source	Spray-dried whey	-0.02741
Percent added × source	Crystalline lactose	-0.06619
Percent added × source	Course ground whey permeate	-0.099660

[a] All data was analyzed using PROC MIXED in SAS 8.1. There was a lactose source × level interaction ($P < 0.01$).

Table 4.3 Parameter estimates for effects of specialty protein sources, Exp. 2

Table 3. Parameter estimates for effects of specialty protein sources, Exp. 2[a]

Effect	Specialty protein	Estimate
Intercept		54.8855
Source	Spray-dried animal plasma, powered	-0.001
Source	Spray-dried animal plasma, granular	0.109
Source	Spray-dried blood cells, powder	-0.371
Source	Spray-dried blood cells, granular	-0.1945
Source	Fish meal	0
Percent added		-0.0242
Percent added × source	Spray-dried animal plasma, powered	0.1378
Percent added × source	Spray-dried animal plasma, granular	-0.1873
Percent added × source	Spray-dried blood cells, powder	-0.071
Percent added × source	Spray-dried blood cells, granular	0.2761
Percent added × source	Fish meal	0

[a] All data was analyzed using PROC MIXED in SAS 8.1. There was a specialty protein source × level interaction ($P < 0.01$).

Table 4.4 Parameter estimates for effects of lactose sources, Exp. 3

Table 4. Parameter estimates for effects of lactose sources, Exp. 3[a]

Effect	Lactose source	Estimate
Intercept		51.423
Source	Course ground whey permeate	-1.2087
Source	Spray-dried whey (edible grade)	0.1267
Source	Crystalline lactose	-1.7023
Source	Whey permeate	0
Percent added		0.07576
Percent added × source	Course ground whey permeate	-0.08956
Percent added × source	Spray-dried whey	-0.04853
Percent added × source	Crystalline lactose	0.019
Percent added × source	Whey permeate	0
Humidity		-0.03043
Humidity × source	Course ground whey permeate	0.1747
Humidity × source	Spray-dried whey	0.01987
Humidity × source	Crystalline lactose	0.05593
Humidity × source	Whey permeate	0
Percent added ×humidity		-0.00127
Percent × humidity × source	Course ground whey permeate	0.000698
Percent × humidity × source	Spray-dried whey	0.00052
Percent × humidity × source	Crystalline lactose	-0.00169
Percent × humidity × source	Whey permeate	0

[a] All data was analyzed using PROC MIXED in SAS 8.1. There was a lactose source × inclusion level × humidity interaction ($P < 0.01$).

Table 4.5 Parameter estimates for effects of specialty protein sources, Exp. 4

Table 5. Parameter estimates for effects of specialty protein sources, Exp. 4[a]

Effect	Specialty protein	Estimate
Intercept		54.88
Source	Spray-dried animal plasma, powder	0.20134
Source	Spray-dried animal plasma, granular	-0.2533
Source	Spray-dried blood meal, powder	-0.2788
Source	Spray-dried blood meal, granular	-0.2626
Source	Fish meal	0
Percent added		0.03237
Percent added × source	Spray-dried animal plasma, powder	-0.1058
Percent added × source	Spray-dried animal plasma, granular	-0.1843
Percent added × source	Spray-dried blood meal, powder	-0.07746
Percent added × source	Spray-dried blood meal, granular	-0.1646
Percent added × source	Fish meal	0
Humidity		0.06786
Humidity × source	Spray-dried animal plasma, powder	0.0109
Humidity × source	Spray-dried animal plasma, granular	0.006447
Humidity × source	Spray-dried blood meal, powder	0.02463
Humidity × source	Spray-dried blood meal, granular	0.00175
Humidity × source	Fish meal	0
Percent added ×humidity		0.000298
Percent × humidity × source	Spray-dried animal plasma, powder	0.001283
Percent × humidity × source	Spray-dried animal plasma, granular	0.000635
Percent × humidity × source	Spray-dried blood meal, powder	-0.00036
Percent × humidity × source	Spray-dried blood meal, granular	-0.00008
Percent × humidity × source	Fish meal	0

[a] All data was analyzed using PROC MIXED in SAS 8.1. There was a specialty protein source × inclusion level × humidity interaction ($P < 0.01$).

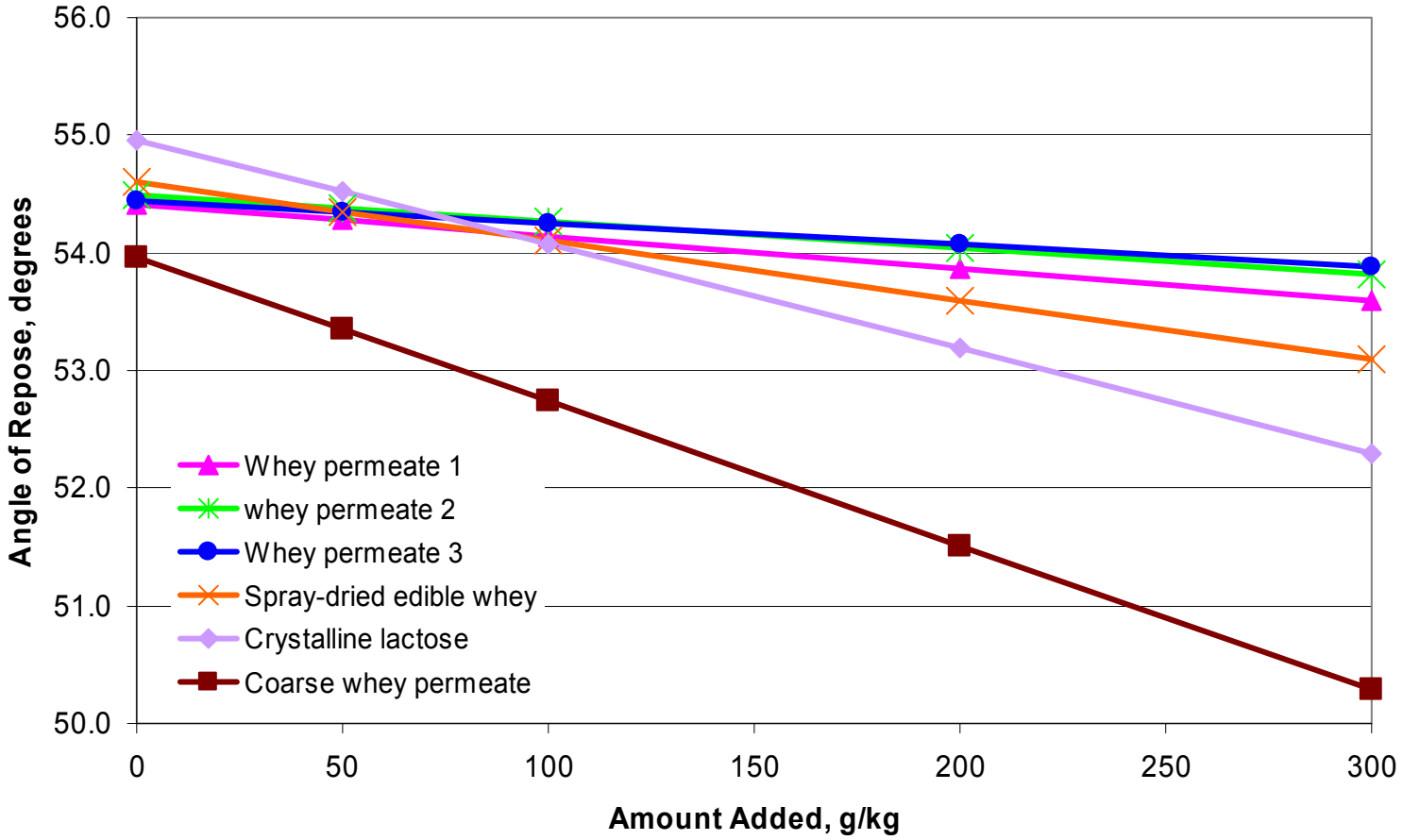

Figure 4.1 Effect of lactose sources on flow ability.

Figure 1. There was a lactose source × level interaction ($P < 0.01$). As all lactose sources increased, angle of repose decreased, therefore, improving flow ability. The course ground lactose source had the greatest decrease in angle of repose as the inclusion rates increased, therefore, having the best flow ability.

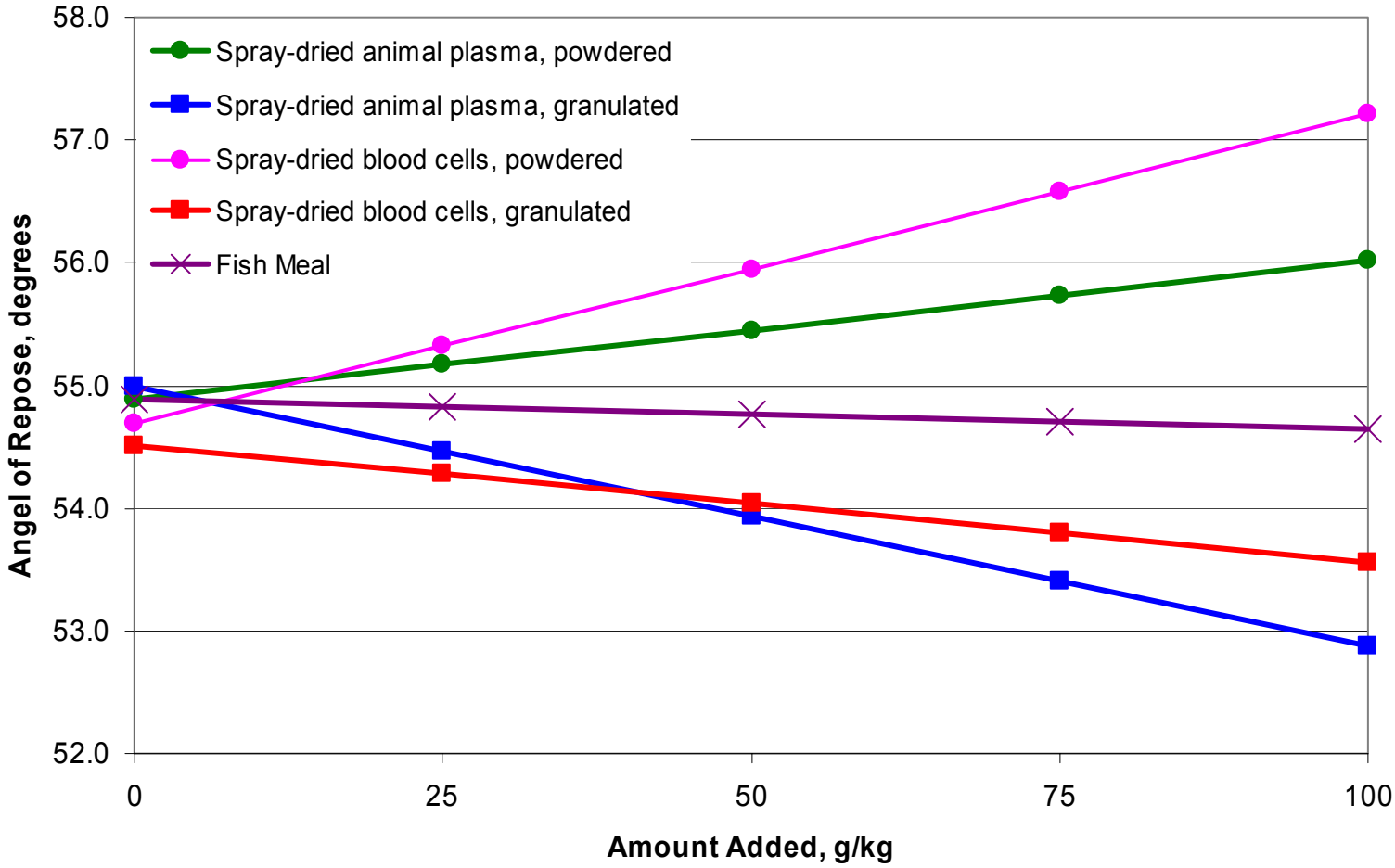

Figure 4.2 Effect of specialty protein sources on flow ability.

Figure 2. There was a specialty protein source × level interaction ($P < 0.01$). Angle of repose increased with increasing inclusions of powdered animal plasma and blood cells, therefore, resulting in poorer flow ability. The angle of repose decreased as granulated animal plasma and blood cells inclusions increased, therefore, having a better flow ability. Increasing fish meal did not influence angle of repose.

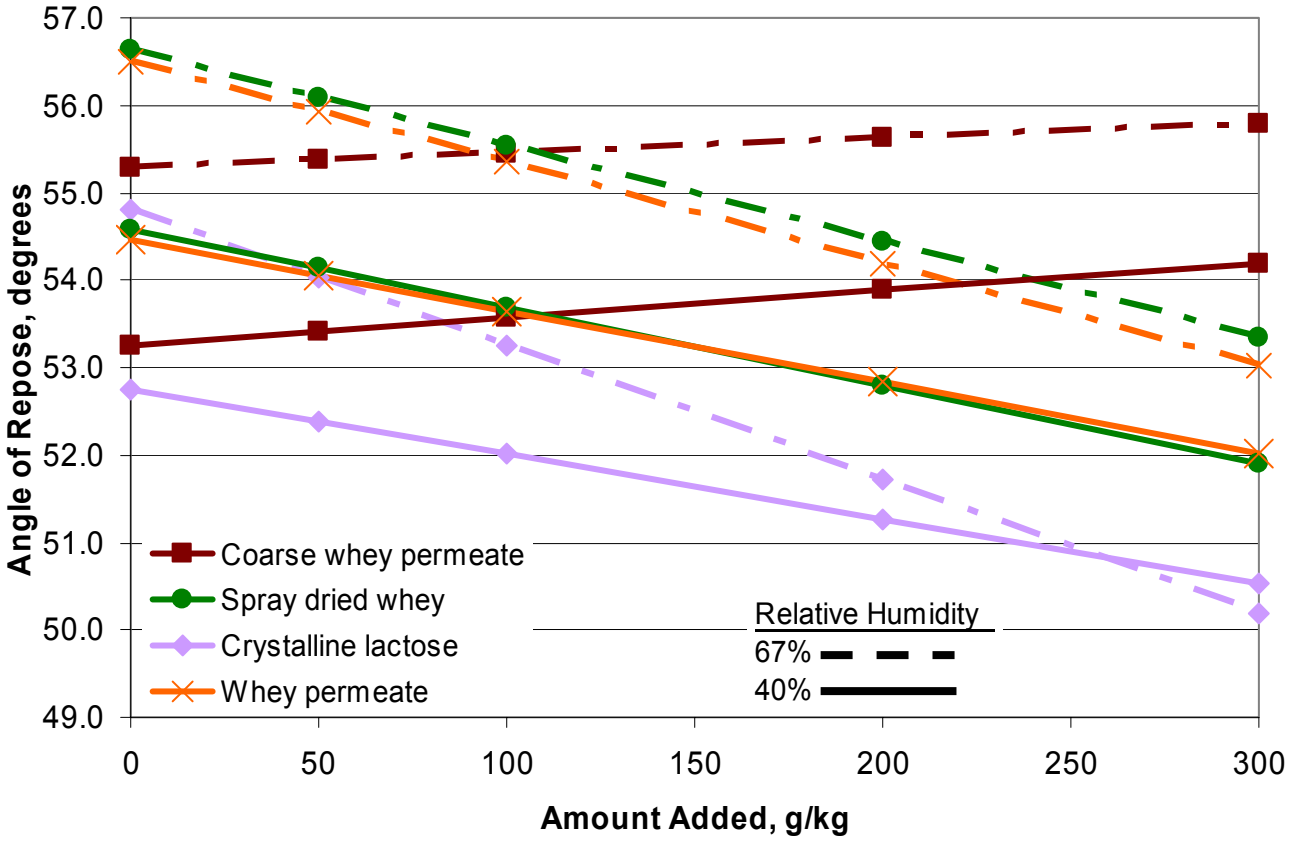

Figure 4.3 Effect of humidity on the flow ability of lactose sources.

There was a lactose source × inclusion level × humidity interaction ($P < 0.01$) was observed. As crystalline lactose increased, angle of repose decreased, decreasing faster at 67% humidity compared to 40% humidity. As dried whey and the whey permeates increased, angle of repose decreased. The coarse whey permeate had little change in angle of repose as inclusion rate increased. As relative humidity increased, angle of repose increased for all ingredients.

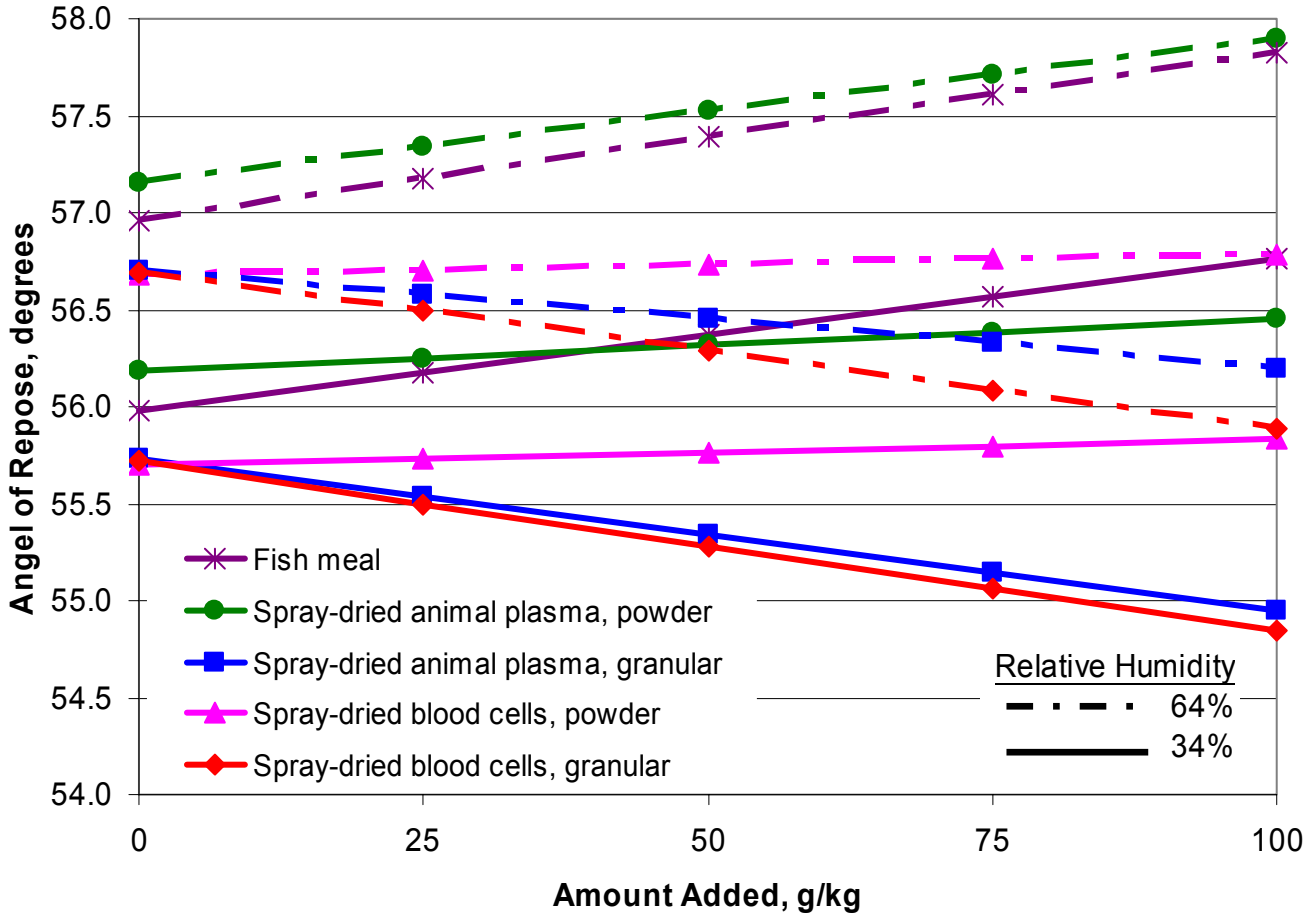

Figure 4.4 Effect of humidity on the flow ability of specialty protein sources.

There was a specialty protein source × inclusion level × humidity interaction ($P < 0.01$). As powdered spray-dried animal plasma and fish meal increased, angle of repose increased, increasing faster for fish meal at 34% humidity compared with 64% humidity. Angle of repose decreased as granular spray-dried blood cells and animal plasma inclusion increased, decreasing faster at 34% humidity compared with 64% humidity. Although there was an interaction changes in the angle of repose slope for ingredient source was minimal between humidity levels; however, increasing relative humidity increased angle of repose for all ingredients.

CHAPTER 5 - Effects of irradiation of feed ingredients added to meal or pelleted diets on growth performance of weanling pigs

ABSTRACT: Two experiments were conducted to evaluate the effect of ingredient irradiation in meal and pelleted diets on nursery pig performance. In Exp. 1, 192 pigs (initial average BW of 6.0 kg) were used in a 25-d trial. Pigs were blocked by weight and randomly allotted in a 2 × 2 factorial with main effects of diet form (meal or pellet) and either irradiated (11.92 kGy) or non-irradiated spray-dried animal plasma (SDAP). Irradiation of SDAP lowered total bacterial levels compared to non-irradiated SDAP, while pelleting also lowered bacterial levels compared with diets in meal form. There was a diet form × SDAP irradiation interaction ($P < 0.05$) for ADG from d 0 to 11 and d 0 to 25. This interaction was the effect of pigs fed irradiated SDAP in either diet form had increased ADG, increasing at a greater rate in meal diets. Also, from d 0 to 11, pigs fed pelleted diets and pigs fed irradiated SDAP had improved G:F ($P < 0.01$) compared to pigs fed meal diets and regular SDAP, respectively. In Exp. 2, 350 pigs (initial average BW of 4.9 kg) were used in a 22-d trial to determine the effects of feeding irradiated protein sources (SDAP, soybean meal, fish meal, or all three) in meal and pellet diets on pig performance. Pigs were blocked by weight and randomly allotted to one of ten treatments consisting of a single diet formulation fed in either meal or pellet form containing either no irradiated protein sources or irradiated SDAP, soybean meal, fish meal, or all three irradiated protein sources (10.20 kGy). Irradiation of the SDAP,

soybean meal, and fish meal reduced total bacterial levels compared to non-irradiated plasma and pelleting reduced bacterial levels compared with diets in meal form. There were no irradiation × diet form interactions ($P < 0.16$). From d 0 to 11, pigs fed diets containing irradiated protein sources had improved ($P < 0.03$) G:F compared to the control diets, with no difference in ADG or ADFI. From d 0 to 11, and overall (d 0 to 22) pigs fed pellet diets had improved G:F ($P < 0.01$) compared with pigs fed meal diets with no difference in ADG and ADFI. These studies indicated that both irradiation and pelleting are manufacturing processes that can reduce bacteria levels in feed ingredients and diets. Irradiation of SDAP, soybean meal, and fish meal improved G:F compared to the control diets containing non-irradiated ingredients. Furthermore, pigs fed pelleted diets had increased G:F compared to pigs fed meal diets.

Key words: irradiation, pig, pellet, spray-dried animal plasma

INTRODUCTION

Specialty proteins, such as spray dried animal plasma (SDAP) and fish meal, are used to stimulate pig feed intake immediately after weaning (Kats et al., 1994; Grinstead et al., 2000). However, these specialty ingredients included in nursery diets often contain high levels of bacteria (Morris et al., 1970; Maciorowski et al., 2007) that may result in limiting their beneficial effects for improving growth performance. Starter pig diets are typically fed in pelleted form. The heating and conditioning of ingredients before and during the pelleting process has been shown to improve growth performance (Steidinger et al., 2000; Myint et al., 2007) and may affect microbial populations within complete pelleted feeds. Recent studies suggest that nursery pigs started on pelleted diets have increased gain and feed intake when compared to pigs started on meal diets (Steidinger et

al., 2000; Groesbeck et al., 2006). Pelleting the diet increases the cost; therefore, feeding meal-based nursery diets may result in a less expensive option for swine producers, but potential bacteria from ingredients not pelleted on growth performance is not well understood.

Previous research has demonstrated an improvement in nursery pig growth performance when fed diets that contain irradiated SDAP compared to non-irradiated SDAP (DeRouchey et al., 2003a,b; 2004), indicating that ingredient bacterial concentrations may affect growth performance in meal diets. DeRouchey et al., (2003b) also demonstrated that nursery pigs fed diets containing irradiated soybean meal had increase ADG, ADFI and G:F, while pigs fed diets containing irradiated fish meal tended to have improved G:F.

Therefore, the objectives of these experiments were to determine the effects of non-irradiated or irradiated SDAP fed in either meal or pellet form on nursery pig performance, and evaluate the effects of irradiated protein sources (SDAP, soybean meal, and fish meal) in the diet and fed in either meal or pelleted form on nursery pig performance.

MATERIALS AND METHODS

The Kansas State University Animal Care and Use Committee approved all experimental protocols used in these experiments. All pigs used in these experiments were 21 ± 3 days of age at weaning and randomly allotted and blocked by weaning weight to dietary treatments. All diets were formulated to meet or exceed the NRC (1998) nutrient requirements. Initial temperature of the nursery was maintained at 32°C

for the first week and decreased approximately 2°C each week thereafter. All pens contained a self-feeder and waterer to provide ad libitum access to feed and water.

Raw ingredient samples were collected before diet manufacturing, and complete feed samples were collected for analysis at the start of each trial. Bacterial concentrations were determined on ingredient and final diets by total plate and coliform counts (Carter and Cole, 1990).

Exp. 1

A total of 192 pigs (PIC 337 × C22, Franklin, KY) with initial average BW of 6.0 ± 0.82 kg were used in a 25-d growth assay. Pigs were blocked by weight and randomly allotted to one of 4 treatments with 6 pigs/pen and 8 replications/treatment. Pigs were housed in an environmentally controlled nursery in 1.2 × 1.5-m pens with woven metal flooring.

Pigs were allotted in a 2 × 2 factorial arrangement. Main effects included diet form (meal or pellet) and either non-irradiated (regular) or irradiated SDAP. Treatment diets were fed from d 0 to 11 (Table 1). Treatments consisted of a single diet containing 5% SDAP (non-irradiated or irradiated) fed in either meal or pelleted form. For Phase 2, (d 11 to 25), all pigs were fed a common diet in meal form. The SDAP (AP920, American Protein Corporation, Ames, IA) used in this experiment was all obtained from the same lot. The SDAP was irradiated at Iowa State University Linear Accelerator Facility (Ames, IA) with an average irradiation dose of 11.92 kGy. Originally two meal diets were manufactured, one with irradiated SDAP and one with non-irradiated SDAP. One half of each meal batch was then conditioned at 60°C and pelleted using a CPM (Century Model, 100 HP, California Pellet Mill Co., Crawfordsville, IN.) equipped with a

die that had an effective thickness of 31.8 mm and holes 3.18 mm in diameter. Pigs were weighed and feed disappearance was measured on d 0, 11, and 25 to determine ADG, ADFI, and G:F.

Exp. 2

A total of 350 pigs (PIC 337 × 1050) with initial average BW of 4.9 ± 0.95 kg were used in a 22-d growth assay. Pigs were blocked by weight and randomly allotted to one of 10 treatments, with 5 pigs/pen and 7 pens/treatment. Pigs were housed in an environmentally controlled nursery in 1.2 × 1.2-m pens with woven metal flooring.

Treatments consisted of a single diet formulation that was fed in either meal or pelleted form (Table 1). Within each form, the diet was fed without irradiated ingredients or with irradiated SDAP, soybean meal, fish meal, or all three irradiated protein sources. These diets were fed from d 0 to 11. All pigs were then fed a common diet for phase 2 (d 11 to 22). The SDAP, soybean meal, and fish meal were irradiated at Iowa State University Linear Accelerator Facility (Ames, IA) with an average irradiation dose of 10.20 kGy. The five meal diets were manufactured with one half of each of the meal diet steam conditioned to 65.5°C and pelleted using a California Pellet Mill (Master Model HD, Series 2000 Crawfordsville, IN.) equipped with a die that had an effective thickness of 31.8 mm and holes 3.96 mm in diameter, resulting in the ten experimental dietary treatments. Pigs were weighed and feed disappearance was measured on d 0, 14, and 22 to determine ADG, ADFI, and G:F

Statistical Analysis

Analyses were performed using the MIXED procedures of SAS (SAS Inst. Inc., Cary, NC). Data from Exp. 1 were analyzed as a 2 × 2 factorial (pellet or meal, and non-

irradiated or irradiated SDAP) with pen as the experimental unit. Experiment 2 was analyzed as randomized complete block design with pen as the experimental unit. Contrasts were used to evaluate differences between diets with non-irradiated and irradiated ingredients and meal and pelleted diets.

RESULTS

Exp.1

Irradiation of SDAP reduced the level of total bacteria compared to non-irradiated SDAP (Table 2). Pelleting of diets resulted in a slight decrease in total plate counts when compared to meal diets. No difference was seen comparing complete diets with or without irradiated SDAP.

There was a diet form × SDAP irradiation interaction ($P < 0.05$) for ADG, d 0 to 11 (Table 3). This interaction was the effect of pigs fed irradiated SDAP in either diet form had increased ADG, increasing at a greater rate in meal diets. There was no difference ($P < 0.18$) in ADFI between treatments. Also, from d 0 to 11, pigs fed pelleted diets and pigs fed irradiated SDAP had improved G:F ($P < 0.01$) compared to pigs fed meal diets and regular SDAP, respectively.

From d 11 to 25, there was a diet form × irradiated SDAP interaction for both ADG ($P < 0.03$) and ADFI ($P < 0.04$). This interaction was the effect of pigs fed irradiated plasma in meal form had increased ADG and ADFI, while pigs fed diets with irradiated SDAP in pelleted form had a slight decreased in ADG and ADFI when compared to pigs fed non-irradiated SDAP. Pigs fed meal diet had a tendency for increased ($P < 0.08$) G:F compared with pigs fed diets in pelleted form.

Overall (d 0 to 25), there was a diet form × irradiated SDAP interaction for ADG ($P < 0.02$) and a tendency for ADFI ($P < 0.06$). Pigs fed irradiated SDAP in either diet form had increased ADG, increasing at a greater rate in meal diets. Pigs fed irradiated SDAP and pigs fed the pelleted diets had increased ADG, with the greatest increased occurring in the meal fed pigs. Pigs fed the pelleted diets had a tendency ($P < 0.06$) for increased G:F compared to the pigs fed the meal diets. Pigs fed the diets containing irradiated SDAP had a tendency ($P < 0.06$) for increased G:F compared to the pigs fed the diets containing the non-irradiated SDAP.

Exp. 2

Irradiation of the SDAP, soybean meal, and fish meal reduced total bacteria and coliform plate counts (Table 4). Pelleting of the diets also resulted in a reduction in the total bacterial counts when compared to the meal diets.

There were no irradiation × diet form interactions ($P > 0.16$) observed for growth performance criteria (Table 5). From d 0 to 11, pigs fed the diets containing irradiated protein sources had increased ($P < 0.03$) G:F compared with pigs fed the control diets, with no difference in ADG or ADFI. Pigs fed pelleted diets had increased ($P < 0.01$) G:F compared with pigs fed meal diets with no difference in ADG and ADFI.

From d 11 to 22, pigs fed meal diets had a tendency for increased ($P < 0.10$) ADFI compared with pigs fed pelleted diets with no difference in ADG or G:F.

Overall (d 0 to 22), pigs fed pelleted diets had increased ($P < 0.01$) G:F compared with pigs fed meal diets. Pigs fed diets containing irradiated protein sources had a tendency for increased ($P < 0.10$) G:F compared with pigs fed control diets.

DISCUSSION

Nursery pig diets are a complex formulation of several ingredients including grains, protein sources, lactose sources, and amino acids. As grain prices continue to increase and the swine industry continues to include expensive specialty ingredients in diets to maximize growth performance, producers are evaluating alternative ways to reduce diet cost and maintain growth performance. Majority of the starter nursery pig diets are pelleted, adding additional cost to an already expensive diet. If producers could eliminate the need to pellet and feed diets in meal form, they could potentially reduce diet costs. A recent study demonstrated that nursery pigs started on pelleted diets have increased gain and feed intake when compared to pigs started on meal diets (Groesbeck et al., 2006). Similar to our studies, Steidinger et al. (2000) has also demonstrated that pigs fed pelleted diets have increased ADG and G:F.

One factor that could contribute to the difference between the growth performance responses between the pigs fed the meal diets and pigs fed the pelleted diets could be bacterial concentration in the feed. As expected, data from both experiments demonstrated that meal diets have a slightly higher concentration of bacteria compared to pelleted diets, indicting that meal diets would have a greater potential of containing pathogenic bacteria when compared with diets that are pelleted. Spray-dried animal plasma, fish meal, and soybean meal are ingredients sources that have potential for greater bacterial concentrations (Kume et al., 1982; DeRouchey et al., 2004; Maclorowski et al., 2007). Fish meal has even been shown to be a source of *Salmonella* (Morris et al., 1970), which can reduce growth performance of weanling pigs. Therefore, irradiation of ingredients with high bacteria concentrations may allow producers to wean

and start pigs on meal diets and achieve equal performance to pigs weaned and started on pelleted diets (DeRouchey et al., 2004).

In both experiments, pelleting of the diet reduced total bacteria and coliform concentrations compared with meal diets. The bacteria reduction can be attributed to heat treatment of the feed during conditioning and pelleting (Skoch et al., 1983; Myint et al., 2007). The reduction of bacteria by pelleting is dependant on temperature, conditioning duration, and the moisture concentration (Maciorowski et al., 2004). A conditioning duration of 15s at 70-80°C has been shown to significantly reduce coliforms in meal diets (Furuta et al., 1980) while a temperature of 85°C was needed to reduce the presence of *E. coli* and *Salmonella* (Ekperigin et al., 1990). Nursery diet mash is typically heated to 75 or 85° C depending on formulation of diet (Hancock and Behnke, 2001). Complex diets containing high inclusions of spray-dried animal plasma and whey are pelleted at lower temperatures, which is not high enough to completely eliminate the presence of all bacteria. However, as demonstrated in our studies, pelleting at 65°C will reduce bacterial concentrations. This decrease in dietary bacterial concentrations could be beneficial to bacterial population in the gut. These changes in bacterial concentration could contribute to the increased growth performance of pigs weaned and started on pelleted diets compared with pigs weaned and started on meal diets.

The addition of specialty ingredients has become standard in diets for weanling pigs. The addition of SDAP consistently improves ADG and ADFI when fed to weanling pigs (Bergstrom et al., 1997; Lawrence et al., 2004; Pierce et al., 2005). Fish meal can be added as a protein source in place of high levels of soybean meal (Stoner et al., 1990) to improve nursery pig growth performance. However, bacteria analysis reveled that

SDAP, soybean meal, and fish meal have high bacteria concentrations. These data are similar to other studies showing bacteria concentration in feed ingredients (Morris et al., 1970; Kume et al., 1982). Irradiation can be used to reduce bacteria and coliform concentrations, and therefore may be used as a management tool to reduce bacterial concentrations in ingredients. Irradiation has been used to reduce bacterial concentrations in feed ingredients in both pig and chick diets (Cambell et al., 1986; DeRouchey et al., 2003a,b), as well as reducing bacterial concentrations in animal-based protein sources (Kume et al., 1982; DeRouchey et al., 2004).

Previous research has demonstrated an improvement in growth performance in weanling pigs fed diets that contained irradiated SDAP compared to non-irradiated spray-dried animal plasma (DeRouchey et al., 2003a,b; 2004). The only factor altered in these treatment diets was the bacterial concentration of the SDAP (irradiated or non-irradiated), suggesting that the reduction of bacteria was a contributing factor improving growth performance. Although Exp. 2 did not demonstrate an improvement in growth for pigs fed diets containing irradiated soybean meal or fish meal, previous research has demonstrated that pigs fed diets containing irradiated soybean meal have increase ADG, ADFI and G:F, while pigs fed diets containing irradiated fish meal tended to have improved G:F (DeRouchey et al., 2003b). However, when the complete diet was irradiated, there was no improvement in growth performance. DeRouchey et al. (2003a) also demonstrated that pigs fed diets containing an irradiated combination of SDAP and spray-dried egg improved ADG, and pigs fed diets containing irradiated spray-dried blood meal also tended to have increased G:F compared with pigs fed the corresponding non-irradiated treatments.

Results from these studies indicated that irradiation of feed ingredients is an effective process to reduce total bacteria and coliform counts. While data in the present studies are not in total agreement, it appears that feeding a meal diet with irradiated SDAP may result in similar growth performance to that of pigs fed pelleted diets. Irradiation of ingredients SDAP, soybean meal, and fish meal improved feed efficiency compared to pigs fed diets containing non-irradiated ingredients. Furthermore, pigs fed pelleted diets had greater improvement in ADG, ADFI, and G:F compared with pigs fed meal diets.

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Table 5.1 Ingredient composition of experimental diets (Exp. 1 and 2; as fed basis)

Table 1. Ingredient composition of experimental diets (Exp. 1 and 2; as-fed basis)[1, 2]

Item	SDAP	Common[3]
Corn	44.02	53.71
Soybean meal, 46.5% CP	19.40	31.54
Spray-dried whey	20.00	10.00
Spray-dried animal plasma	5.00	---
Fish meal	5.00	---
Soy oil	3.00	---
Monocalcium phosphate, 21% P	0.75	1.50
Limestone	0.65	0.95
Salt	0.25	0.35
Vitamin premix[4]	0.25	0.25
Trace mineral premix[4]	0.15	0.15
Antibiotic[5]	0.70	0.70
Zinc oxide	0.38	---
L-lysine.HCl	0.23	0.33
DL-methionine	0.15	0.15
L-threonine	0.08	0.13
Total	100.00	100.00
Calculated analysis		
Total lysine, %	1.50	1.30
ME, kcal/kg	3,422	3,250
CP, %	22.6	20.9
Ca, %	0.88	0.84
P, %	0.80	0.76
Available P, %	0.57	0.46
Lysine:ME, g/Mcal	4.38	4.00

[1]In Exp. 1, the phase 1 (d 0 to 11) spray-dried animal plasma (SDAP) diet was feed in either meal or pelleted form with irradiated SDAP or non-irradiated SDAP.
[2]In Exp. 2 the phase 1 (d 0 to 11) diet was feed in either meal or pelleted form with irradiated protein sources (SDAP, soybean meal, fish meal or a diet containing all three irradiated protein sources).
[3]Phase 2 was a common diet fed to all pigs in meal form, Exp. 1 (d 11 to 25), and Exp. 2 (d 11 to 22).
[4]Provided (per kilogram of complete diet): 11,025 IU of vitamin A; 1,654 IU of vitamin D; 44 IU of vitamin E; 4.4 mg of vitamin K (as menadione dimethylpyrimidinol bisulfate); 55.1 mg of niacin; 33.1 mg of pantothenic acid (as d-calcium pantothenate); 9.9 mg of riboflavin; 0.044 mg of vitamin B_{12}; 16.5 mg of Cu; 165.4 mg of Fe; 39.7 mg of Mn; 0.3 mg of Se; 165.4 mg of Zn; and 0.3 mg of I.

[5]Provided 140g Neomycin sulfate and 140g Oxytetracycline HCl per ton of complete feed.

Table 5.2 Aerobic bacteria concentration, Exp. 1

Table 2. Aerobic bacteria concentration (Exp. 1)

Item	Total plate count	Total coliform count
Spray-dried animal plasma, CFU/g		
Non-irradiated	1.1×10^5	$< 1.0 \times 10^1$
Irradiated[1]	$< 1.0 \times 10^1$	$< 1.0 \times 10^1$
Diet with non-irradiated SDAP, CFU/g		
Meal	2.6×10^4	3.9×10^2
Pellet	2.0×10^3	$< 1.0 \times 10^1$
Diet with irradiated SDAP, CFU/g		
Meal	2.1×10^4	$< 1.0 \times 10^1$
Pellet	4.8×10^3	$< 1.0 \times 10^1$

[1]Spray-dried animal plasma (SDAP) was irradiated at 11.92 kGy.

Table 5.3 Effects of meal and pelleted diets with or without irradiated spray-dried animal plasma

Table 3. Effects of meal and pelleted diets with or without irradiated spray-dried animal plasma (Exp.1)[1]

	Non-irradiated SDAP[2]		Irradiated SDAP			Probability, P <		
Data	Meal	Pellet	Meal	Pellet	SE	Diet form	SDAP irradiation	Diet form × SDAP irradiation
D 0 to 11								
ADG, g	283	360	348	374	16.5	0.01	0.01	0.05
ADFI, g	346	373	378	371	15.7	0.18	0.37	0.15
G:F	0.82	0.96	0.92	1.01	0.02	0.01	0.01	0.16
D 11 to 25								
ADG, g	398	434	435	429	13.8	0.10	0.08	0.03
ADFI, g	516	579	569	574	19.1	0.02	0.08	0.04
G:F	0.77	0.75	0.76	0.75	0.01	0.08	0.60	0.87
D 0 to 25								
ADG, g	353	404	401	407	14.1	0.01	0.01	0.02
ADFI, g	449	496	494	495	17.2	0.05	0.08	0.06
G:F	0.79	0.81	0.81	0.83	0.01	0.06	0.06	0.58

[1]A total of 192 pigs (six pigs per pen and eight pens per treatment) with an initial average initial BW of 6.0 ± 0.82 kg were used in the study.
[2]Spray-dried animal plasma (SDAP).

Table 5.4 Aerobic bacteria concentration, Exp. 2

Table 4. Aerobic bacteria concentration (Exp. 2)[1]

Item	Total plate count	Total coliform count
Protein source, CFU/g		
SDAP	4.8×10^4	2.9×10^2
Soybean meal	3.3×10^3	3.8×10^2
Fish meal	5.4×10^5	2.6×10^2
Irradiated protein source, CFU/g		
SDAP	3.0×10^1	$< 1.0 \times 10^1$
Soybean meal	1.8×10^1	$< 1.0 \times 10^1$
Fish meal	4.1×10^1	$< 1.0 \times 10^1$
Complete meal diet , CFU/g		
Control	1.5×10^5	3.6×10^2
Irradiated SDAP	2.0×10^3	$< 1.0 \times 10^1$
Irradiated soybean meal	2.1×10^3	$< 1.0 \times 10^1$
Irradiated fish meal	1.8×10^4	$< 1.0 \times 10^1$
All three irradiated sources	1.8×10^3	$< 1.0 \times 10^1$
Complete pelleted diet, CFU/g		
Control	1.7×10^2	$< 1.0 \times 10^1$
Irradiated SDAP	1.4×10^2	$< 1.0 \times 10^1$
Irradiated soybean meal	1.8×10^2	$< 1.0 \times 10^1$
Irradiated fish meal	1.6×10^2	$< 1.0 \times 10^1$
All three irradiated sources	1.4×10^2	$< 1.0 \times 10^1$

[1]The spray-dried animal plasma (SDAP), fish meal and soybean meal was irradiated at Iowa State University Linear Accelerator Facility (Ames, IA) with an average irradiation dose of 10.20 kGy.

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Table 5.5 Effects of irradiation of protein source fed in meal or pelleted diets on nursery pig growth performance, Exp. 2

Table 5. Effects of irradiation of protein source fed in meal or pelleted diets on nursery pig growth performance (Exp. 2) [1,2,3]

	Meal Diet					Pellet Diet							
		Irradiated Ingredient					Irradiated Ingredient					Probability, P <	
Item	Control	SDAP[4]	SBM[4]	Fish Meal	All 3	Control	SDAP	SBM	Fish Meal	All 3	SE	Irr vs Non	Meal vs Pellet
D 0 to 11													
ADG, g	233	237	256	236	257	228	246	256	257	235	21.0	0.28	0.95
ADFI, g	275	268	275	261	268	249	246	259	268	254	18.0	0.99	0.17
G:F	0.84	0.87	0.93	0.90	0.95	0.91	0.99	0.98	0.96	0.92	0.03	0.03	0.01
D 11 to 22													
ADG, g	592	577	591	585	560	587	552	582	569	573	30.0	0.37	0.57
ADFI, g	764	724	754	723	722	715	697	722	725	695	36.0	0.33	0.10
G:F	0.78	0.80	0.78	0.81	0.77	0.82	0.80	0.82	0.78	0.83	0.03	0.97	0.21
D 0 to 22													
ADG, g	358	353	378	361	364	358	353	374	368	354	22.0	0.71	0.90
ADFI, g	447	423	449	427	429	418	404	427	431	409	23.0	0.59	0.12
G:F	0.80	0.83	0.84	0.84	0.84	0.85	0.87	0.88	0.85	0.87	0.02	0.10	0.01

[1]A total of 350 pigs (5 pigs/ pen and 7 pens/treatment) with an average initial average BW of 4.9 ± 0.95 kg were used in the study.
[2]Phase 1 (d 0 to 11) diet was feed in either meal or pelleted form with irradiated protein sources (SDAP, soybean meal, fish meal or a diet containing all three irradiated protein sources). Phase 2 (d 11 to 22) diet was a common diet fed to all pigs in meal form.
[3]No interactions between (P > 0.16) irradiation of protein source × diet form were observed.
[4]Spray-dried animal plasma (SDAP), soybean meal (SBM).

CHAPTER 6 - Relative abundance of mRNA for selected genes in gastrointestinal tissues and bacterial diversity of gastrointestinal contents from pigs fed meal or pelleted diets containing irradiated or non-irradiated spray-dried animal plasma

Abstract: Two swine feeding technologies, pelleting and addition of irradiated spray-dried animal plasma (SDAP), improve growth performance of nursery pigs and this effect on pig growth may be associated with changes in expression of selected gastrointestinal (GI) genes and diversity of bacterial populations in the gut. In Exp. 1, we evaluated relative abundance of mRNA for the neonatal Fc receptor (FcRn), TNF-α, insulin-like growth factor-1 (IGF-I), and proglucagon using real-time PCR in GI tissues from weaned pigs fed meal or pelleted diets with irradiated or non-irradiated spray-dried animal plasma (SDAP) in a 2 x 2 factorial arrangement of treatments. Diversity of GI bacteria was assessed using denaturing gradient gel electrophoresis (DGGE). Relative abundance of mRNA for FcRn, TNF-α, IGF-I and proglucagon and bacterial diversity were assessed in GI tissues at the conclusion of an 11 d feeding period (n = 6 pigs/treatment combination). Relative abundance of FcRn mRNA was greater in pigs fed the non-irradiated SDAP compared with the pigs fed irradiated SDAP ($P < 0.02$). In addition, FcRn mRNA was more abundant in pigs fed meal diets compared with the pigs fed pelleted diets ($P < 0.05$). Neither diet form nor irradiation of SDAP affected relative abundance of mRNA

for TNF-α, IGF-1, or proglucagon. However, there was an effect of tissue type for TNF-α and proglucagon with relative abundance of TNF-α greatest in jejunal tissues ($P < 0.02$) and proglucagon greatest in cecal tissues ($P < 0.07$). Neither diet form nor SDAP irradiation affected GI bacterial diversity. In Exp. 2, fetal pigs were obtained at d 55 and 70 of gestation (n = 5 fetuses/gestational age) and the relative abundance of FcRn mRNA was determined in the presumed absence of a GI a bacterial population. Greater relative abundance of FcRn mRNA was observed in d 55 fetuses compared to d 70 fetuses ($P < 0.01$). In conclusion, relative abundance for FcRn in GI tissues appears be responsive to diet form (meal or pellet) and irradiation of SPAD in weanling pigs and to decrease with advancing fetal age in fetal pigs. These changes do not appear to be tightly coupled with GI bacterial diversity.

Key Words: Neonatal Fc Receptor, bacterial diversity, spray-dried animal plasma, weanling pig

1. Introduction

The classic role of the neonatal Fc receptor (FcRn) is to transport IgG from milk across intestinal epithelial cells in newborns (Simister et al., 1997). The FcRn also has been implicated in extending the half-life of circulating IgG (Kacskovics, 2006). The FcRn is a heterologous macromolecule, structurally similar to major histocompatibility complex (MHC) class-I, consisting of a triplet of Ig-like α chains associated with β-2-microglobulin (Claypool et al., 2004). The receptor participates in intracellular trafficking of IgG and the maintenance of circulating IgG (Dickinson et al., 1999). The FcRn was detected by immunostaining on the apical surface of human fetal small intestine (Israel et

al., 1997) and was found to be equally distributed among stomach, ileal, and colonic epithelium (Shah et al., 2003).

Feeding spray-dried animal plasma (SDAP) to weanling pigs reduced basal IL-1β and TNF-α mRNA expression in all tissues leading Touchette et al. (2002) to conclude that basal immune activation may be reduced in pigs fed SDAP. Moreover, SDAP may alter epithelial cell proliferation or turnover because both villous height and crypt depth were reduced in pigs fed SPAP (Touchette et al., 2002). In addition, irradiation of SDAP improved growth performance of nursery pigs and the growth enhancement associated with irradiation was presumed to be the effect of irradiation to reduced bacterial load in this specialty feed ingredient (DeRouchey et al., 2004). Finally, pelleting of nursery diets is associated with improved growth performance and results in feed containing lower total bacterial counts.

The aforementioned factors collectively led us to hypothesize that the combination of irradiation of SDAP and pelleting could alter expression of selected GI gene transcripts and alter small intestinal bacterial diversity. We selected the FcRn as a gene of interest because of its putative role in handling luminal Ig and because the Ig fraction of SDAP is thought to impart the growth response in diets for weaned pigs (Owen et al., 1995; Spencer et al., 1997). Additionally, we evaluated TNF-α because of the aforementioned effect of SDAP to reduce TNF-α mRNA globally in nursery pigs (Touchette et al., 2002). Gut expression of mRNA for IGF-I is sensitive to dietary (Li et al., 2006) and management (Tang et al., 2002) technologies that favor enhanced growth of weaned pigs. Finally, we evaluated proglucagon because glucagon-like peptide 2 (post translational processing product of proglucagon in the gut; see Drucker, 2002 for review)

is associated with epithelial proliferation in the small intestine of pigs (Burrin et al., 2002).

2. Materials and Methods

2.1 Experiment 1

The Kansas State University Animal Care and Use Committee approved all protocols used in these experiments. Pigs used in this experiment were 21 ± 3 days of age at weaning. All diets were formulated to meet or exceed the NRC (1998) nutrient requirements. Initial ambient temperature of the nursery was maintained at 32°C for the first week and decreased by approximately 2°C each week thereafter. All pens contained one self-feeder and one waterer to provide ad libitum access to feed and water.

A total of 24 pigs (initial BW 5.2 kg) were used. Pigs were initially blocked by weight, and randomly allotted in a 2 × 2 factorial arrangement of dietary treatments (Table 1). Main effects included diet form, meal or pellet, and either non-irradiated or irradiated SDAP. Treatment diets were fed from d 0 to 11. Treatments consisted of a single diet containing 5% SDAP fed in either meal or pelleted form, with non-irradiated or irradiated SDAP (AP 920; American Protein, Ames, IA). The SDAP was irradiated at Iowa State University Linear Accelerator Facility (Ames, IA) with an average irradiation dose of 11.92 kGy. All diets were manufactured at Kerber Milling, Emmetsburg, IA. Originally two meal diets were manufactured, one with irradiated SDAP and one with non-irradiated SDAP. One half of each meal batch was then conditioned at 60°C and pelleted with a mill (Century Model, 100 HP, California Pellet Mill Co., Crawfordsville, IN) equipped with a die that had an effective thickness of 31.8 mm and holes 3.18 mm in diameter. At the conclusion of 11 d of feeding, all pigs were euthanized. Then, an

incision was made down the abdominal midline, and the ileocecal junction was immediately located. The jejunal, ileal, and cecal sections were immediately clamped off and digestive contents and sections of tissues of interest were collected into 1.5 mL microcentrifuge tubes. All samples were rapidly frozen in liquid nitrogen and remained frozen at -80°C until assayed. Tissues were later homogenized and total RNA was isolated using TRI® Reagent (Sigma–Aldrich Co.). Total RNA extraction, synthesis of cDNA, and real-time quantitative PCR were carried out as described previously from our laboratory (Burkey et al., 2007). Primer-probe sets for TaqMan assays were developed using published GenBank® sequences (FcRn, AY135635; TNF-α, NM_214022; IGF-1, M31175; and proglucogon, AY242124) and PrimerExpress® software (Applied Biosystems). Eukaryotic 18S rRNA (Applied Biosystems) primers and probe served as an endogenous control.

Genomic DNA was extracted from digestive contents using the MO BIO Laboratories, Inc. UltraClean^{TM} Fecal DNA Kit (Carlsbad, California). Denaturing gradient gel electrophoresis (DGGE) was used to determine changes in the intestinal microbial populations due to treatment effects. DGGE is a technique that identifies microbial species' diversity based on the genetic makeup of the organism; each band present on a polyacrylamide gel correlates to a separate bacterial species present in the jejunal, ileal, or cecal contents of the pig sampled. For PCR-DGGE analysis of total bacteria, each DNA sample was standardized to 20 μg/mL and then amplified using primers specific for conserved sequences flanking the variable V3 region of 16S rDNA (341F:5′CACGGGGGGGCCTACGGGAGGCA GCAG 3′ + 5′ 40 nucleotide GC clamp and 534R: 5′ ATTACCGCGGTGCTGG 3′), as described previously (Collier et al.,

2003). Similarity of bacterial populations present were determined using Bionumerics Software (Applied Maths, Austin, Texas), which determined similarity coefficients based on the number and location of the bands for each sample. Band number corresponds to the number of individual bands in a single gel lane.

2.2 Experiment 2

This study utilized mRNA isolated from intestinal tissues of fetuses collected for another study already published from our laboratory (Brown et al., 2007). Relative abundance of mRNA was determined for FcRn as for Exp. 1.

2.3 Statistical Analysis

Statistical analysis was performed using the MIXED procedures in SAS. In Exp. 1 data were analyzed as a 2 × 2 factorial arrangement of treatments with main effects of diet form (meal or pellet) and irradiated or non-irradiated plasma. Contrasts were used to evaluate differences between pigs fed diets with non-irradiated and irradiated ingredients and meal versus pelleted diets. Relative abundance of gene targets were analyzed using the ΔΔCT method as described previously (Burkey et al., 2007). For this study, ΔCT from pigs fed the combination of meal diets and non-irradiated SDAP were utilized as the reference expression to compare relative expression of the remaining treatments. In Exp. 2 relative abundance of FcRn in fetal intestinal tissues was analyzed using ΔCT values from pigs at d 55 or 70 of gestation (as described by Brown et al., 2007). These data were analyzed as a completely random design with pig as the experimental unit and with gestational age as the sole source of variation in the model.

3. Results

In Exp. 1, FcRn mRNA (Figure 1) was more abundant in pigs fed the non-irradiated spray-dried animal plasma compared with the pigs fed irradiated animal plasma($P < 0.02$) and was also more abundant in pigs fed meal diets compared with the pigs fed pelleted diets ($P < 0.05$). Neither diet form nor irradiation of SDAP affected relative abundance of mRNA for TNF-α, IGF-I, or proglucagon (Tables 2 and 3). However, there was an effect of tissue type for TNF-α and proglucagon mRNA. The relative expression of TNF-α mRNA was greatest ($P < 0.02$) in jejunal tissues compared with ileal and cecal tissue samples. The relative expression of proglucagon was greatest ($P < 0.07$) in the cecal tissues compared with jujunal and ileal tissue samples. Neither irradiation nor diet form affected the number of bacterial bands present on the DGGE; however, the there was an effect ($P < 0.08$) of tissue type on the number of V3-16S PCR-DGGE bands (Figures 3 and 4). Each band represents at least one bacterial species (Collier et al., 2003), and as expected, cecal contents had the greatest number of bands and therefore the greatest bacterial diversity.

In Exp. 2, FcRn transcripts were observed in all fetuses (Figure 1). Relative abundance of FcRn was lower in the d 70 fetuses compared to the d 55 fetuses ($P < 0.01$).

4. Discussion

To our knowledge, this is the first report of expression of the FcRn in fetal or in weaned pigs. Our observation of the presence of FcRN gene transcripts in intestinal tissues of pigs is consistent with the observation of FcRn on the apical surface of human fetal small intestine (Israel et al., 1997) and distributed rather uniformly among stomach,

ileal, and colonic epithelium (Shah et al., 2003). Similarly, in the current study, tissue of origin in weaned pigs did not affect the relative abundance of mRNA for FcRn.

Our data suggest that the relative abundance of FcRn mRNA is affected both by diet form and by irradiation of SDAP. The FcRn was relatively more abundant in pigs fed non-irradiated SDAP and in pigs fed meal diets. We are unaware of other documented links between feed manipulations and changes in gene expression for FcRn within GI tissues of pigs. However, because all pigs in the current study were fed SDAP and the Ig fraction of SDAP is thought to account for the positive effects on growth performance (need refs), it is reasonable to assume that FcRn might participate in handling Ig from SDAP at the gut level. It should be acknowledged, however, that our measurement of steady state levels of mRNA for FcRn do not asssure parallel changes at the transcriptional level for functional FcRn protein.

It is tempting to speculate that relative abundance of FcRn may be related to bacterial diversity in the gut. Both irradiation (DeRouchey et al., 2003a,b) and pelleting (Groesbeck, 2008) have well-docmented effects on bacterial counts in feed components and(or) the complete diet (in the case of pelleting). In fact, both total plate counts and total coliforms were reduced as expected by irradiation of SDAP and by pelleting for diets used in the current study. The bacterial plating data were a part of another set of growth studies and are reported elsewhere (Groesbeck, 2008). Despite these effects, however, we could not document statistically significant effects of treatment on bacterial diversity, although bacterial diversity increased in the colon compared to the jejunum and ileum. On the other hand, numerical trends in bacterial diversity paralleled the statistically significant effects of irradiation of SDAP and diet form observed for FcRn

(see Figure 1 compared to Figure 3). There was considerable variability among animals in DGGE estimates of bacterial diversity in GI contents. Therefore, whether GI bacterial diversity affects both mRNA and functional FcRn in pigs remains to be determined. On the other hand, our data indicate that FcRn is expressed relatively early in the pig fetal intestine and that relative abundance of GI FcRn varies with advancing fetal age even in the (presumed) absence of both luminal Ig or GI bacterial colonization. We cannot say with certainty if relative abundance of FcRn would have continued to decline as gestation advanced beyond d 70.

In general, the effects of SDAP irradiation and diet pelleting had minimal effects on other gene transcripts evaluated in the current study. Our original hypothesis was not borne out as neither irradiation of SDAP nor pelleting affected steady state levels of mRNA for TNF-α, IGF-1 or proglucagon. However, relative abundance of TNF-α decreased in GI tissues from the jejunum to the cecum and relative abundance of proglucagon tended to be increased in the cecum. Essentially our conclusions must be limited to the only other thing we measured in the current study, namely bacterial diversity across the jejunum, ileum, and cecum. Whether the effect on bacterial diversity within these GI regions is associated with our observed changes in TNF-α, and proglucagon must be verified with additional research.

In conclusion, relative abundance for FcRn in GI tissues appears be responsive to diet form (meal or pellet) and irradiation of SPAD in weanling pigs and to decrease with advancing fetal age in fetal pigs. These changes do not appear to be tightly coupled with GI bacterial diversity.

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Table 6.1 Composition of diets (Exp. 2; as-fed basis)

Table 1. Composition of diets, as-fed basis, Exp. 2

Item	d 0 to 11[1]
Corn	44.01
Soybean meal, 46.5% CP	19.40
Spray dried whey	20.00
Spray dried animal plasma	5.00
Menhaden fish meal	5.00
Soy oil	3.00
Monocalcium phosphate, 21% P	0.75
Limestone	0.65
Salt	0.25
Vitamin premix	0.25
Trace mineral premix	0.15
Antibiotic[2]	0.70
Zinc oxide	0.38
L-Threonine	0.08
L-Lysine HCl	0.23
DL-Methionine	0.15
	100.00
Calculated analysis	
Total lysine, %	1.50
ME, kcal/lb	1,552
Protein, %	22.6
Ca, %	0.88
P, %	0.80
Available P, %	0.57
Lysine:calorie ratio, g/Mcal	4.38

[1]The phase 1 (d 0 to 11) diet was feed in either meal or pelleted form with irradiated spray dried animal plasma or non-irradiated spray dried animal plasma.
[2]Provided 140g Neomycin sulfate and 140g Oxytetracycline HCl per ton of feed.

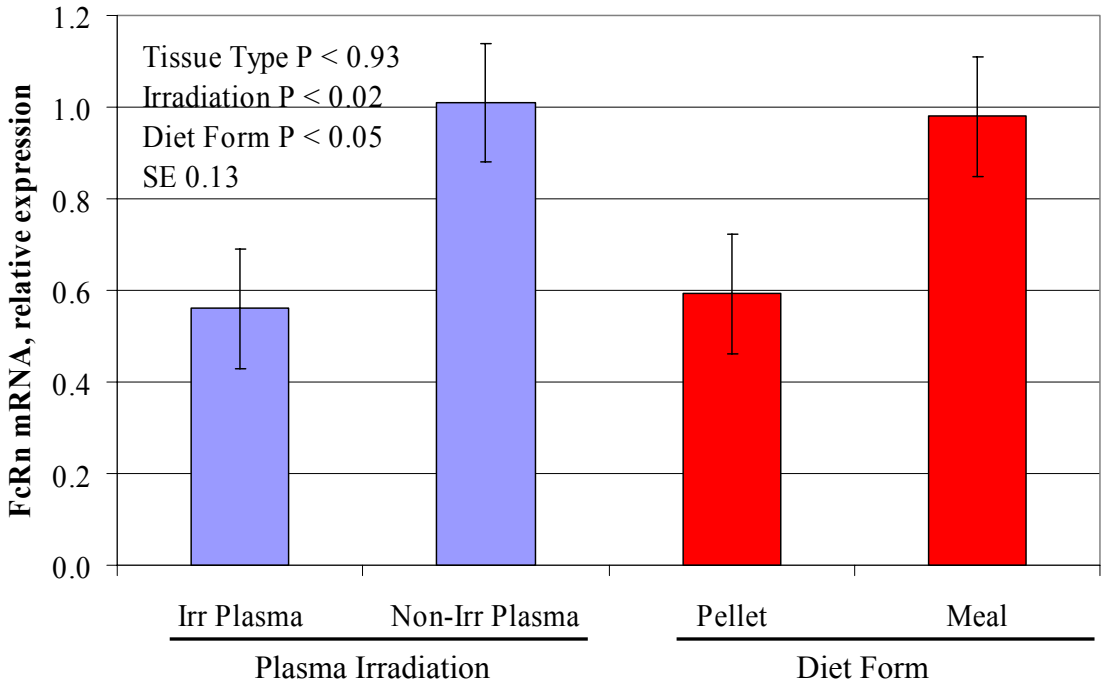

Figure 6.1 The effects of plasma irradiation (Irr) and diet form on the relative abundance of the FcRn in weanling pigs.

The FcRn mRNA was more abundant ($P < 0.02$) in pigs fed the non-irradiated plasma compared with the pigs fed irradiated plasma. The FcRn mRNA was more abundant ($P < 0.05$) in pigs fed the meal diets compared with the pigs fed pelleted diets.

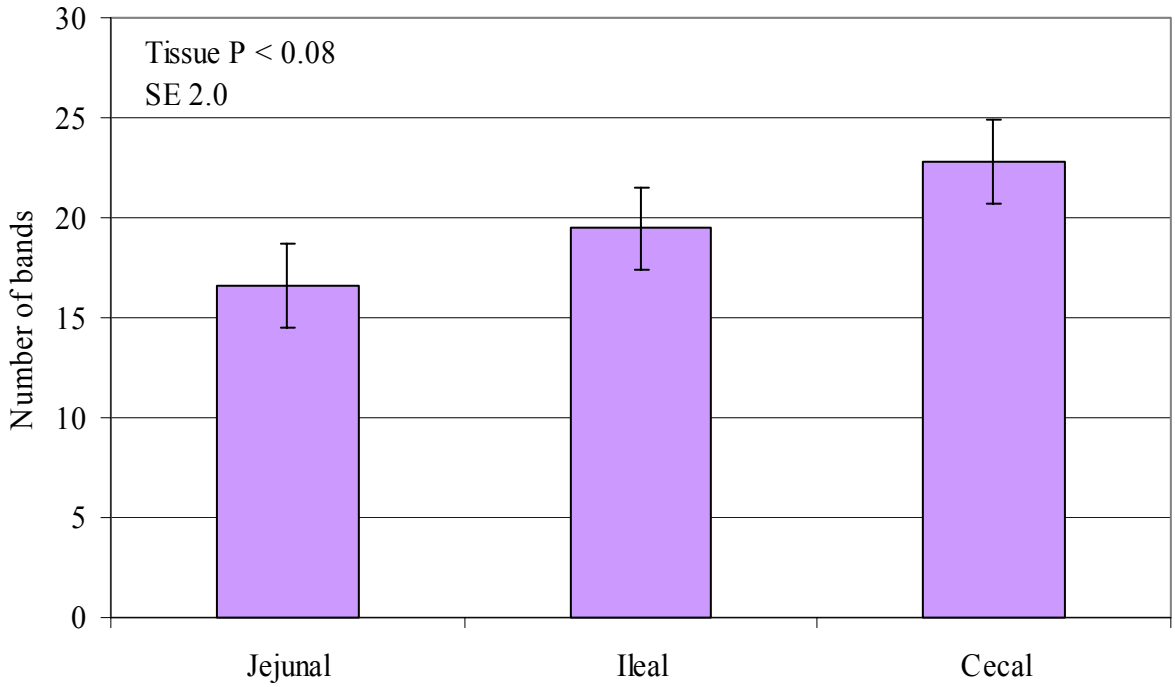

Figure 6.2 Effect of tissue type on number of DGGE bands

The effect of tissue type on the number of V3-16S PCR-DGGE bands. Each band represents at least one bacterial species. The number of bands associated with each treatment were counted and averaged. Tissue type affects number of DGGE bands. The cecal tissue had the greatest number of bands and therefore the largest bacterial load.

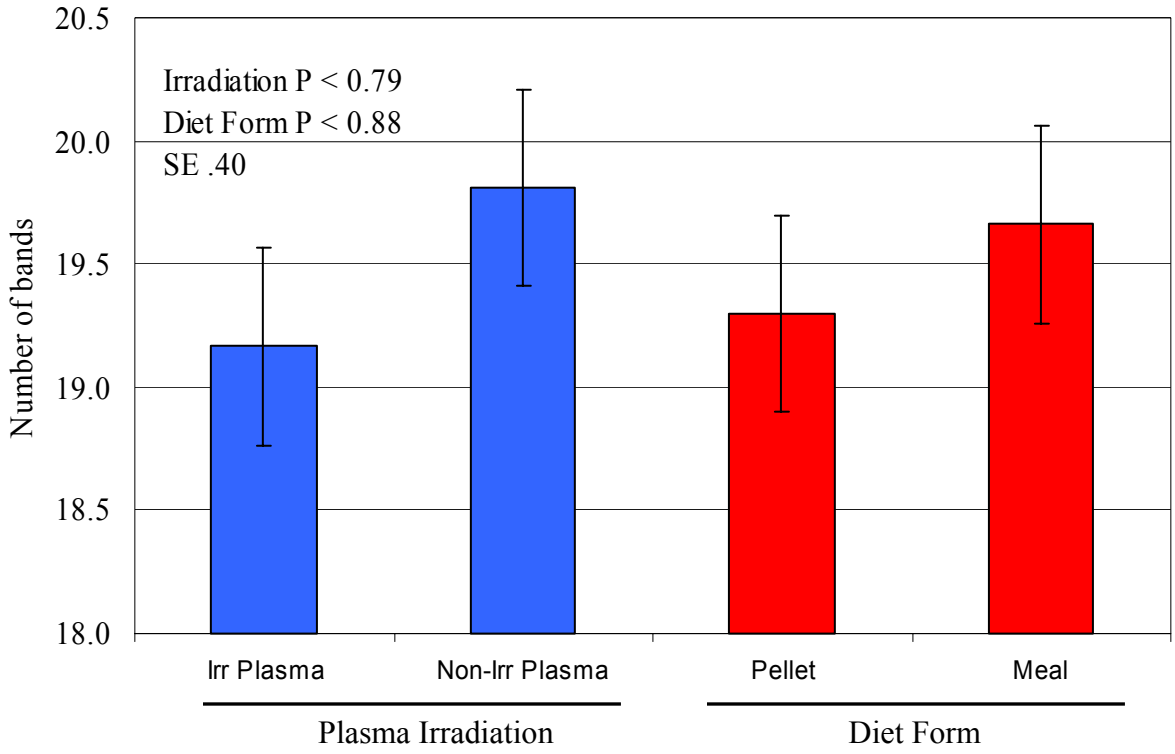

Figure 6.3 The effect of treatment on number of DGGE bands

The effect of irradiation or diet form on the number of V3-16S PCR-DGGE bands. Each band represents at least one bacterial species. The number of bands associated with each treatment were counted and averaged. There were no effects of irradiation or diet form on number of DGGE bands.

Table 6.2 Relative expression of mRNA in weanling pigs

Table 2. Relative expression of mRNA in weanling pigs[1]

	SDAP Irradiation		Diet Form			P <	
Item	Irr	Non	Meal	Pellet	SE	SDAP Irr	Diet Form
TNF-α	1.16	1.51	1.32	1.36	0.26	0.34	0.92
IGF-1	1.02	1.20	1.13	1.11	0.24	0.23	0.97
Proglucagon	1.23	1.31	1.27	1.26	0.19	0.76	0.98

[1]Values represent the mean value of tissue samples collected from the jejunum, ileum, and cecum from 24 weanling pigs.

Table 6.3 Relative expression of mRNA in tissues of weanling pigs

Table 3. Relative expression of mRNA in tissues of weanling pigs[1]

	Tissue				
Item	Jejunum	Ileum	Cecum	SE	P <
TNF-α	2.08	1.18	0.75	0.33	0.02
IGF-1	0.95	1.21	1.20	0.28	0.71
Proglucogon	1.09	1.07	1.61	0.21	0.07

[1]Values represent the mean value of tissue samples collected from the jejunum, ileum, and cecum from 24 weanling pigs.

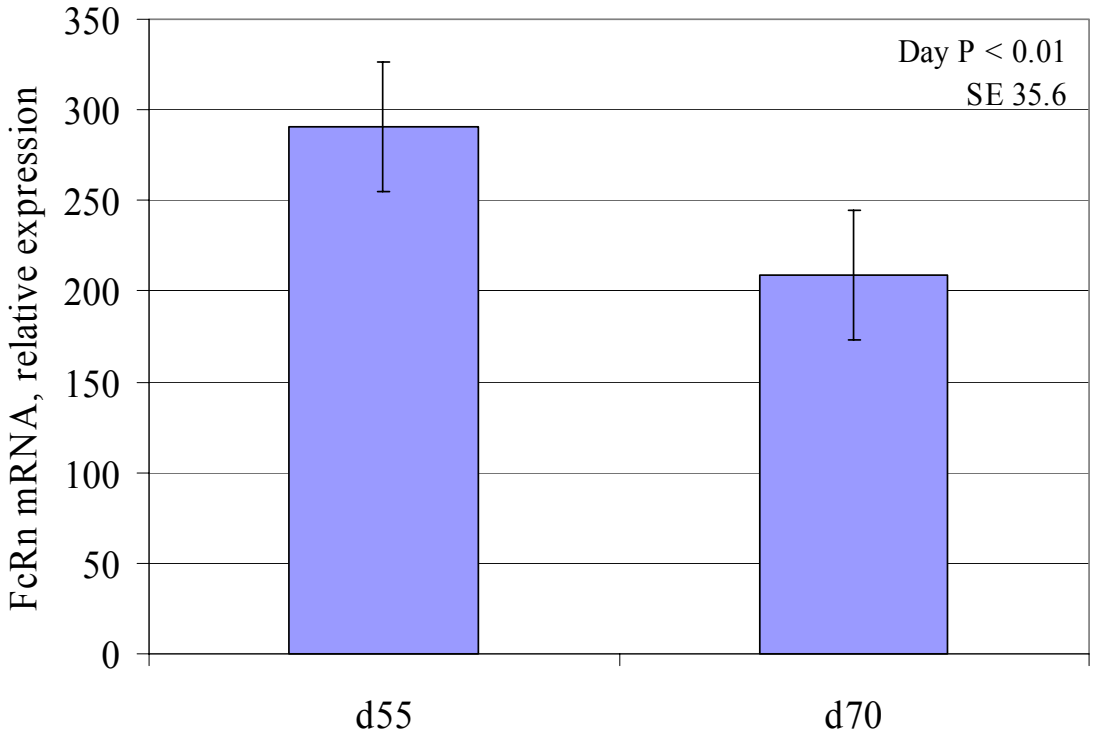

Figure 6.4 The relative expression of FcRn mRNA in fetal pig intestinal tissues collected at d 55 and d 70 of gestation.

The Fc receptor transcripts were observed in all fetuses. Relative abundance of FcRn was lower in the d 70 fetuses compared to the d 55 fetuses.

CHAPTER 7 - Influence of Pulmotil, Tylan, and Paylean on pig growth performance and weight variation

Summary

Objectives: To evaluate the effects of a feeding regimen including the use of Pulmotil®, Tylan®, and Paylean® from weaning to market compared with pigs fed no feed additives on growth performance and the potential impact on pig weight variation.

Methods: A total of 1,344 pigs were housed in a single room with open gating in a 143-d wean-to-finish trial. Pigs were blocked by pen weight and randomly allotted to one of two treatments. Experimental treatments included a control program without antibiotics (or Paylean®) or a treatment program including Pulmotil 18®, 399 ppm from d 0 to 21, Tylan 40®, 110 ppm d 21 to 42, 44 ppm from d 42 to 90, and 22 ppm from d 90 to 115, and Paylean®, 5 ppm from d 115 to 143. Individual pig weights were collected on d 0, 21, 52, 78, 115, and 143 to calculate growth performance and within pen weight variability. Carcass measurements were obtained to calculate percentage lean and fat-free lean index.

Results: For d 0 to 143, pigs fed the combination treatment (Pulmotil 18®, Tylan 40®, and Paylean®) had increased ($P < 0.01$) ADG and improved ($P < 0.01$) Gain:Feed compared with the pigs fed the control diet. Pigs fed the Pulmotil®, Tylan®, and Paylean® had a greater ($P < 0.01$) live weight, carcass weight, and loin depth at market compared with the pigs that were fed the control diet.

Implications: The feeding regimen including Pulmotil®, Tylan®, and Paylean® resulted in improved ADG and Gain:Feed primarily in the nursery phase (Pulmotil®) and late finishing (Paylean®).

Keywords: swine, feeding program, Pulmotil, Tylan, Paylean

Variation in pig weight at market is a concern within the swine industry as pork retailers are demanding a more uniform product. This requires the packer to implement pricing grids that help them narrow the weight range of pigs delivered to the plant. Through the implementation of these grids, packers are essentially encouraging producers to market uniform pigs. However, with the normal variation in growth rate observed in pigs[1], this is a challenging task for the producer. The light pigs in the group are the most heavily discounted for the producer. Light pigs that do not meet the packing grid weight specifications result in a loss of potential income to the producer. It is theorized that the use of a feeding program including antimicrobials will help maintain a high health status among the pigs and reduce variation in weight. This may benefit the producers by reducing variation within a group of pigs at time of market. Pulmotil®, Tylan®, and Paylean® are products of Elanco Animal Health, a division of Eli Lilly and Company, Indianapolis, Indiana. Previous research has shown that Pulmotil and Tylan, in separate studies, have had a positive effect on decreasing lightweight pigs and improving growth variation at marketing[1, 2, 3]. Pulmotil® (tilmicosin phosphate) is a feed medication fed to pigs that aids in the treatment and prevention of respiratory diseases like bacterial pneumonia. Tylan® (tylosin phosphate) is an antimicrobial added to feed that it used to improve weight gains and feed efficiency in nursery, grower, and finisher aged pigs[4,5]. Paylean® (ractopamine HCl) is a feed additive that re-directs energy used for fat deposition and channels it to promote lean muscle growth[6,7,8]. Therefore, the objective of the study was to evaluate the effects of a feeding regimen including the use of Pulmotil®, Tylan®, and Paylean® from weaning to market compared with pigs fed no feed additives on growth performance and the potential impact on pig weight variation.

Materials and Methods

All experimental protocols were approved by Kansas State University Institutional Animal Care and Use Committee.

A total of 1,344 pigs (PIC 337 × 1050, initial average BW of 6.3 ± 1.1 kg, 18 ± 1 d of age) were weaned into a wean-to-finish barn for the 143-d trial. The pigs coming from this sow source had a history of enteric salmonellosis and Pasturella pneumonia. Pigs were housed in a double curtain sided commercial finishing barn with totally-slatted concrete floors that had been modified for wean-to-finish production. Each pen was 3.33 × 6-m and contained one self-feeder and one cup waterer to provide ad libitum access to feed and water. Pigs were blocked by pen weight and randomly allotted to one of two dietary treatments with 28 pigs/pen and 24 pens/treatment, (12 pens of barrows and 12 pens of gilts per treatment). Experimental treatments included a control program without antibiotics (or Paylean®) or a treatment program including Pulmotil 18®, 399 ppm from d 0 to 21, Tylan 40®, 110 ppm d 21 to 42, 44 ppm from d 42 to 90, and 22 ppm from d 90 to 115, and Paylean®, 5 ppm from d 115 to 143 (Table 1 and 2). During the nursery phase of the study, diets were fed based on a feed budget of 0.91 kg/pig of the SEW diet, 1.81 kg/pig of the transition diet, and 6.8 kg/pig of the phase 2 diet. The remaining diets were fed based on a weight range from 11 to 25, 25 to 41, 41 to 64, 64 to 86, and 86 to 109 kg. In the last phase (86 to 109 kg), control pigs were fed a diet containing 0.80% total lysine and treatment pigs were fed a 1.10% total lysine diet containing 5 ppm Paylean®. The SEW and transition diets fed immediately after weaning were pelleted with all remaining diets fed in a meal form. Pulmotil®, Tylan®, and Paylean® replaced corn in the control diet to provide the treatment diets.

Pigs were individually identified using electronic identification (EID) ear tags to collect individual pig weights on d 0, 21, 52, 78, 115, and 143 to calculate within pen weight variability. Pen weights were collected at approximately 14 d intervals between the individual pig weight collections on d 34, 69, 90, 104, and 129. Feed disappearance was determined on each weigh day during the entire experiment. Average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (gain-to-feed ratio, G:F) and pen weight variation (standard deviation) were determined.

In an attempt to minimize the salmonella challenge to pigs in this trial, a commercial salmonella vaccine was administered to all pigs upon arrival at the trial site and initiation of the trial. Despite the administration of the vaccine, water medications of gentamycin or neomycin was scripted under the direction of the attending consulting veterinarian and administered to the entire barn on d 2 to 9, d 20, and d 28 to d 32 because of salmonella diarrhea in a significant percentage of pigs in the facility. No differences in severity of diarrhea between treatment groups were observed. To address a significant swine influenza and PRRSV clinical outbreak, the attending consulting veterinarian scripted aspirin administration in the water for all the pigs in the barn from d 66 to 81.

Pigs from the study were harvested on d 143. Five pigs per pen were selected for carcass data collection and marketed at this time. The selection process involved collecting individual pig weights on d 115, and selecting 12 pigs close to the mean pen weight. The 12 pigs per pen were identified as each pen of pigs was weighed on d 143, the individual weight of the 12 previously selected pigs was recorded and from this group, the five pigs weighing closest to the mean pen weight were selected. The five

selected pigs were marked for identification purposes with permanent color marker (a different color for each treatment × gender combination) and tattooed with the pen number. After weighing, all selected pigs were removed from the pen and loaded onto the semi-trailer. The semi-trailer compartments were loaded with four pens of pigs at a time with one of each treatment combination colors. This allowed easier sorting of pigs upon arrival at the packing plant. Pigs were marketed at Swift and Co. Worthington, MN. Standard packing plant carcass measurements (backfat, longissimus muscle depth, and hot carcass weight) were obtained to calculate percentage lean and fat-free lean index (FFLI).

Analysis

Treatment differences were evaluated using an analysis of varience mixed model for a complete randomized block design[9]. Pigs were blocked by weight, and pen was the experimental unit. Data was analyzed using the Proc Mixed procedure of SAS version 8.1 (SAS Institute, Cary, North Carolina).

Results

There were no ($P = 0.50$) interactions between treatment and gender observed in the trial (Table 3). Pigs fed Pulmotil 18® from d 0 to 21 had increased ($P < 0.01$) ADG and improved ($P < 0.05$) G:F compared with pigs fed the control diet. Feeding Tylan 40® (110 ppm d 21 to 42 and 44 ppm from d 42 to 90) had no effect ($P > 0.14$) on ADG, ADFI, and G:F compared with the pigs fed the control diet. From d 90 to 115, feeding Tylan 40® (22 ppm) had no effect ($P = 0.16$) on ADG but tended ($P < 0.08$) to improve G:F compared with pigs fed the control diet. There were no differences ($P = 0.10$) observed in ADG, ADFI, or G:F for the overall Tylan 40® feeding period (d 21 to 115).

There also were no differences ($P = 0.10$) observed for the combined Pulmotil® and Tylan® feeding period (d 0 to 115) in ADG, ADFI, and G:F. Feeding Paylean® (d 115 to 143) increased ($P < 0.01$) ADG and improved ($P < 0.01$) G:F compared with pigs fed the control diet. For the overall feeding period (d 0 to 143) pigs fed the combination treatment (Pulmotil 18®, Tylan 40®, and Paylean®) had increased ($P < 0.01$) ADG and improved ($P < 0.01$) G:F compared with the pigs fed the control diet. Carcass data was collected from the five selected pigs from each pen (Table 4). Pigs that were fed the Pulmotil®, Tylan®, and Paylean® treatment had a greater ($P < 0.01$) live weight, carcass weight, and longissimus muscle depth at market compared with the pigs that were fed the control diet.

Because individual pig weights were collected at several weigh periods, variation among pigs was evaluated (Table 5). There was a tendency ($P < 0.10$) for a treatment × interaction, d 21, with gilts fed the combination treatment had less variation compared with gilts fed the control diet, barrows fed the control diet had greater variation compared with the barrows fed the combination treatment. This treatment × interaction tendency was consistent for d 52 ($P < 0.09$), d 78 ($P < 0.06$), and d 143 ($P < 0.17$). There were no differences between the control and the combination treatment on the percentage of pigs treated or removed from test.

Discussion

There was an improved growth response during the Pulmotil feeding period and a numeric growth response for the Tylan period compared to the pigs fed the control diets containing no antibiotics and no paylean. However, most of the growth response for the entire trial can be attributed to the improved ADG and G:F in the Paylean feeding period.

The 11% greater ADG in the Paylean fed pigs in this study is consistent with the results of previous research[7,8]. Previous research supplementing finishing pigs with Paylean has shown either no effect or a decrease in feed intake[6,10], which is in agreement with the feed intake data during the Paylean feeding period. The 12% improvement in G:F in the Paylean feeding period is also in agreement with the results of previous Paylean studies[6,8,10]. The carcass data response to the feeding regimen including Pulmotil®, Tylan®, and Paylean® in this study results in data consistent with a typical Paylean response. There were no differences in percentage of pigs medicated or removed from test, and no treatment response on pig weight variation. Previous research would indicate that feeding Pulmotil, or Tylan alone may reduce pig weight variation[2,3,11]. Final pig weigh variation has not been affected with Paylean supplementation. Paylean has been shown to shift the entire weight curve to the right without affecting weigh variation within a pen[12]. The Pulmotil and Tylan results in this study are different from some previous findings and may be due to the salmonella challenge during the Pulmotil and Tylan feeding periods[2,4,13]. The respiratory viral challenges occurred during the Tylan 40 (44 ppm) feeding period and were infectious agents which Tylan would not express efficacy against. In this study one half of the pigs in the barn and therefore the common air space were treated with antibiotics and the other half was not. This may have provided different pathogen levels and disease dynamics than administering antibiotics to an entire barn.

In this study, a feeding regimen including Pulmotil, Tylan, and Paylean resulted in improved ADG and G:F primarily in the nursery phase (Pulmotil) and late finishing (Paylean). Individual production systems, herd health, environmental factors, and

management will influence the magnitude of the response and should be considered when making decisions on dietary feed additions.

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Table 1. Composition of diets (as-fed)[1,2]

Item	SEW	Transition	Phase 2	Phase 3
Corn[3]	29.69	38.27	52.13	58.61
Soybean meal, 46.5% CP	12.50	20.00	27.55	35.15
Spray-dried whey	32.00	25.00	---	---
Spray-dried animal plasma	6.67	2.50	---	---
Fish meal	6.00	5.00	6.00	---
Feeding oatmeal	5.00	---	---	---
Blood cells	1.00	1.25	---	---
Deproteinized whey	---	---	9.00	---
Choice white grease	5.00	5.00	3.00	3.00
L-lysine HCl	0.15	0.30	0.30	0.30
L-threonine	0.09	0.13	0.14	0.13
DL-methionine	0.15	0.18	0.15	0.13
Monocalcium P, 21% P	0.10	0.70	0.45	1.15
Limestone	0.45	0.45	0.50	0.95
Salt	0.25	0.30	0.30	0.35
Vitamin premix[4]	0.17	0.14	0.13	0.13
Trace mineral premix	0.20	0.20	0.10	0.10
Zinc oxide	0.38	0.38	0.25	---
Acidifier[5]	0.20	0.20	---	---
Total	100.00	100.00	100.00	100.00
Feed budget, kg/pig[6]	0.91	1.81	6.8	11.3
Calculated analysis				
Total lysine, %	1.71	1.68	1.51	1.45
ME, kcal/kg	3,512	3,510	3,475	3,457
CP, %	22.6	21.8	21.5	21.3
Ca, %	0.81	0.83	0.74	0.71
P, %	0.74	0.77	0.67	0.65
Available P, %[4]	0.56	0.55	0.39	0.32

[1]A total of 1,344 pigs (PIC 337 × 1050, initial BW 6.3 ± 1.1 kg) were used. Pigs were blocked by gender and randomly allotted to one of two dietary treatments with 28 pigs/pen and 24 pens/treatment, (24 pens of barrows and 24 pens of gilts).
[2]SEW and Transition diets were pelleted, while Phase 2 and 3 diets where fed in meal form.
[3]Corn was replaced by Pulmutil® (399 ppm) in the SEW, Transition, and the Phase 2 diets. Tylan® (44 ppm) replaced corn in the Phase 3 diet.
[4]Vitamin premix contained phytase. Available phosphorus values include the appropriate phytase phosphorus release by the added phytase.

[5]Kem-gest™, Kemin Industries, Inc. Des Moines, IA.
[6]Amount of each diet allocated per pig, kg.

Table 2. Composition of diets (as-fed)[1,2]

	Average pig weight, kg				
Ingredient	25 to 41	41 to 64	64 to 86	86 to 109[3]	86 to 109[4]
Corn[5]	59.43	66.74	70.47	74.57	63.64
Soybean meal, 46.5% CP	32.35	25.10	21.50	17.45	28.35
Choice white grease	6.00	6.00	6.00	6.00	6.00
Monocalcium P, 21% P	0.65	0.65	0.55	0.55	0.55
Limestone	0.85	0.85	0.85	0.85	0.85
Salt	0.35	0.35	0.35	0.35	0.35
L-threonine	0.03	---	---	---	---
L-lysine HCl	0.15	0.15	0.15	0.10	0.10
Vitamin premix[6]	0.09	0.08	0.06	0.06	0.06
Trace mineral premix	0.10	0.08	0.07	0.07	0.07
Paylean, 5 ppm	---	---	---	---	0.03
Total	100.00	100.00	100.00	100.00	100.00
Total lysine, %	1.25	1.05	0.95	0.80	1.10
ME, kcal/kg	3,611	3,613	3,620	3,622	3,616
CP, %	20.1	17.4	16.0	14.5	18.6
Ca, %	0.57	0.55	0.52	0.51	0.54
P, %	0.53	0.50	0.46	0.44	0.49
Available P , %[6]	0.21	0.20	0.18	0.17	0.19

[1]A total of 1,344 pigs (PIC 337 × 1050, initial BW 6.3 ± 1.1 kg) were used. Pigs were blocked by gender and randomly allotted to one of two dietary treatments with 28 pigs/pen and 24 pens/treatment, (24 pens of barrows and 24 pens of gilts).
[2]Growing and finishing diets were switched based on the average weight of all pigs in the barn.
[3]Control diet fed from d 115 to 143.
[4]Treatment diet fed d 115 to 143, containing Paylean (5 ppm) and 1.10% lysine.
[5]Corn was replaced by Tylan® (44 ppm) in the 25 to 41 kg, 41 to 64 kg diet, and (22 ppm)in the 64 to 86 kg diet.
[6]Vitamin premix contained phytase. Available phosphorus values include the appropriate phytase phosphorus release by the added phytase.

Table 3. Effects of Pulmotil, Tylan, and Paylean on growth performance[1]

Item	Treatment		Gender		SE	Probability, P <	
	Control	Pulmotil, Tylan, and Paylean	Barrow	Gilt		Treatment	Gender
D 0 to 21, Pulmotil period (399 ppm)							
ADG, kg	0.29	0.31	0.30	0.29	0.01	0.01	0.36
ADFI, kg	0.38	0.39	0.39	0.38	0.01	0.24	0.08
G:F	0.60	0.58	0.59	0.59	0.01	0.05	0.67
D 21 to 90, Tylan 44 ppm period							
ADG, kg	0.73	0.73	0.73	0.72	0.01	0.89	0.14
ADFI, kg	1.39	1.41	1.42	1.38	0.02	0.52	0.12
G:F	0.86	0.87	0.87	0.86	0.01	0.14	0.46
D 90 to 115, Tylan 22 ppm period							
ADG, kg	1.05	1.08	10.6	10.7	0.02	0.17	0.74
ADFI, kg	2.49	2.52	2.25	2.49	0.04	0.63	0.71
G:F	1.08	1.06	1.08	1.07	0.01	0.08	0.14
D 21 to 115, Tylan period							
ADG, kg	0.82	0.83	0.83	0.82	0.01	0.40	0.48
ADFI, kg	1.71	1.72	1.73	1.70	0.02	0.54	0.30
G/F	0.92	0.92	0.93	0.92	0.01	0.92	0.19
D 0 to 115, Pumotil and Tylan period							
ADG, kg	0.75	0.76	0.76	0.75	0.01	0.33	0.45
ADFI, kg	1.54	1.56	1.56	1.53	0.02	0.52	0.28
G:F	0.88	0.88	0.88	0.88	0.01	0.66	0.20
D 115 to 143, Paylean period (5 ppm)							
ADG, kg	0.88	0.98	0.93	0.93	0.01	0.01	0.82
ADFI, kg	2.64	2.59	2.63	2.60	0.04	0.36	0.66
G:F	1.36	1.21	1.29	1.28	0.02	0.01	0.76
D 0 to 143, Overall							
ADG, kg	0.78	0.81	0.79	0.78	0.01	0.01	0.46
ADFI, kg	1.76	1.76	1.78	1.75	0.03	0.89	0.35
G:F	0.98	0.95	0.97	0.95	0.01	0.01	0.29

[1]A total of 1,344 pigs (PIC 337 × 1050, initial BW 6.3 ± 1.1 kg) were used. Pigs were blocked by gender and randomly allotted to one of two dietary treatments with 28 pigs/pen and 24 pens/treatment, (24 pens of barrows and 24 pens of gilts).

Table 4. Effects of Pulmotil, Tylan, and Paylean on carcass characteristics[1,2]

	Treatment		Gender			Probability, P <	
Item	Control	Pulmotil, Tylan, and Paylean	Barrow	Gilt	SE	Treatment	Gender
Live wt, kg	111.4	115.1	113.4	112.9	0.88	0.01	0.61
Hot carcass weight, kg	84.8	88.0	86.6	86.1	0.69	0.01	0.57
Dressing percentage	76.0	76.3	76.2	76.1	0.20	0.24	0.76
Average back fat, mm	18.0	18.0	18.0	18.3	0.02	0.93	0.68
Longissimus muscle depth, cm	5.79	6.02	5.94	5.87	0.02	0.01	0.29
Percentage lean, %	54.9	55.1	55.1	54.9	0.28	0.57	0.58
FFLI[3]	49.9	49.6	49.6	49.4	0.26	0.42	0.62

[1]A total of 1,344 pigs (PIC 337 × 1050, initially 6.3 ± 1.1 kg) were used. Pigs were blocked by gender and randomly allotted to one of two dietary treatments with 28 pigs/pen and 24 pens/treatment, (24 pens of barrows and 24 pens of gilts).

[2]Pigs from the study were harvested after the final individual weight was collected (d 143). Five pigs per pen were selected and marketed at this time. The selection process involved collecting individual pig weights on d 115. Then twelve pigs per pen, closest to the mean weight of the pen were identified. As each pen of pigs was weighed on d 143, the individual weights of the twelve previously selected pigs was recorded and from this the five pig weighing closest to the mean weight of all the pigs in the pen were selected.

[3]FFLI = fat-free lean index

Table 5. Effects of Pulmotil, Tylan, and Paylean on pig weight variation, standard deviation, percentage of treated pigs, and percentage of removals[1]

	Treatment		Gender			Probability, P <	
Item	Control	Pulmotil, Tylan, and Paylean	Barrow	Gilt	SE	Treatment	Gender
Standard deviation[2]							
d 0	2.4	2.4	2.3	2.4	0.07	0.94	0.33
d 21	5.1	5.1	5.0	5.2	0.17	0.81	0.54
d 52	11.4	11.2	11.2	11.5	0.32	0.74	0.48
d 78	18.1	17.4	17.6	17.9	0.63	0.44	0.72
d 115	28.0	28.2	27.4	28.8	0.98	0.88	0.33
d 143	31.7	30.9	29.9	32.7	1.13	0.60	0.09
No. pigs treated, %[3]	2.3	2.9	2.4	2.8			
No. pigs removed, %[4]	5.7	6.7	5.1	7.1			

[1]A total of 1,344 pigs (PIC 337 × 1050, initial BW 6.3 ± 1.1 kg) were used. Pigs were blocked by gender and randomly allotted to one of two dietary treatments with 28 pigs/pen and 24 pens/treatment, (24 pens of barrows and 24 pens of gilts).

[2]Mean estimates for the standard deviation (SD) of pig weight variation. Individual pig weights were collected d 0, 21, 52, 78, 115, and 143. The individual weights were used to determine pig weight variation among all pigs within a pen.

[3]All individual pigs that received injectable medications the date, reason for treatment, medication dose, and type were recorded. Penicillin, Exceed, or Naxcel were used for the treatment of individual pigs.

[4]Any pig that died or removed from test was weighed and date recorded. The suspected cause of death or reason for removal was documented.