Effects of sodium, chloride, and sodium metabisulfite in nursery and grow-finish pig diets

by

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B.S., The University of Findlay, 2016

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Animal Sciences and Industry
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2018

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Abstract

A total of 12,229 pigs were used in nine experiments to determine the effects of Na, Cl, and sodium metabisulfite-based feed additives on pig growth performance. Experiments 1, 2, and 3 were conducted to determine the effects of added dietary salt on growth performance of pigs weighing 7 to 10, 11 to 30, and 27 to 65 kg. The BLL models suggested the optimal dietary added salt concentration to maximize ADG for pigs weighing 7 to 10 and 11 to 30 kg was 0.59% (0.34% Na and 0.58% Cl) and 0.51% added salt (0.22% Na and 0.42% Cl), respectively. There was no evidence to indicate that growth of 27 to 65 kg pigs was improved beyond a 0.10% added salt inclusion (0.11% Na and 0.26% Cl). Experiments 4, 5, and 6 were conducted to determine the effects of source and concentration of Na and Cl on the growth performance of pigs weighing 7 to 12 kg. In Exp. 4, pigs fed an added salt diet that contains a Na and Cl concentration of 0.35% and 0.60% had greater growth performance compared to pigs fed a deficient Na concentration of 0.18%. In Exp. 5, pigs fed a Na concentration of 0.35%, regardless of ion source, had improved ADG compared to pigs fed a Na concentration of 0.13% or 0.57%. In Exp. 6, maximum ADG and G:F could be obtained with a Cl concentration of 0.38% based on the BLL and QP models. Experiments 7, 8, and 9 were conducted to evaluate the effects of Product 1 (Provimi, Brooksville, OH), Product 2 (Nutriquest, Mason City, IA), and sodium metabisulfite (SMB) on the growth performance of nursery pigs weighing approximately 6 to 25 kg. In Exp. 7, pigs fed Product 1 had higher ADG compared to pigs fed the control. In Exp. 8, pigs fed either Product 1 or 2 at the highest concentration and for the longest period of time had greater ADG compared to pigs fed the control diet. In Exp. 9, pigs fed SMB or Product 1 had greater ADG compared to pigs fed a lower concentration of SMB and the control.

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Acknowledgements

I would like to thank my major professors, Dr. Mike Tokach and Dr. Bob Goodband, for their guidance, wisdom, and patience throughout my program. To the members of my committee, Drs. Dritz, Woodworth, and DeRouchey, thank you for your instruction and dedication. To my fellow graduate students, thank you for making this journey possible and enjoyable. I would also like thank the teams at New Horizon Farms (Heath, Marty, and Craig) and Hord Livestock (Pat, Jay, Phil, Kayla, and Kaye) for animals, research facilities, and technical support. Finally, I would like to thank my mother and brother, Victoria and Duane, for their endless encouragement and support throughout this journey.

Dedication

This thesis is dedicated to the memory of my father, Dale Shawk.

Chapter 1 - Effects of added dietary salt on pig growth performance

ABSTRACT

Three studies were conducted to determine the effects of added dietary salt on growth performance of pigs weighing 7 to 10, 11 to 30, and 27 to 65 kg. In Exp. 1, 325 pigs were used in a 14-day trial with 5 pigs per pen and 13 pens per treatment. Pigs were fed a common diet (0.39% Na and 0.78% Cl) for 7 days after weaning, then randomly assigned to 1 of 5 diets with either 0, 0.20, 0.40, 0.60, or 0.80% added salt. All diets were corn-soybean meal-based with 10% dried whey. Calculated Na concentrations were 0.11, 0.19, 0.27, 0.35, and 0.43% and calculated Cl concentrations were 0.23, 0.35, 0.47, 0.59, and 0.70%, respectively. Increasing salt increased (linear, $P < 0.05$) average daily gain (ADG) and gain to feed ratio (G:F). For ADG, the linear, quadratic polynomial (QP), and broken line linear (BLL) models were competing with the breakpoint for the BLL at 0.59% salt. For G:F, the BLL reported a breakpoint at 0.33% while the QP indicated maximum G:F at 0.67% added salt. In Exp. 2, 300 pigs were used in a 34-day trial with 5 pigs per pen and 12 pens per treatment. Pigs were weaned at 21 days of age and fed a common phase 1 diet (0.50% Na and 0.67% Cl) for 11 days and then a common phase 2 diet (0.35% Na and 0.59% Cl) for 14 days. Then pens of pigs were randomly assigned to 1 of 5 corn-soybean meal-based diets containing 0.20, 0.35, 0.50, 0.65, or 0.80% added salt. Calculated dietary Na levels were 0.10, 0.16, 0.22, 0.28, and 0.34% and calculated Cl levels were 0.23, 0.32, 0.41, 0.50, and 0.59%, respectively. Overall, ADG, and G:F increased (quadratic, $P < 0.07$) with increasing added salt. For ADG, the QP and BLL had similar fit with the breakpoint for BLL at 0.51% added salt. For G:F, the BLL model predicted a break point at 0.35% added salt. In Exp. 3, 1,188 pigs were used in a 44-day study with 27 pigs per pen and 11 pens per treatment. Pens of pigs were randomly assigned to 1 of 4 corn-soybean meal-based diets containing 0.10, 0.33, 0.55, or 0.75% added salt. Calculated dietary Na concentrations were 0.10, 0.19, 0.28, and 0.36% and calculated Cl concentrations were 0.23, 0.36, 0.49, and 0.61%, respectively. Overall, there was no evidence to indicate that added salt above 0.10% of the diet affected growth. In conclusion, the BLL models suggested to maximize ADG for 7 to 10 and 11 to 30 kg pigs was 0.59% (0.34% Na and 0.58% Cl) and 0.51% added salt (0.22% Na and 0.42% Cl), respectively. There was no evidence that growth of 27 to 65 kg pigs was improved beyond 0.10% added salt (0.11% Na and 0.26% Cl).

Key words: chloride, growth, pig, salt, sodium

INTRODUCTION

Sodium and chloride are ions that serve several key roles in the body. Both ions are involved in acid-base balance. Sodium is a cation that is involved in the body's sodium potassium pump, nerve impulse, and muscle contraction. Chloride is anion that regulates osmotic pressure and is a component of HCl, which is critical in digestion. The NRC (1998) requirement estimate for Na and Cl were 0.20% and 0.20% for 5 to 10 kg pigs, 0.15% and 0.15% for 10 to 20 kg pigs, and 0.10% and 0.08% for 20 to 80 kg pigs. Mahan et al. (1996) evaluated Na and Cl requirements separately in corn-soybean meal diets with 20% dried whey and observed that ADG increased up to a dietary Na concentration of 0.34% in 7 to 8 kg pigs and a dietary Cl concentration of 0.50% in 6 to 9 kg pigs. In two separate studies, Mahan et al. (1999) evaluated Cl concentrations by adding HCl. Average daily gain improved up to a dietary Cl concentration of 0.32% and N retention improved up to a dietary Cl concentration of 0.38%. Mahan et al. (1999) also noted improvements in ADG of 7 to 15 kg pigs up to a dietary addition of 0.40% salt (0.36% Na and 0.49% Cl) in corn-soybean meal diets containing lactose and spray-dried plasma protein.

Based on the observations of Mahan et al. (1996, 1999) and others, the NRC (2012) increased the Na and Cl requirement estimates to 0.35 and 0.45% for 7 to 11 kg pigs, 0.28 and 0.32% for 11 to 25 kg pigs, and 0.10 and 0.08% for 25 to 75 kg pigs. Sodium bicarbonate, sodium tripolyphosphate, ammonium chloride, and HCl are sources of Na and Cl that have been used to establish the Na and Cl requirement; however, in commercial diets the most common source of Na and Cl is added salt. Currently there is limited research to confirm the Na and Cl requirement estimates of modern genotype pigs and effects of added salt. Therefore, the objective of these experiments was to evaluate added salt on the growth performance of nursery pigs weighing 7 to 10 and 11 to 30 kg and grower pigs weighing 27 to 65 kg.

MATERIALS AND METHODS

The Kansas State University Institutional Animal Care and Use Committee approved the protocols used in these experiments.

Experiment 1

A total of 325 maternal line barrows (Line 200 × 400; DNA, Columbus, NE, initially 6.6 kg BW) were used in a 21-day growth trial with 5 pigs per pen and 13 pens per treatment. Pigs were weaned at 21 days of age and were randomly allotted to pens of 5 based on their initial BW. Pigs were fed a common diet (0.39% Na and 0.78% Cl) for 7 days after weaning. On day 7 after weaning, considered day 0 in the trial, pens of pigs were blocked by BW and then randomly assigned 1 of 5 dietary treatments fed for 14 days. The dietary treatments were corn-soybean meal-based with 10% dried whey. They included a diet with no added salt, or diets with either 0.20, 0.40, 0.60, or 0.80% added salt; resulting in calculated Na concentration of 0.11, 0.19, 0.27, 0.35, and 0.43% and calculated Cl concentrations of 0.23, 0.35, 0.47, 0.59, and 0.70%, respectively (Table 1-1). Pigs were then fed a common diet from day 14 to 21 (0.16% Na and

0.34% Cl). Pens of pigs were weighed and feed disappearance was recorded weekly to determine ADG, average daily feed intake (ADFI), and G:F.

The study was conducted at the Kansas-State University Segregated Early Weaning Facility in Manhattan, KS. Each pen (1.22 × 1.22 m) was equipped with a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Diets were manufactured at the K-State O.H. Kruse Feed Technology Innovation Center. Soybean meal, salt, and L-Lysine–HCl samples were collected at the mill, pooled, and subsamples for chemical analysis. The 0 and 0.80% added salt diets were manufactured then blended to create the intermediate diets. Feed samples were collected from 8 feeders per treatment, pooled, and subsampled for chemical analysis.

Experiment 2

A total of 300 pigs (Line 241 × 600; DNA, Columbus, NE; initially 11.3 kg BW) were used in a 34-day trial with 5 pigs per pen and 12 pens per treatment. Pigs were weaned at 21 days of age and were allotted to pens based on their initial BW. All pigs were fed a common phase 1 diet (0.50% Na and 0.67% Cl) for 11 days and then a common phase 2 diet (0.35% Na and 0.59% Cl) for 14 days. At day 25 after weaning, considered day 0 of the trial, pens of pigs were blocked by BW and then randomly assigned to 1 of 5 diets which were fed for 27 days. Dietary treatments were corn-soybean meal-based and contained either 0.20, 0.35, 0.50, 0.65, or 0.80% added salt (Table 1-2). This resulted in calculated dietary Na concentrations of 0.10, 0.16, 0.22, 0.28, and 0.34% and calculated dietary Cl concentrations of 0.23, 0.32, 0.41, 0.50, and 0.59%, respectively. Pigs were then fed a common diet from day 27 to 34 (0.16% Na and 0.29% Cl). Pens of pigs were weighed and feed disappearance was recorded weekly to determine ADG, ADFI, and G:F.

This study was conducted at the Kansas-State University Swine Teaching and Research Center in Manhattan, KS. Each pen (1.2 × 1.5 m) was equipped with a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Diets were manufactured at the K-State O.H. Kruse Feed Technology Innovation Center. Feed samples were collected from 8 feeders per treatment, pooled, and subsampled for analysis.

Experiment 3

A total of 1,188 pigs (PIC 359 × 1050; initial BW 27.1 kg) were used in a 44-day trial with 27 pigs per pen and 11 pens per treatment. Pigs were blocked by BW and then randomly assigned to 1 of 4 dietary treatments that were fed for 44 days. Dietary treatments were corn-soybean meal-based and contained either 0.10, 0.33, 0.55, or 0.75% added salt (Table 1-3). This resulted in calculated dietary Na concentrations of 0.10, 0.19, 0.28, and 0.36% and calculated Cl concentrations of 0.23, 0.36, 0.49, and 0.61%, respectively. Pens of pigs were weighed and feed disappearance was recorded on day 0, 16, 31, and 44 to determine ADG, ADFI, and G:F.

This study was conducted at a commercial research-finishing site located in southwest Minnesota. Pigs were housed in a naturally ventilated and double-curtain-sided barn. Each pen (3 × 5.5 m) contained a 4-hole stainless steel feeder and cup waterer for ad libitum access to feed and water. Feed additions to each individual pen were made and recorded by a robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN). Experimental diets for Exp. 3 were manufactured at New Horizon Feed LLC. Dried distillers grain with solubles samples were collected at the mill, pooled, and subsampled for analysis prior to manufacturing the dietary treatments. Feed samples from 6 feeders per treatment were collected at the beginning and the end of the trial, pooled, and subsampled for analysis.

Chemical analysis

Feed samples for Exp.1 and dried distillers grain with solubles samples and feed samples for Exp. 3 were submitted for analysis of Na and Cl (Ward Laboratories, Kearney, NE). Sodium samples were prepared by removing organic matter and lipids with HNO_3, HCl, and H_2O_2 (Campbell et al., 1991; Wolf et al., 2003) and samples were then analyzed for Na via inductively coupled plasma spectroscopy (Kovar, 2003). Dietary Cl concentrations were determined by titrating sliver nitrate until all Cl ions are precipitated and then detecting the concentration of free sliver ions using a Metrohm 855 Robitic Titrosampler and a Metrohm 6.0430.100 Ag Titrode (Metrohm USA Inc, Riverview, FL, AOAC 969.10, 1990; Kalra et al., 1991; Mills et al., 1991). Soybean meal, L-Lys-HCl, salt, and feed samples for Exp. 2 were submitted to Cumberland Valley Analytical Service (Maugansville, MD) for analysis of Na and Cl. Sodium within each sample was analyzed following procedures outlined by AOAC (2000). To analyze samples for Cl samples were prepared with nitric acid and then analyzed using a Metrohm 848 Titrono Plus (Metrohm USA Inc, Riverview, FL). Standard procedures from AOAC (2006) were followed for analysis of moisture (Method 934.01), and CP (Method 990.03; K-State Analytical Laboratory, Manhattan, KS).

Statistical Analysis

Data for all experiments were analyzed as a randomized complete block design with body weight as the blocking factor. An initial model was evaluated for each experiment where dietary treatment was considered as a categorical fixed effect and block was considered a random effect with pen as the experimental unit. Models were evaluated separately for individual experiments. The base model was used to evaluate the heterogeneity of residual variance using Bayesian Information Criteria (BIC) to determine the best fit. For Exp. 1, heterogenous variance was used for ADFI and G:F while homogenous variance was used for ADG. For Exp. 2, heterogenous variance was used for ADG and G:F while homogenous variance was used for ADFI. For G:F, block was removed from the model as it did not contribute to the model fit but degrees of freedom were adjusted manually to account for the degrees of freedom contributed by block. Linear and quadratic polynomials were used to evaluate increasing salt.

For Exp. 1 and Exp. 2, added salt dose response curves were predicted using PROC GLIMMIX and PROC NLMIXED to optimize ADG, ADFI, and G:F following the procedure outlined by Goncalves et al. (2016). The dose response models that were evaluated were linear, quadratic polynomial (QP), broken-line linear (BLL), and broken-line quadratic (BLQ). Bayesian Information Criterion was used to determine best fit, with a decrease in 2 or more points indicating a better fit of the model (Raftery, 1996). As with the base model, heterogeneous variance was accounted for where appropriate. Individual pen means and the response curves were plotted for the best fitting models. For the BLL models, the breakpoints and 95% CI are reported. For the QP model, the maximum response and 95% CI are reported. The CI was calculated by plotting the regression equation with the 95% CI across the doses and projecting the maximum response across the *y*-axis using a horizontal line. The intersection between the horizontal line and CI boundaries of the predicted line is then projected onto the x-axis to estimate the CI of the optimum dose level (Goncalves et al., 2016).

RESULTS AND DISCUSSION

Chemical Analysis

Chemical analysis of the salt sample indicated a Na concentration of 40.26% and a Cl concentration of 58.72%, which would be similar to the NRC (2012) Na and Cl concentration estimates of 39.5% and 59%. Analysis of the L-Lys-HCl samples indicated a Na concentration of

0.01% and a Cl concentration of 19.37%. Results of the chemical analysis indicated a Na concentration of 0.22 and a Cl concentration of 0.19 for dried distillers grain with solubles. Chemical analysis indicated that Na and Cl concentration of the soybean meal sample was 0.01 and 0.02%, respectively. The NRC (2012) Na and Cl concentration estimate for soybean meal is 0.08% and 0.49% while the NRC (1998) Na and Cl concentration estimate for soybean meal is 0.02% and 0.05%. The Na concentration of the soybean meal sample (0.01%) is similar to NRC (2012) and NRC (1998) concentration estimates. However, the Cl concentration (0.02%) of the soybean meal sample is significantly less than NRC (2012) concentration estimate of 0.49%, though is similar to the NRC (1998) concentration estimate of 0.05%. Based on these results, the NRC (1998) concentration estimate for Na and Cl was used in the formulation of experimental diets used in our experiments.

For Exp. 1, chemical analysis of diets indicated that analyzed values for Na and Cl were similar to calculated values with dietary Na concentrations ranging from 0.09 to 0.40% and dietary Cl concentrations ranging from 0.23 to 0.72% (Table 1-4). Results for Exp. 2 closely matched calculated concentrations except for the 0.80% added salt diet, which was slightly lower in Na and Cl when compared to calculated concentrations (Table 1-5). Diets contained increasing Na concentrations that ranged from 0.11 to 0.30% and Cl concentrations that ranged from 0.23 to 0.50%. For Exp. 3, analyzed Na and Cl concentrations were similar to calculated values with dietary Na concentration ranging from 0.11 to 0.34% and dietary Cl concentrations ranging from 0.26 to 0.61% (Table 1-3).

Experiment 1

From day 0 to 14, increasing salt increased (linear, $P < 0.015$) ADG, ADFI, and day 14 BW (Table 1-8). Despite the linear response, there were only small improvements observed beyond 0.60% added salt. Gain to feed increased (quadratic, $P < 0.019$) as salt increased from 0 to 0.60%, with no further benefits observed thereafter.

From day 14 to 21, when pigs were fed a common diet with 0.35% added salt, those previously fed low salt diets appeared to have compensatory ADG and G:F (linear, $P < 0.013$) compared with those previously fed high salt diets. There was no evidence of difference to indicate that previous dietary treatments influenced ADFI or day 21 BW.

For ADG, the linear, QP, and BLL models were competing with similar BIC (Figure 1-1). The predicted response for the QP model was indicated as ADG =193.22 + 139.12 × (added salt, %) - 76.936 × (added salt, %)^2 with the predicted maximum greater than the highest amount fed (0.90%; 95% CI [0.45, >0.80%]) though a 0.59% added salt inclusion could obtain 97% of the maximum performance. The BLL model breakpoint was 0.59% salt with ADG= 253.50 – 99.58 × (0.59 – added salt, %), when salt < 0.59% and ADG = 253.8, if added salt ≥ 0.59%. For ADFI, the QP and linear models were competing with similar BIC. The predicted response for the QP model was indicated as ADFI = 193.05 + 144.74 × (added salt, %) - 83.963 × (added salt, %)^2 with the predicted maximum greater than the highest amount fed (0.86%; 95% CI [0.45, >0.80%]) while 95% of the maximum performance could be obtained with 0.47% salt (Figure 1-2). For G:F, the QP and BLL models were competing with similar BIC (Figure 1-3). The predicted response for the QP model was indicated as G:F = 626.61 + 429.91 × (added salt, %) - 321.92 × (added salt)^2 with the maximum performance obtained with 0.67% (95% CI [0.37, >0.80%]) added salt while 95% of the predicted maximum performance could be obtained with 0.33% added salt. For the BLL model, the breakpoint was at 0.33% added salt with G:F = 756.47 – 394.82 × (0.33 – added salt, %), when added salt < 0.33% and G:F = 756.7, if added salt ≥ 0.33%.

Based on the results of the BLL and QP models, the inclusion concentration in which maximum performance was obtained was 0.59% (BLL) and 0.90% (QP) added salt for ADG, 0.86% (QP) added salt for ADFI, and 0.33% (BLL) and 0.67% (QP) for G:F. If the goal of production system was to capture maximum ADG while maintaining G:F then the QP models would indicate the optimal salt inclusion to be between 0.67% and 0.90% added salt. However 0.59% added salt would still obtain 97% of the ADG and G:F performance based on the QP ADG and G:F model. An inclusion of 0.59% added salt would result in diets that would have a Na concentration of approximately 0.34% and Cl concentration of 0.58%. A dietary Na concentration of 0.34% would agree with the NRC (2012) requirement estimates of 0.35% while a Cl concentration of 0.58% would be greater than the Cl requirement estimate of 0.45% for the 7 to 11 kg pig. In two studies evaluating Na and Cl separately with Na_2PO_4 and HCl in corn-soybean meal-based diets that also contained dried whey, Mahan (1996) observed improvements in growth performance up to a dietary Na concentration of 0.34% in 7 to 8 kg pigs and a dietary Cl concentration of 0.50% in 6 to 9 kg pigs. Mahan et al. (1999) did not observe an interaction between Na and Cl, sourced from Na_2PO_4 and HCl in corn-soybean meal diets with lactose and spray dried plasma protein; however, ADG increased with increasing dietary Cl concentrations up to 0.45% in 7 to 11 kg pigs. In a different study, HCl was used to evaluate Cl concentrations in a corn-soybean meal diet with lactose and spray dried animal plasma. Average daily gain improved up to a dietary Cl concentration of 0.32%. Considering both of these trials, a Cl concentration of 0.32% to 0.45% would be significantly lower than the 0.58% Cl which corresponded to the optimal salt inclusion concentration (0.59% added salt) observed in our experiment.

Mahan et al. (1996) observed a quadratic response to added salt with improvements in ADG up to 0.40% added salt (0.44% Na and 0.51% Cl) in corn-soybean meal diets with 20% dried whey for 7 to 9 kg pigs. Mahan et al. (1999) also suggested 0.40% added salt (0.36% Na and 0.49% Cl) in a corn-soybean meal diet with lactose and spray dried animal plasma was needed to maximize growth of 7 to 15 kg pigs. The addition of 0.40% salt is lower than the calculated optimal inclusion observed in our study of 0.59% (0.34% Na and 0.58% Cl); but because of the added spray dried animal plasma and the higher inclusion of dried whey used in their studies, the actual Na and Cl concentrations are similar.

Experiment 2

From day 0 to 14, ADG and ADFI improved (quadratic, $P < 0.001$ and 0.089) as added salt increased from 0.20 to 0.65%, with no further benefits observed thereafter (Table 1-9). Gain to feed ratio and day 14 BW increased (quadratic, $P < 0.029$ and 0.088) with increasing added salt.

From day 14 to 27, there was no evidence of difference to indicate dietary treatment affected ADG though pigs fed the 0.50% added salt diet had numerically the highest ADG. Average daily feed intake improved (linear, $P < 0.015$) with increasing added salt and G:F tended (linear, $P < 0.084$) to slightly worsen with increasing salt with the optimal G:F obtained with 0.50% added salt diet.

From day 0 to 27, ADG improved (quadratic, $P < 0.005$; Table 1-9) as added salt increased from 0.20 to 0.80%, with the greatest marginal improvement observed from 0.20 to 0.50% added salt. Average daily feed intake increased (linear, $P < 0.001$) with increasing added salt. Gain to feed ratio and day 27 BW tended (quadratic, $P < 0.064$ and 0.088, respectively) to increase from 0.20 to 0.80% added salt with the greatest incremental benefit up to 0.50% added salt.

From day 27 to 34, when pigs were fed a common diet, there was no evidence to indicate previous dietary treatments affected ADG. However, pigs previously fed increasing salt had increased ADFI (linear, $P < 0.001$) and poorer (linear, $P < 0.001$) G:F.

For ADG, the QP and BLL models were competing with similar BIC (Figure 1-4). The predicted response for the QP model was indicated as ADG = 600.44 + 358.82 × (added salt, %) - 258.68 × (added salt, %)^2 with the maximum performance obtained with 0.69% added salt (95% CI [0.45, >0.80%]) while 99% of maximum performance could be obtained with 0.51% added salt. For the BLL model, the breakpoint was at 0.51% with ADG = 722.07 – 187.83 × (0.51 – added salt, %), when added salt < 0.51% and ADG = 721.2 if added salt ≥ 0.51%. For ADFI, the QP, linear, and BLL models were competing with similar BIC with the predicted response for the QP model indicated as ADFI = 1,020.22 + 284.61× (added salt, %) -177.15 × (added salt, %)^2 with the maximum amount tested (0.80%; 95% CI [0.45, > 0.80%]) giving the greatest ADFI (Figure 1-5) although 99.6% of the performance could be obtained with 0.65% added salt. For the BLL model, the breakpoint was at 0.65% with ADFI = 1135.5 – 139.76 × (0.65 – added salt, %), when salt < 0.65% and ADFI = 1,135.4 if added salt ≥ 0.65%. For G:F, the linear and BLL were competing models with the breakpoint for BLL at 0.35% salt and G:F = 638.57 – 150.04 × (0.35 – added salt, %) when added salt < 0.35% and G:F = 638.0, if added salt ≥ 0.35% (Figure 1-6).

Overall, the response to added salt was not static throughout this experiment. From day 0 to 14, when pigs weighed between 11 to 20 kg, ADG and G:F was optimized by 0.65% added salt. Chemical analysis of the 0.65% added salt diet indicated a Na concentration of 0.28% and a

Cl concentration of 0.48%. The 0.65% added salt diet would have a Na (0.28%) and Cl (0.48%) concentration that would agree with NRC (2012) Na requirement estimate (0.28%) and exceed the Cl requirement estimate (0.32%) for 11 to 25 kg pigs. From day 14 to 27, when pigs weighed between 20 to 30 kg, there was no evidence to indicate that added salt influenced ADG, though pigs fed 0.50% added salt had the highest G:F. Chemical analysis of the 0.50% added salt diet indicated a Na and Cl concentration of 0.20% and 0.39%. A Na concentration of 0.20% would be intermediate between the NRC (2012) Na requirement estimate for 11 to 25 kg pigs (0.28%) and 25 to 75 kg pigs (0.10%). A Cl concentration of 0.39% is significantly higher the NRC (2012) Cl requirement estimate for both 11 to 25 kg pigs (0.32%) and 25 to 75 kg pigs (0.08%).

The QP models would indicate an optimal addition of 0.69% added salt; however, the BLL models would suggest a lower addition of 0.51%. An inclusion of 0.51% salt would obtain 99% performance of the ADG QP model thus giving confidence in the BLL model. The addition of 0.51% salt would have a Na concentration of approximately of 0.22% and a Cl concentration of approximately 0.42%. A Na concentration of 0.22% would be intermediate between the NRC (2012) requirement estimate for 11 to 25 kg pigs (0.28%) and the NRC (2012) requirement estimate for 25 to 75 kg pigs (0.10%). A Cl concentration of 0.42% is significantly higher than the NRC (2012) estimate for both 11 to 25 kg pigs (0.32%) and 25 to 75 kg pigs (0.08%). While independently evaluating Na and Cl with 8.5 to 19.7 kg pigs, Honeyfield and Froseth (1985) observed improved ADG up to a Na concentration of 0.11% and no improvements beyond Cl concentration of 0.10% in corn-soybean meal diets with added ammonium chloride and sodium tripolyphospahtae. A Na and Cl concentration of 0.11% and 0.10%, respectively would be significantly lower than the Na (0.22%) and Cl (0.42%) concentration associated with 0.51% added salt. However, in the present experiment, salt was used instead of ammonium chloride and triployphosphate. Also, the models predicting the optimal salt inclusion are based on the BW range of 11.3 to 30.4 kg pigs whereas the BW range of the pigs in the experiment conducted by Honeyfield and Froseth (1985) was 8.5 to 19.7 kg. Hagsten and Perry (1976) observed improvements in ADG up to 0.13% added salt in corn-soybean meal diets for 12 to 24 kg pigs and 0.14% added salt in diets for 17 to 32 kg pigs. Alcantara et al. (1980) also observed improvements in ADG up to 0.14% added salt (0.089% Na) in 9.5 to 25.0 kg pigs. A Na concentration of 0.089% would be significantly lower than the 0.22% Na associated with 0.51% added salt and would be significantly lower than the optimal salt inclusion determined in our experiment.

Experiment 3

From day 0 to 44, there was no evidence of difference to indicate that ADG, ADFI, G:F or d 44 BW improved beyond 0.10% added salt (Table 1-10). According to the chemical analysis, the 0.10% added salt diet had a Na concentration of 0.11% and a Cl concentration of 0.26%. A Na concentration of 0.11% would be similar to the NRC (2012) Na estimate for 25 to 75 kg pigs (0.10%). A Cl concentration of 0.26% would be significantly greater than the NRC (2012) requirement estimate for 25 to 75 kg pigs (0.08%).

Honeyfield et al. (1985) noted improvement in ADG of 36 to 89 kg pigs up to Cl concentration of 0.18% and no improvements beyond a Na concentration of 0.08%, in corn-soybean meal diets with added sodium tripolyphosphate and ammonium chloride. A Na concentration of 0.18% would be slightly greater than the Na concentration of 0.11% in our lowest added salt diet. A Cl concentration of 0.08% would be significantly lower than the Cl concentration of the 0.10% added salt diet (0.26%). Previous research conducted by Alcantara et al. (1980) indicted an optimal inclusion of 0.08% salt (0.065% Na) in 25 to 50 kg pigs, which is similar to the optimal level observed in our experiment. Hagsten et al. (1976) also observed an optimal level of 0.10% added salt in 18 to 91 kg pigs.

The NRC (2012) Na and Cl estimates are based on the results of Na, Cl, and added salt studies. By independently evaluating Na and Cl, researchers have been able to predict the requirement estimate of the pig for each ion independently. It is important to note that in our studies Na and Cl were not independently evaluated but rather in the form of added salt. In added salt diets, Na could be considered the limiting ion because the Na and Cl requirements are similar and salt is composed of approximately 39% Na and 61% Cl. Because Na is the limiting ion, a lower inclusion of salt is needed to meet the Cl requirement but a higher inclusion is needed to meet the Na requirement. Thus, if the NRC (2012) Na and Cl estimates are accurate, optimal amounts of salt will meet the pig's Na requirement and exceed the Cl requirement. This would suggest that when titrating added salt, performance will increase with increasing Na and Cl concentrations until the Cl requirement of pig is met and then any additional performance observed would be due to meeting the pig's Na requirement. This is supported by results of our study in which the diets that met the NRC (2012) Na requirement estimate and exceeded the Cl requirement estimate for the appropriate BW range had optimal growth performance compared to diets that were deficient in Na or Cl.

In conclusion, the BLL models for ADG suggest pigs weighing 7 to 10 and 11 to 30 kg, required 0.59% (0.34% Na and 0.58% Cl) and 0.51% added salt (0.22% Na and 0.42% Cl), respectively. There was no evidence to indicate that growth of 27 to 65 kg pigs was improved beyond 0.10% (0.11% Na and 0.26% Cl) added salt.

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Table 1-1. Diet composition, Exp. 1 (as-fed basis)

Ingredient, %	Experimental[1]	Common phase 3[2]
Corn	51.00	63.77
Soybean meal (48% CP)[3]	29.60	32.86
Dried whey	10.00	---
HP 300 (Hamlet Protein)[4]	5.00	---
Choice white grease	1.00	---
Monocalcium P (21% P)	1.05	1.10
Limestone	1.05	0.98
Salt	---	0.35
L-Lysine HCl	0.30	0.30
DL-Methionine	0.18	0.12
L-Threonine	0.15	0.12
Trace mineral premix[5]	0.15	0.15
Vitamin premix[6]	0.25	0.25
Phytase[7]	0.02	0.02
Zinc oxide	0.25	---
TOTAL	100	100
Calculated analysis		
Standardized ileal digestible (SID) amino acids, %		
Lysine	1.35	1.35
Isoleucine:lysine	63	57
Leucine:lysine	124	117
Methionine:lysine	35	30
Methionine and cystine:lysine	59	51
Threonine:lysine	66	57
Tryptopahn:lysine	19	17
Valine:lysine	67	62
Total lysine, %	1.49	1.37
Net energy, kcal/kg	2,321	2,363
Crude protein, %	22.8	21.4
Calcium, %	0.78	0.70
Phosphorus, %	0.68	0.64
Available Phosphorus, %	0.48	0.41
Sodium, %	0.11	0.16

Chloride, %	0.23	0.34
Potassium, %	1.15	0.96
Dietary electrolyte balance, mEq/kg8	276	218

[1] Experimental diets were fed approximately from 7 to 12 kg. Corn was removed and replaced with salt to create the treatment diets. Treatment diets containing 0% and 0.80% salt were manufactured and blended at the feed mill to create the intermediate diets of 0.20%, 0.40%, and 0.60% salt.

[2] Common Phase 3 diet fed to all pigs from d 21 to 28 after weaning.

[3] Na and Cl values from NRC (1998) were used for soybean meal. Values for all other ingredients are from NRC (2012).

[4] Hamlet Protein, Findlay, OH.

[5] Provided per kilogram of premix: 22 g Mn from manganese oxide; 73 g Fe from iron sulfate; 73 g Zn from zinc sulphate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

[6] Provided per kilogram of premix: 3,527,360 IU vitamin A; 881,840 IU vitamin D3; 17,637 IU vitamin E; 3,307 mg riboflavin; 1,764 mg menadione; 11,023 mg pantothenic acid; 33,069 mg niacin; and 15.4 mg vitamin B12.

[7] Ronozyme HiPhos 2700 (DSM Nutritional Products, Inc., Parsippany, NJ), providing 406.3 phytase units (FTU)/kg and an estimated release of 0.10% available P.

[8] Calculated as = (Na*434.98) + (K*255.74) – (Cl*282.06).

Table 1-2. Diet composition, Exp. 2 (as-fed basis)

Ingredient, %	Experimental[1]	Common grower[2]
Corn	60.12	71.50
Soybean meal (48% CP)[3]	34.66	25.71
Choice white grease	1.30	---
Monocalcium P (21% P)	1.15	0.55
Limestone	0.88	1.13
L-Lysine HCl	0.35	0.31
DL-Methionine	0.16	0.06
L-Threonine	0.14	0.09
L-Tryptophan	0.004	---
L-Valine	0.04	---
Trace mineral premix[4]	0.15	0.15
Vitamin premix[5]	0.25	0.15
Phytase[6]	0.02	0.02
Sand	0.60	---
Salt	0.20	0.35
TOTAL	100	100
Calculated analysis		
Standardized ileal digestible (SID) AA, %		
Lysine	1.30	1.05
Isoleucine:lysine	61	62
Leucine:lysine	124	135
Methionine:lysine	35	30
Methionine and cystine:lysine	58	55
Threonine:lysine	62	61
Tryptopahn:lysine	18.5	18.0
Valine:lysine	69	69
Total lysine, %	1.45	1.18
Net energy, kcal/kg	2,447	2,463
Crude protein, %	22.0	18.5
Calcium, %	0.70	0.62
Phosphorus, %	0.65	0.49
Available Phosphorus, %	0.43	0.29

Sodium, %	0.10	0.17
Chloride, %	0.23	0.46
Potassium, %	0.97	0.81
Dietary electrolyte balance, mEq/kg[7]	226	154

[1] Experimental diets were fed from approximately 11 to 30 kg. Sand was removed and replaced with salt to create the additional experimental treatment diets.

[2] Common grower diet was fed to all pigs from approximately 30 to 37 kg.

[3] Na and Cl values from NRC (1998) were used for soybean meal. Values for all other ingredients are from NRC (2012).

[4] Provided per kilogram of premix: 22 g Mn from manganese oxide; 73 g Fe from iron sulfate; 73 g Zn from zinc sulphate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

[5] Provided per kilogram of premix: 3,527,360 IU vitamin A; 881,840 IU vitamin D3; 17,637 IU vitamin E; 3,307 mg riboflavin; 1,764 mg menadione; 11,023 mg pantothenic acid; 33,069 mg niacin; and 15.4 mg vitamin B12.

[6] Ronozyme HiPhos 2700 (DSM Nutritional Products, Inc., Parsippany, NJ), providing 406.3 phytase units (FTU)/kg and an estimated release of 0.10% available P.

[7] Calculated as = (Na*434.98) + (K*255.74) – (Cl*282.06).

Table 1-3. Diet composition, Exp. 3 (as-fed basis)[1]

	Added salt, %			
Item	0.10	0.33	0.55	0.75
Ingredient, %				
Corn	54.15	53.75	53.35	52.97
Soybean meal (48% CP)[2]	22.72	22.75	22.78	22.81
Dried distillers grain with solubles[3]	20.00	20.00	20.00	20.00
Beef tallow	0.75	0.90	1.05	1.20
Monocalcium P (21% P)	0.20	0.20	0.20	0.20
Limestone	1.26	1.25	1.25	1.24
Salt	0.10	0.33	0.55	0.75
Vitamin and trace mineral premix[4]	0.15	0.15	0.15	0.15
L-Lysine HCl	0.48	0.48	0.48	0.48
DL-Methionine	0.05	0.05	0.05	0.05
L-Threonine	0.11	0.11	0.11	0.11
L-Tryptophan	0.02	0.02	0.02	0.02
Phytase[5]	0.01	0.01	0.01	0.01
TOTAL	100	100	100	100
Calculated analysis				
Standardized ileal digestible (SID) AA, %				
Lysine	1.17	1.17	1.17	1.17
Isoleucine:lysine	61	61	61	61
Leucine:lysine	147	147	146	146
Methionine:lysine	31	31	31	31
Methionine and cystine:lysine	56	56	56	56
Threonine:lysine	62	62	62	62
Tryptopahn:lysine	18.5	18.5	18.5	18.5
Valine:lysine	70	70	70	70
Total lysine, %	1.34	1.34	1.34	1.34
Net energy, kcal/kg	2,474	2,474	2,474	2,474
Crude protein, %	20.8	20.8	20.8	20.8
Calcium, %	0.58	0.57	0.57	0.57
Phosphorus, %	0.52	0.52	0.52	0.52
Available Phosphorus, %	0.34	0.34	0.34	0.34

Sodium, %	0.10	0.19	0.28	0.36
Chloride, %	0.23	0.36	0.49	0.61
Potassium, %	0.68	0.68	0.68	0.68
Dietary electrolyte balance, mEq/kg[6]	155	156	157	158
Chemical analysis, %				
Dry matter	85.90	87.39	85.83	86.56
Crude protein	16.57	17.23	15.64	17.72
Sodium	0.11	0.22	0.25	0.34
Chloride	0.26	0.46	0.50	0.61

[1] Experimental diets were fed for 44 d from approximately 27 to 64 kg.

[2] Na and Cl values from NRC (1998) were used for soybean meal. Values for all other ingredients are from NRC (2012).

[3] Dried distillers grain with solubles were analyzed for dietary Na (0.22%) and Cl (0.19%) and analyzed values were used in formulation.

[4] Provided per kilogram of premix: 22 g Mn from manganese oxide; 73 g Fe from iron sulfate; 73 g Zn from zinc sulphate; 11 g Cu from copper sulfate; 0.22 g I from calcium iodate; 0.20 g Se from sodium selenite; 3,527,360 IU vitamin A; 881,840 IU vitamin D3; 17,637 IU vitamin E; 3,307 mg riboflavin; 1,764 mg menadione; 11,023 mg pantothenic acid; 33,069 mg niacin; and 15.4 mg vitamin B12.

[5] Optiphos 2000 (Huvepharma, Sofia, Bulgaria) provided an estimated release of 0.11% available P.

[6] Calculated as = (Na*434.98) + (K*255.74) – (Cl*282.06).

Table 1-4. Chemical analysis of feed ingredients, (as-fed basis)[1]

Item	Na, %	Cl, %
Salt	40.26	58.72
L-Lysine-HCl	0.01	19.37
Soybean meal (48% CP)	0.01	0.02
Dried distillers grain with solubles4	0.22	0.19

[1] Samples were collected from the mill, homogenized, and then subsampled for analysis.

Table 1-5. Chemical analysis of experimental diets, Exp. 1, (as-fed basis)[1]

	Added salt, %				
Item, %	0	0.20	0.40	0.60	0.80
Dry matter	88.83	89.07	89.57	89.01	89.03
Crude protein	21.50	19.51	19.29	19.52	20.70
Na	0.09	0.17	0.23	0.38	0.40
Cl	0.23	0.37	0.46	0.56	0.72

[1] Multiple samples were collected from each diet throughout the study, homogenized, and then subsampled for analysis.

Table 1-6. Chemical analysis of experimental diets, Exp. 2 (as-fed basis)[1]

	Added salt, %				
Item, %	0.20	0.35	0.50	0.65	0.80
Dry matter	86.89	87.63	88.22	87.68	87.40
Crude protein	19.77	20.26	21.64	21.15	23.37
Na	0.11	0.14	0.20	0.28	0.30
Cl	0.23	0.29	0.39	0.48	0.50

[1] Multiple samples were collected from each diet throughout the study, homogenized, and then subsampled for analysis

Table 1-7. Effects of increasing salt on growth performance of 7 to 10 kg pigs (Exp. 1)[1]

	Added salt, %[2]						*P* value	
Item	0	0.20	0.40	0.60	0.80	SEM	Linear	Quadratic
Day 0 to 14								
ADG, g	194	216	234	254	253	10.2	0.001	0.218
ADFI, g	309	305	319	326	334	9.3	0.015	0.609
G:F, g/kg	626	705	732	779	758	20.9	0.001	0.019
Post treatment (day 14 to 21)								
ADG, g	432	353	361	379	334	24.6	0.013	0.318
ADFI, g	557	523	548	550	531	24.5	0.701	0.911
G:F, g/kg	772	672	652	683	623	24.1	0.001	0.135
BW, kg								
d 0	6.6	6.6	6.6	6.6	6.6	0.05	0.630	0.789
d 14	9.4	9.7	9.9	10.2	10.2	0.15	0.001	0.297
d 21	12.4	12.1	12.4	12.8	12.5	0.25	0.229	0.982

[1] A total of 325 maternal line barrows (Line 200 × 400; DNA, Columbus, NE) were used in a 14-d study with 5 pigs per pen and 13 pens per treatment. Pigs were weaned at approximately 21 d, fed a common starter diet for 7 d post-weaning, then placed on experimental diets.

[2] Experimental diets were fed from d 0 to 14 and a common Phase 3 diet was fed from d 14 to 21. Treatment diets with 0 and 0.80% added salt were manufactured and blended at the feed mill to create the intermediate levels of 0.20, 0.40, and 0.60% added salt.

Table 1-8. Effects of increasing salt on growth performance of 11 to 30 kg pig (Exp. 2)[1]

	Added salt, %[2]						*P* value	
Item	0.20	0.35	0.50	0.65	0.80	SEM	Linear	Quadratic
Day 0 to 14								
ADG, g	527	593	609	634	629	12.1	0.001	0.001
ADFI, g	844	879	889	919	903	15.7	0.001	0.089
G:F, g/kg	625	676	685	691	697	11.2	0.001	0.029
Day 14 to 27								
ADG, g	806	804	835	814	827	14.9	0.213	0.672
ADFI, g	1,323	1,316	1,360	1,383	1,377	20.2	0.002	0.766
G:F, g/kg	609	611	614	588	601	6.9	0.084	0.819
Day 0 to 27								
ADG, g	661	695	718	721	723	10.0	0.001	0.005
ADFI, g	1,075	1,089	1,116	1,142	1,129	15.8	0.001	0.211
G:F, g/kg	616	638	643	631	641	6.0	0.024	0.064
Post treatment period (day 27 to 34)								
ADG, g	916	879	916	895	881	16.8	0.316	0.884
ADFI, g	1,673	1,700	1,747	1,780	1,764	24.6	0.001	0.272
G:F, g/kg	548	517	525	503	500	7.7	0.001	0.345
BW, kg								
d 0	11.3	11.3	11.3	11.3	11.3	0.22	0.875	0.894
d 14	18.7	19.6	19.9	20.2	20.4	0.34	0.001	0.061
d 27	29.2	30.0	30.7	30.8	31.1	0.45	0.001	0.088
d 34	35.6	36.2	37.1	37.1	37.3	0.47	0.001	0.112

[1] A total of 300 pigs (Line 241 × 600; DNA, Columbus, NE) were used in a 34-d study with 5 pigs per pen and 12 pens per treatment. Pigs were weaned at approximately 21 d, fed a common starter diet for 25 d post-weaning, then placed on experimental diets.

[2] Experimental diets were fed from d 0 to 27 and a common grower diet was fed from d 27 to 34.

Table 1-9. Effects of increasing salt on growth performance of 27 to 65 kg pigs (Exp. 3)[1]

	Added salt, %					*P* value	
Item	0.10	0.33	0.55	0.75	SEM	Linear	Quadratic
Day 0 to 44							
ADG, g	852	847	851	847	8.3	0.690	0.919
ADFI, g	1,670	1,689	1,712	1,679	34.6	0.734	0.470
G:F, g/kg	512	502	499	506	8.7	0.598	0.337
BW, kg							
d 0	27.2	27.1	27.1	27.1	0.31	0.205	0.872
d 44	64.7	64.4	64.6	64.5	0.54	0.855	0.747

[1]A total of 1,188 pigs (PIC 337 x 1050) were used in a 44-d study with 27 pigs per pen and 11 replications per treatment.

Figure 1-1. Estimated optimal added salt inclusion to maximize ADG for nursery pigs, Exp. 1[1]

QP BIC=658.1

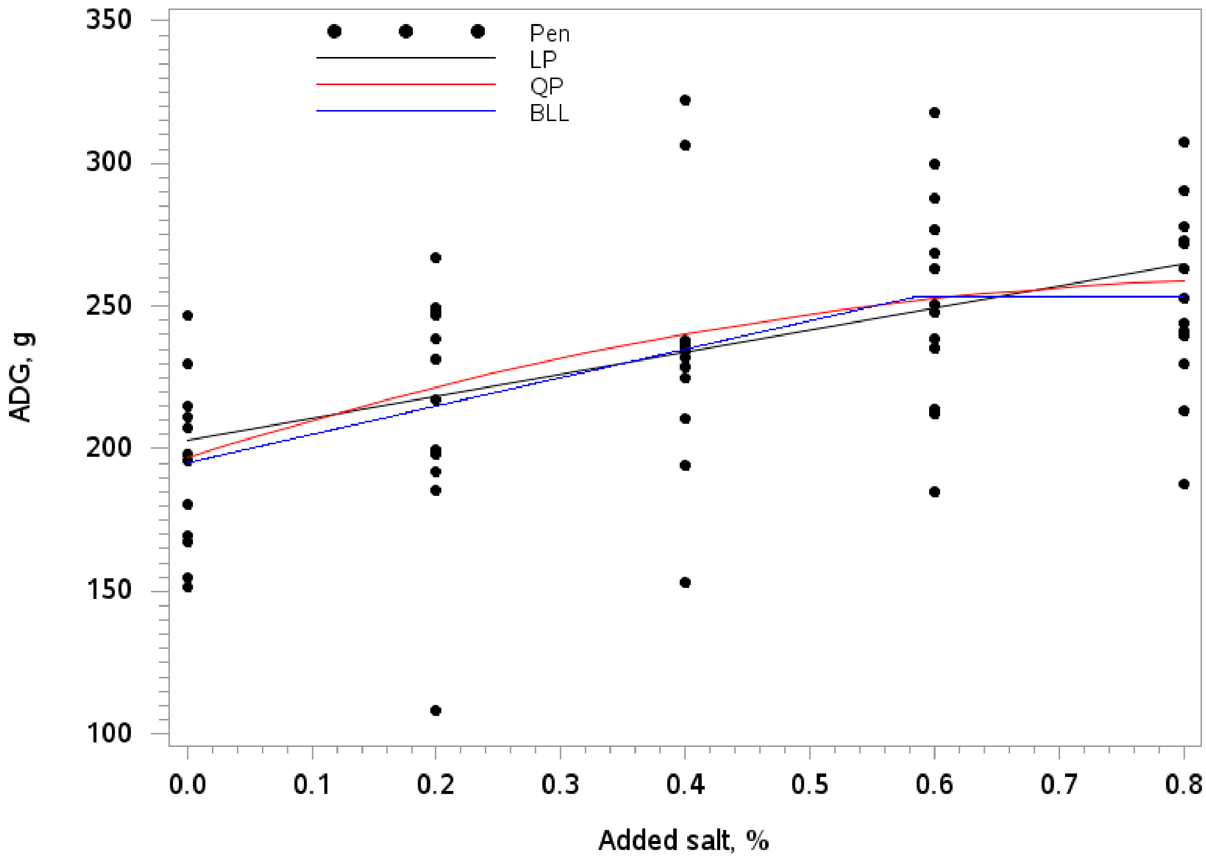
Predicted maximum response at 0.90% added salt (95% CI: 0.47, >0.80)
97% of maximum at 0.59% added salt
ADG =193.22 + 139.12 × (added salt, %) - 76.936 × (added salt, %)^2

Linear BIC=657.2

ADG= 199.37 + 77.57 × (added salt, %)

BLL BIC=657.7

Breakpoint 0.59% added salt
95% CI: [0.27, 0.91]
ADG= 253.50 – 99.58 × (0.59 – added salt, %), when added salt < 0.59%
ADG = 253.8, if added salt ≥ 0.59%



[1] A total of 325 pigs (Line 200 × 400; DNA, Columbus, NE) were used in a 14-d study with 5 pigs per pen and 13 pens per treatment. Pigs were weaned at approximately 21 d, fed a common starter diet for 7 d post-weaning, then placed on experimental diets for 14d. Quadratic polynomial (QP), broken-line linear (BLL), and broken-line quadratic (BLQ) models were fit for the experimental period to estimate optimal salt inclusion for ADG. Bayesian Information Criterion (BIC) was used to determine the best fitting model.

Figure 1-2. Estimated optimal added salt inclusion to maximize ADFI for nursery pigs, Exp. 1[1]

QP BIC=646.0

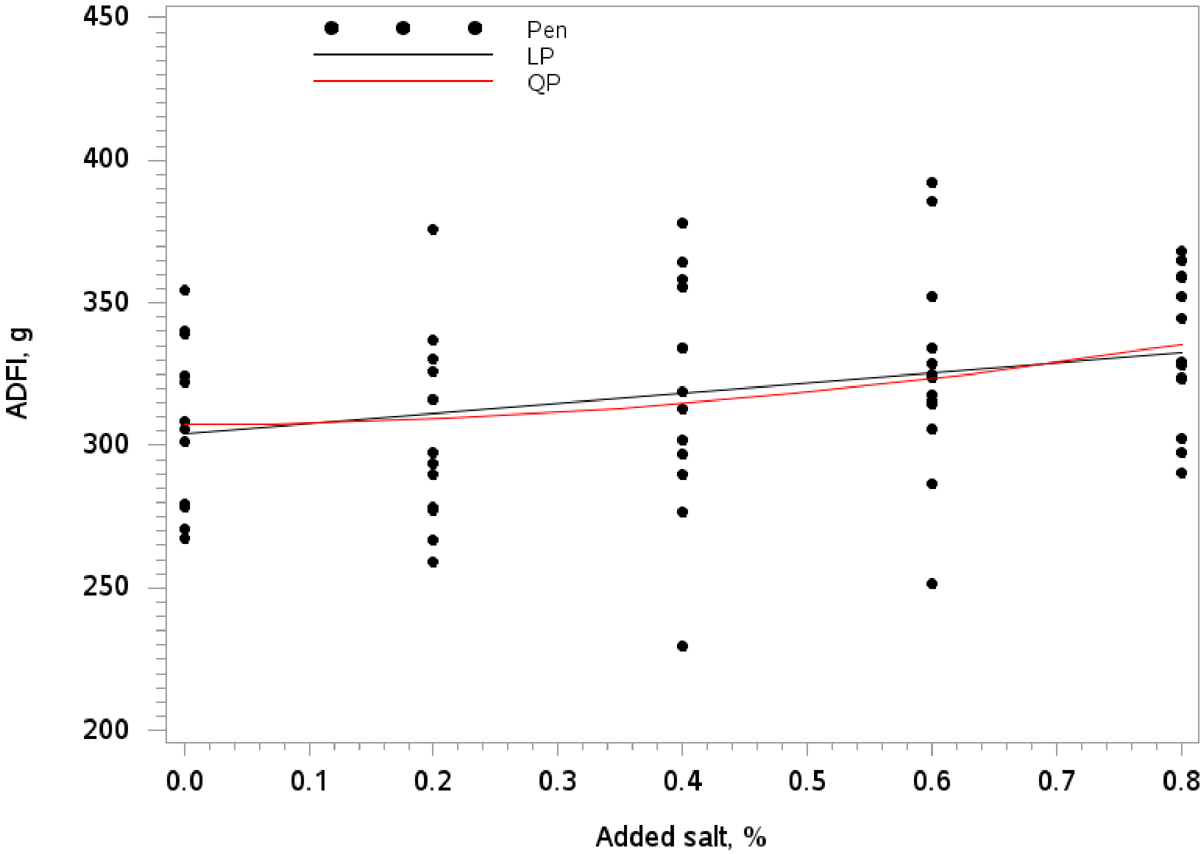
Predicted maximum response at 0.86% added salt (95% CI: 0.45, >0.80)

95% of maximum at 0.47% added salt

ADFI =193.05 + 144.74 × (added salt, %) -83.963 × (added salt, %)^2

Linear BIC=644.1

ADFI= 304.31 + 35.43 × (added salt, %)



[1] A total of 325 pigs (Line 200 × 400; DNA, Columbus, NE) were used in a 14-d study with 5 pigs per pen and 13 pens per treatment. Pigs were weaned at approximately 21 d, fed a common starter diet for 7 d post-weaning, then placed on experimental diets for 14 d. Quadratic polynomial (QP), broken-line linear (BLL), and broken-line quadratic (BLQ) models were fit for the experimental period to estimate optimal salt inclusion for ADFI. Bayesian Information Criterion (BIC) was used to determine the best fitting model.

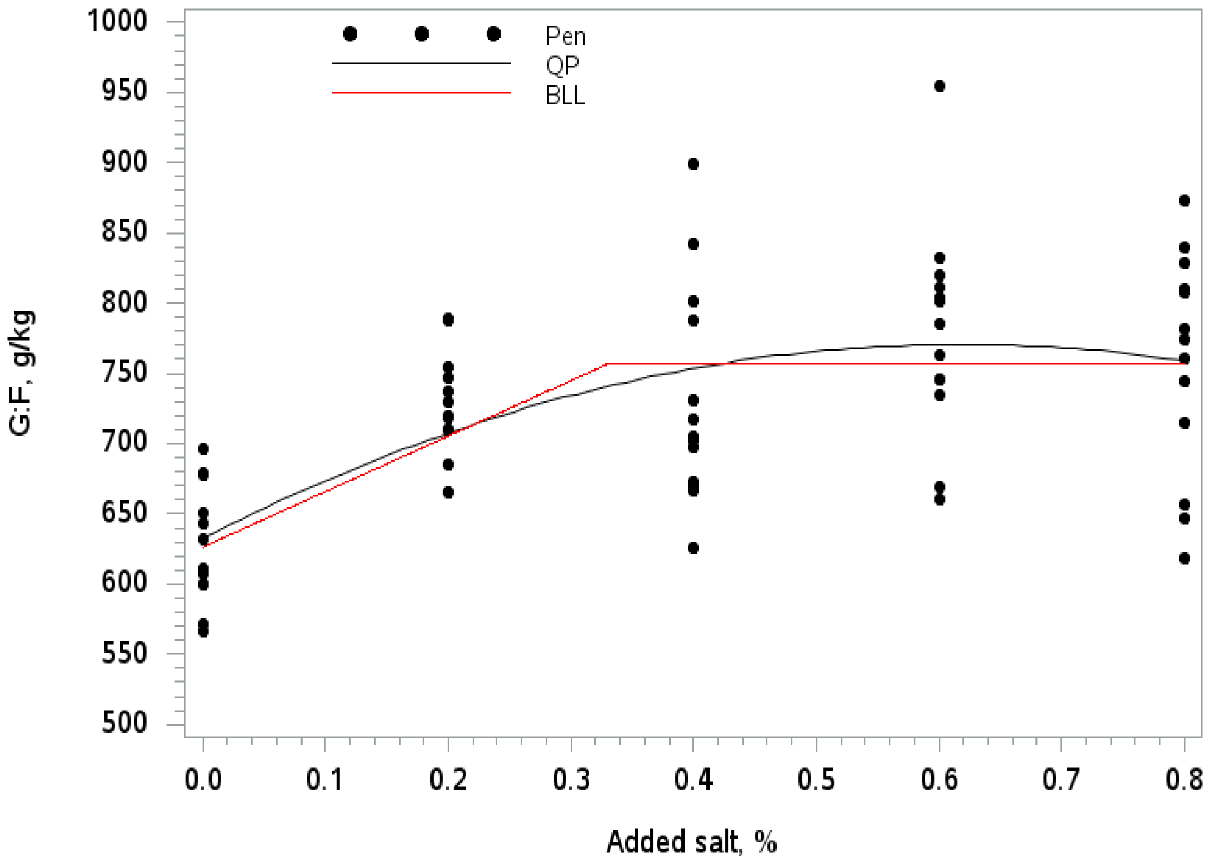
Figure 1-3. Estimated optimal added salt inclusion to maximize G:F for nursery pigs, Exp. 1[1]

QP BIC=749.8

Predicted maximum response at 0.67% added salt (95% CI: 0.37, >0.80)
95% of maximum at 0.33% added salt
G:F =626.61 + 429.91 × (added salt, %) - 321.92 × (added salt, %)^2

BLL BIC=751.3

Breakpoint 0.33% added salt
95% CI: [0.12, 0.54]
G:F= 756.47 – 394.82 × (0.33 – added salt, %), when added salt < 0.33%
G:F = 756.7, if added salt ≥ 0.33%



[1] A total of 325 pigs (Line 200 × 400; DNA, Columbus, NE) were used in a 14-d study with 5 pigs per pen and 13 pens per treatment. Pigs were weaned at approximately 21 d, fed a common starter diet for 7 d post-weaning, then placed on experimental diets for 14 d. Quadratic polynomial (QP), broken-line linear (BLL), and broken-line quadratic (BLQ) models were fit for the experimental period to estimate optimal salt inclusion for G:F. Bayesian Information Criterion (BIC) was used to determine the best fitting model.

Figure 1-4. Estimated optimal added salt inclusion to maximize ADG for nursery pigs, Exp. 2[1]

QP BIC=586.6

Predicted maximum response at 0.69% added salt (95% CI: 0.45, >0.80)

99% of maximum at 51% added salt

ADG = 600.44 + 358.82 × (added salt, %) - 258.68 × $(\text{added salt}, \%)^2$

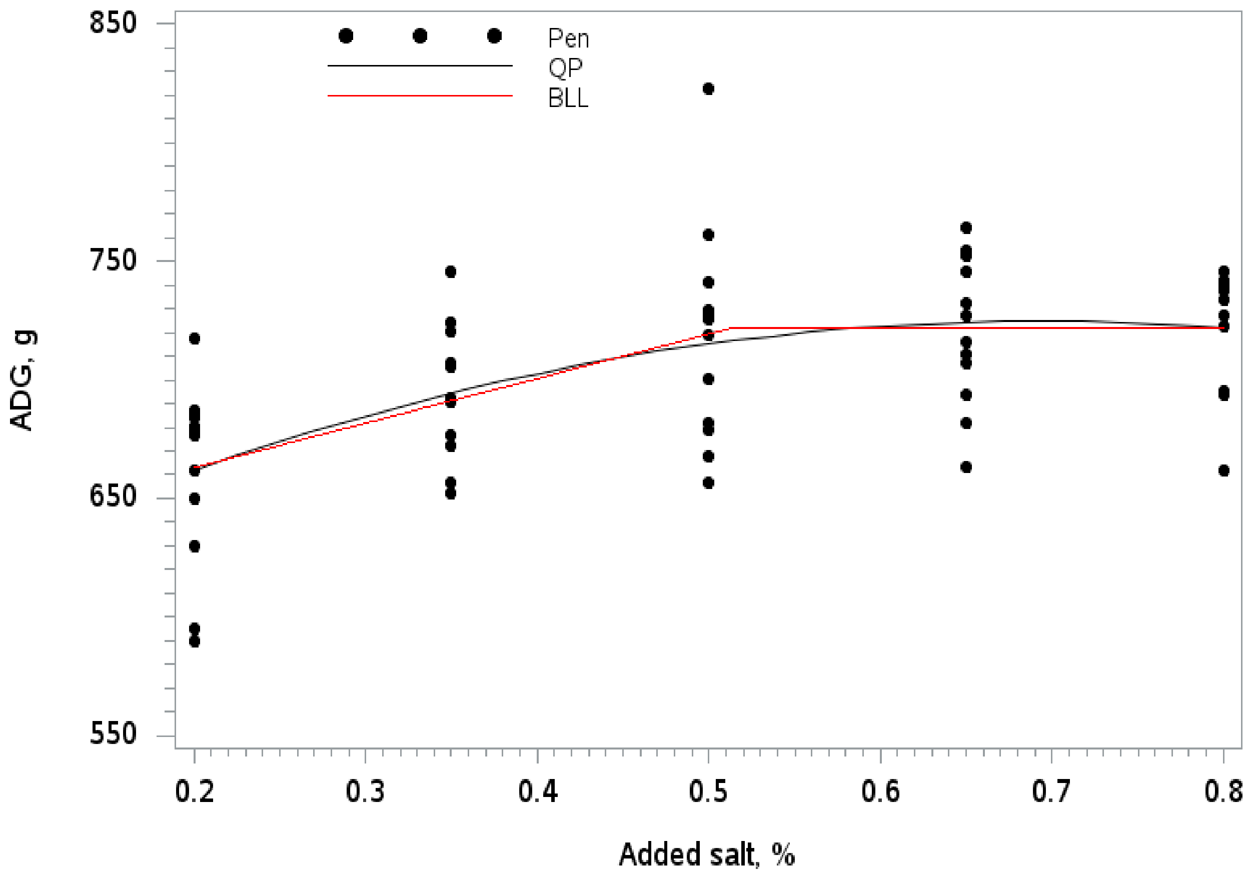
BLL BIC=586.6

Breakpoint 0.51% added salt

95% CI: [0.41, 0.61]

ADG = 722.07 – 187.83 × (0.51 – added salt, %), when added salt < 0.51%

ADG = 721.2, if added salt ≥ 0.51%



[1] A total of 300 pigs (Line 241 × 600; DNA, Columbus, NE) were used in a 27-d study with 5 pigs per pen and 12 pens per treatment. Pigs were weaned at approximately 21 d, fed a common starter diet for 25 d post-weaning, then placed on experimental diets for 27 d. Quadratic polynomial (QP), broken-line linear (BLL), and broken-line quadratic (BLQ) models were fit for the experimental period to estimate optimal salt inclusion for ADG. Bayesian Information Criterion (BIC) was used to determine the best fitting model.

Figure 1-5. Estimated optimal added salt inclusion to maximize ADFI for nursery pigs, Exp. 2[1]

QP BIC=643.8

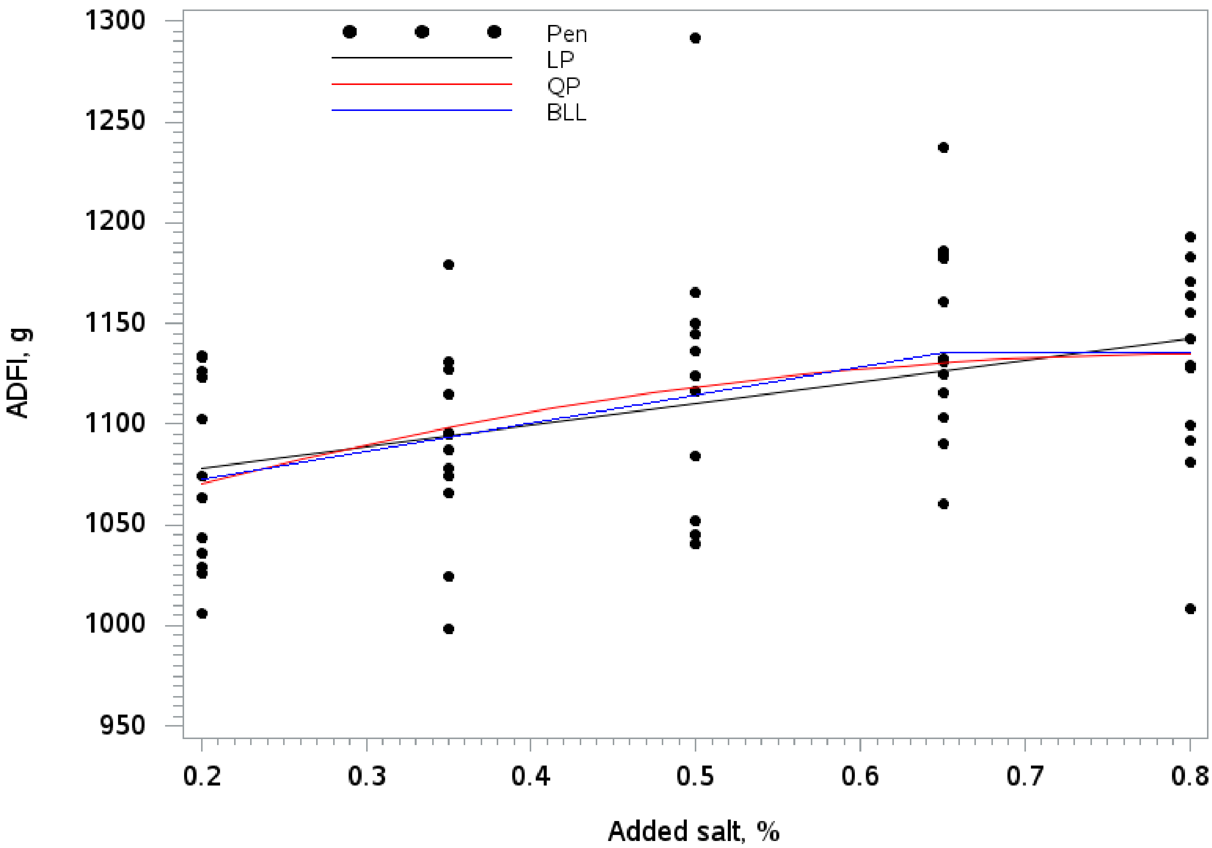
Predicted maximum response at 0.80% added salt (95% CI: 0.45, >0.80)
99.6% of maximum at 0.65% added salt
ADFI = 1020.22 + 284.61× (added Salt, %) - 177.15 × (added salt, %)^2

Linear BIC=642.9

ADFI= 1056.54 + 107.46 × (added salt, %)

BLL BIC=642.5

Breakpoint 0.65% added salt
95% CI: [0.38, 0.92]
ADFI = 1135.5 – 139.76 × (0.65 – added salt, %), when added salt < 0.65%
ADFI = 1,135.4, if added salt ≥ 0.65%



[1] A total of 300 pigs (Line 241 × 600; DNA, Columbus, NE) were used in a 27-d study with 5 pigs per pen and 12 pens per treatment. Pigs were weaned at approximately 21 d, fed a common starter diet for 25 d post-weaning, then placed on experimental diets for 27 d. Quadratic polynomial (QP), broken-line linear (BLL), and broken-line quadratic (BLQ) models were fit for the experimental period to estimate optimal salt inclusion for ADFI. Bayesian Information Criterion (BIC) was used to determine the best fitting model.

Figure 1-6. Estimated optimal added salt inclusion to maximize G:F for nursery pigs, Exp. 2[1]

Linear BIC=546.3

G:F= 1056.54 + 107.46 × (added salt, %)

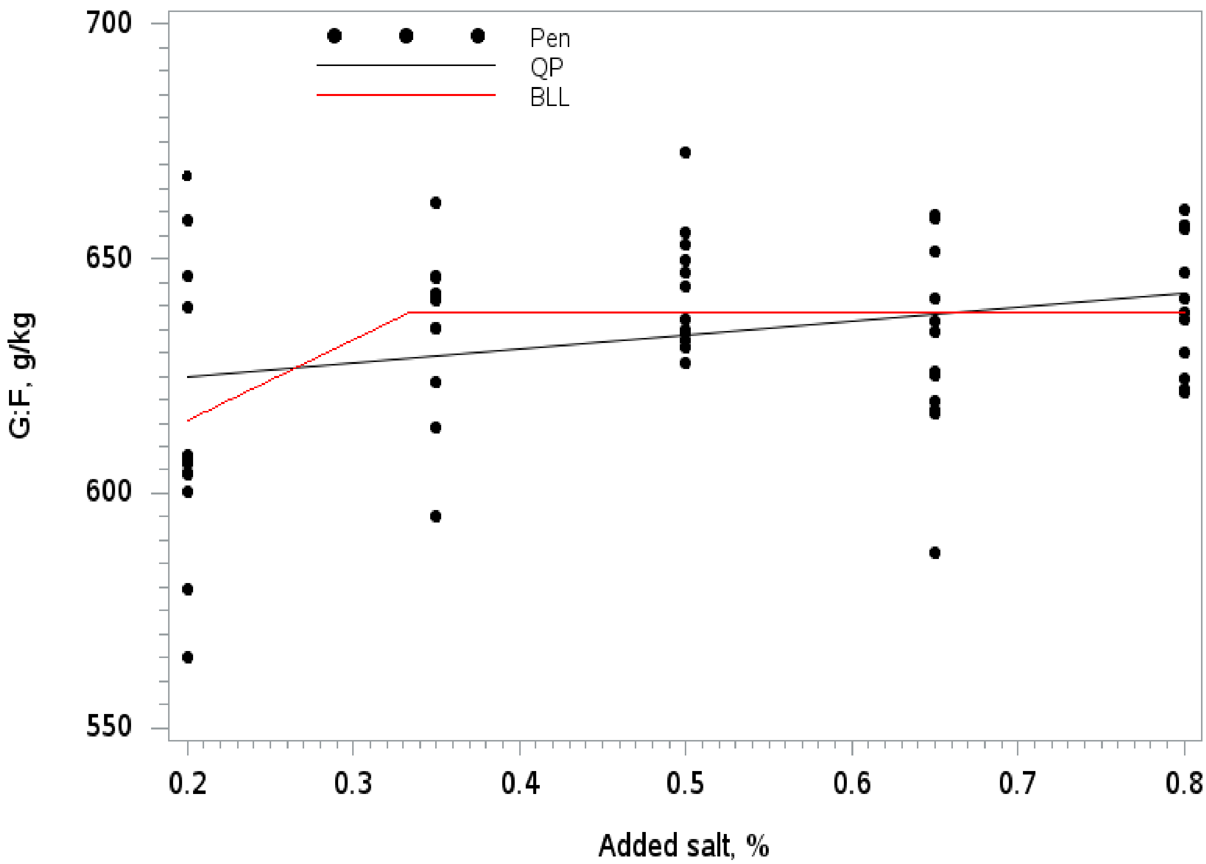
BLL BIC=545.8

Breakpoint 0.35% added salt

95% CI: [0.27, 0.43]

G:F = 638.57 – 150.04 × (0.35 – added salt, %), when added salt < 0.35%

G:F = 638.0, if added salt ≥ 0.35%



[1] A total of 300 pigs (Line 241 × 600; DNA, Columbus, NE) were used in a 27-d study with 5 pigs per pen and 12 pens per treatment. Pigs were weaned at approximately 21 d, fed a common starter diet for 25 d post-weaning, then placed on experimental diets for 27 d. Quadratic polynomial (QP), broken-line linear (BLL), and broken-line quadratic (BLQ) models were fit for the experimental period to estimate optimal salt inclusion for G:F. Bayesian Information Criterion (BIC) was used to determine the best fitting model.

Chapter 2 - Effects of Na and Cl on nursery pig growth

ABSTRACT

Three studies were conducted to determine the effects of source and concentration of Na and Cl on pig growth performance from 7 to 12 kg. In all three experiments, pigs were fed a common diet (0.33% Na and 0.77% Cl) for 7 or 8 days after weaning then randomly assigned to dietary treatments. In Exp. 1, 360 pigs were used in a 14-day study with 15 replications per treatment and 6 pigs per pen. Treatments included a 10% dried whey diet with 0.60% added salt (0.37% Na and 0.75% Cl); or 3 diets with 7.2% crystalline lactose with either: 0.35% added salt (0.18% Na and 0.47% Cl); 0.78% added salt (0.35% Na and 0.72% Cl); or 1.15% $NaHCO_3$ and 0.40% KCl (0.35% Na and 0.45% Cl). Pigs fed the 0.78% added salt-lactose diet had greater ($P < 0.05$) average daily gain (ADG) than pigs fed the 0.35% added salt-lactose diet, with others intermediate. In Exp. 2, 360 barrows were used in a 14-day study with 12 replications per treatment and 5 pigs per pen. Treatments included two added salt diets (providing 0.13% Na and 0.35% Cl diet or 0.35% Na and 0.68% Cl), three diets with Na and Cl provided by KCl and $NaHCO_3$ (0.13, 0.35, or 0.57% Na and 0.50% Cl), or a diet with $NaHCO_3$ and $CaCl_2$ (0.35% Na and 0.50% Cl). Regardless of Na source, ADG and average daily feed intake (ADFI) increased (quadratic, $P < 0.05$) as dietary Na increased from 0.13 to 0.35%, with no further benefits observed thereafter. There was no evidence for differences among pigs fed NaCl or $NaHCO_3$ nor evidence for differences among pigs fed the different Na and Cl sources at similar concentrations. In Exp. 3, 300 pigs were used in a 21-day trial with 10 replications per treatment and 5 pigs per pen. Treatments included a control diet with added salt to provide 0.33% Na and 0.55% Cl or 5 diets with 0.33 % Na and added KCl to provide 0.09, 0.21, 0.32, 0.45, or 0.55% Cl. Average daily gain and gain to feed ratio (G:F) increased (quadratic, $P < 0.035$) as Cl increased from 0.09 to 0.32%. Pigs fed the control diet (added salt) and the 0.55% Cl diet had similar ADG. For ADG and ADFI, the broken line linear model indicated a breakpoint of 0.23% Cl. For G:F, the quadratic polynomial model was the best fitting model with a reported maximum of 0.38% Cl. In conclusion, 7 to 12 kg pigs fed diets that contained at least 0.35% Na and 0.38% Cl had greater ADG and G:F compared to pigs fed diets with lower concentrations and minimal effects were observed among the sources of Na or Cl used in these studies.

Key words: chloride, pig, salt, sodium

INTRODUCTION

Two of the most common electrolytes found in the body are Na and Cl. Each electrolyte has several specific roles including homeostasis of water and electrolytes and acid-base balance. Sodium regulates cellular osmolarity and plasma volume and is critical in cellular transport systems, muscle contraction, and nerve impulse. Chloride is a component of HCl, which is critical in the activation of pepsin. The NRC (1998) requirement estimates for Na and Cl are 0.20% and 0.20% for 5 to 10 kg pigs and 0.15% and 0.15% for 10 to 20 kg pigs. While evaluating Na and Cl independently, Mahan et al. (1996) observed improvements in ADG up to a dietary Na and Cl concentration of 0.34% and 0.50% in pigs weighing approximately 6 to 9 kg. Mahan et al. (1999) noted improvements in ADG up to a dietary Cl concentration of 0.45% in 7 to 12 kg pigs, however; in two additional studies, improvements in ADG and N retention were observed up to a dietary Cl concentration of only 0.32% and 0.38% in pigs weighing approximately 6 to 13 kg pigs. Based on these findings and others, the NRC (2012) increased the Na and Cl requirement estimates of 7 to 11 kg pigs to 0.35% and 0.45%. More recently, Shawk et al. (2018) observed that 0.59% added salt (0.34% Na and 0.58% Cl) maximized ADG of 7 to 10 kg pigs. A Na concentration of 0.34% meets the NRC (2012) requirement estimate of 0.35%, however, a Cl concentration of 0.58% is significantly higher than NRC (2012) requirement estimate of 0.45%. The challenge with determining the Na and Cl requirement by increasing salt is that Na and Cl are not independently evaluated because of the composition of salt (39% Na and 61% Cl). When Na and Cl are independently evaluated, an accurate requirement estimate for each electrolyte can be determined; however, there is limited research available that documents how the dietary source of the Na and Cl ions influences the requirement. Therefore, the objective of these experiments was to evaluate the effects of source and concentration of Na and Cl on the growth performance of nursery pigs weighing approximately 7 to 12 kg.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in these experiments. Pigs were weaned at approximately 21 days of age and at this time, randomly allotted to pens. Each pen was equipped with a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Experiments 1 and 3 were conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. Experiment 2 was conducted at the Kansas State University Segregated Early Weaning Research Facility in Manhattan KS. All experimental diets were manufactured at the Kansas State University O.H. Kruse Feed Technology Innovation Center.

Experiment 1

A total of 360 pigs (Line 241 × 600; DNA, Columbus, NE; initially 6.9 kg) were used in a 14-day study. Pigs were fed a common diet (0.33 Na and 0.76% Cl) for 7 days after weaning. On day 7 after weaning, considered day 0 in the trial, pens or pigs were blocked by body weight and randomly assigned to 1 of 4 dietary treatments with 15 replications per treatment and 6 pigs per pen. Each pen was 1.5 × 1.2 m providing 0.30 m^2 per pig. Four dietary treatments were used to determine if the source of lactose and the source and concentration of the Na and Cl ion influences growth performance. Source of lactose was of interest because dried whey is a significant source of sodium and chloride. The 4 treatments included a 10% dried whey diet with 0.60% added salt (0.37% Na and 0.75% Cl); or 3 diets with 7.2% crystalline lactose and either: 0.35% added salt (0.18% Na and 0.47% Cl); 0.78% added salt (0.35% Na and 0.72% Cl); or 1.15% $NaHCO_3$and 0.40% KCl (0.35% Na and 0.45% Cl; Table 2-1). Thus, the dried whey diet and lactose diet containing 0.78% added salt contained similar Na and Cl levels. The lactose diet containing $NaHCO_3$ and KCl had similar Na to these diets, but similar Cl content to the lactose diet containing 0.35% added salt. Nutrient values used in diet formulation were derived from NRC (2012). Experimental diets were fed for 14 days. Pens of pigs were weighed and feed disappearance was recorded on day 0, 7, and 14 to determine ADG, ADFI, and G:F. Dietary treatments were corn-soybean meal-based and were fed in meal form. Dried whey was replaced with crystalline lactose to equalize lactose, and all diets were formulated to the same net energy concentration. Salt, KCl, or $NaHCO_3$ replaced corn to create the experimental diets.

Experiment 2

A total of 360 barrows (Line 200 × 400; DNA, Columbus, NE; initially 7.1 kg) were used in a 21-day study. Pigs were fed a common diet (0.33 Na and 0.76% Cl) for 8 days after weaning. On day 8 after weaning, considered day 0 in the trial, pens of pigs were blocked by body weight and randomly assigned to 1 of 6 dietary treatments with 12 replications per treatment and 5 pigs per pen. Each pen was 1.2 × 1.2 m providing 0.28 m^2 per pig. Experimental treatments (Table 2-2) included two added salt diets (providing 0.13% Na and 0.35% Cl or 0.35% Na and 0.68% Cl), three diets with Na and Cl provided by $NaHCO_3$ and KCl (0.13, 0.35, or 0.57% Na and 0.50% Cl), or a diet with $NaHCO_3$ and $CaCl_2$ (0.35% Na and 0.50% Cl). Nutrient values used in diet formulation were derived from NRC (2012) with the exception of Na and Cl in soybean meal and dried whey. From Na and Cl analysis of ingredients, Shawk et al. (2018) observed the Cl concentration of soybean meal to be closer to 0.02% Cl, which is similar to NRC (1998) value, but much lower than the 0.49% estimated by NRC (2012). Thus, NRC (1998) Na and Cl values was used for diet formulation. Prior to manufacturing treatment diets, dried whey samples were collected at the mill, pooled, subsampled, and submitted for Na and Cl analysis (Cumberland Valley Analytical Service, Maugansville, MD). Analyzed Na and Cl values for dried whey were then used in diet formulation. Experimental diets were fed for 14 days with a common diet (0.28% Na and 0.50% Cl) fed from day 14 to 21. Pens of pigs were weighed and feed disappearance was recorded every 7 days to determine ADG, ADFI, and G:F. Dietary treatments were corn-soybean meal-based and were fed in meal form. Sand was replaced by an equal amount of either salt, KCl, $CaCl_2$, or $NaHCO_3$ to create the treatment diets.

Experiment 3

A total of 300 pigs (Line 241 × 600; DNA, Columbus, NE; initially 7.1 kg) were used in a 21-day growth trial. At weaning, pigs were assigned to pens (1.5 × 1.2 m providing 0.36 m^2 per pig) with 5 pigs per pen and fed a common diet (0.33% Na and 0.77% Cl) for 7 days after weaning. On day 7 after weaning, considered day 0 in the trial, pens of pigs were blocked by body weight and randomly assigned to 1 of 6 dietary treatments with 10 replications per treatment and 5 pigs per pen. Experimental treatments included a control diet containing 0.33% Na and 0.55% Cl provided by added salt or 5 diets with 0.33 % Na and added KCl to provide 0.09, 0.21, 0.32, 0.45, or 0.55% Cl (Table 2-3). Treatment diets were fed for 14 days with a common diet (0.18% Na and 0.49% Cl) fed from day 14 to 21. Nutrient values used in diet formulation were derived from NRC (2012) with the exception of Cl concentration of soybean meal for which the NRC (1998) value was used. Pens of pigs were weighed and feed disappearance was recorded every 7 day to determine ADG, ADFI, and G:F. Dietary treatments were corn-soybean meal-based with 7.2% crystalline lactose and were fed in meal from. Salt, KCl, or $NaHCO_3$ replaced sand to create the different dietary treatments.

Chemical analysis

In each experiment, diet samples were collected from 6 to 9 feeders, blended and subsampled. In experiment 1, samples were submitted to a commercial laboratory for analysis of Na and Cl (Ward Laboratories, Kearney, NE). Briefly, organic matter and lipids were removed from the samples via HNO_3, HCl, and H_2O_2 (Campbell et al., 1991; Wolf et al., 2003) and then analyzed for Na by inductively coupled plasma spectroscopy (Kovar, 2003). The Cl concentrations were determined by the titration of sliver nitrate until all Cl ions were precipitated and then the concentration of free silver ions was determined by using a Metrohm 855 Robitic Titrosampler and a Metrohm 6.0430.100 Ag Titrode (Metrohm USA Inc, Riverview, FL; AOAC 969.10, 1990; Kalra et al., 1991; Mills et al., 1991). Samples from Exp. 2 and 3 were also submitted to a commercial laboratory for Na and Cl analysis (Cumberland Valley Analytical Service, Maugansville, MD). Sodium samples were ashed, digested with HNO_3 and then analyzed via inductively coupled plasma emission spectroscopy (Perkin Elmer 5300 DV ICP, Perkin Elmer, Shelton, CT; AOAC 985.01, 2000). Chloride samples were extracted with HNO_3 and then analyzed via potentiometric titration with sliver nitrate using a Metrohm 848 Titrono Plus (Metrohm USA Inc, Riverview, FL). Standard procedures from AOAC (2006) were followed for analysis of moisture (Method 934.01), and CP (Method 990.03; K-State Analytical Laboratory, Manhattan, KS).

Statistical analysis

Data for all experiments were analyzed as a completely randomized block design with body weight as the blocking factor. In all studies, data was analyzed using PROC GLIMMIX in SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Results were considered significant at $P \leq 0.05$ and marginally significant between $P > 0.05$ and $P \leq 0.10$.

For Exp. 1, individual treatment means of the growth data were evaluated using the Tukey-Kramer multiple comparison p-value adjustment. For Exp. 2, contrasts were used to determine the linear and quadratic response of Na concentration and inclusion of $NaHCO_3$ and KCl. Contrasts were used to compare the two diets with added salt. The 0.35% Na and 0.45% Cl diet provided by $NaHCO_3$ and KCl was compared to the 0.35% Na and 0.45% Cl diet provided by $NaHCO_3$ and $CaCl_2$, and the 0.13% Na and 0.50% Cl diet provided by $NaHCO_3$ and KCl to the 0.13% Na and 0.35% Cl diet provided by added salt. Another contrast was used to compare the 0.35% Na and 0.45% Cl diet provided by $NaHCO_3$ and KCl to the 0.35% Na and 0.45% Cl diet provided by $NaHCO_3$ and $CaCl_2$ and to the 0.35% Na and 0.68% Cl diet provided by added salt.

For Exp. 3, an initial model was evaluated where dietary treatment was considered a categorical fixed effect and block was considered a random effect with pen as the experiment unit. The base model was used to determine the heterogeneity of residual variance using Bayesian Information Criteria (BIC) to determine the best fit. Homogenous variance was used for ADG, ADFI, and G:F. Linear and quadratic contrasts were used to evaluate increasing Cl. Additionally, the 0.78% added salt control and 0.55% Cl treatment provided by KCl were compared.

Chloride dose response curves for ADG, ADFI, and G:F were predicted following the procedure described by Goncalves et al. (2016) and using PROC GLIMMIX and PROC NLMIXED in SAS (SAS Institute, Inc., Cary, NC). Linear, quadratic (QP), broken-line linear (BLL), and broken-line quadratic (BLQ) were the dose response models that were evaluated. The best fitting model was determined by using the Bayesian Information Criterion (BIC) with a decrease in 2 or more points indicating a better fit (Raftery, 1996). For best fitting models, the response curves and individual pen means were plotted. The breakpoints and 95% CI were reported for the BLL models. The maximum response and 95% CI was reported for the QP model. The CI of the QP model was calculated by plotting the regression equation with the 95% CI across doses and projecting the maximum response across the y-axis via a horizontal line. The intersection between the horizontal line and CI boundaries of the predicted line is then projected onto the x-axis to estimate the CI of the optimum dose level (Goncalves et al., 2016).

RESULTS AND DISCUSSION

Chemical Analysis

For Exp. 1, chemical analysis indicated that the dietary Na concentration of the treatment diets was similar to formulated values, but the analyzed Cl concentrations were slightly lower than formulated (Table 2-1). From Na and Cl analysis of ingredients, Shawk et al. (2018) observed the Cl concentration of soybean meal to be closer to 0.02% Cl, which is similar to NRC (1998) value, but much lower than the 0.49% estimated by NRC (2012). This explained the discrepancy between calculated and analyzed Cl values. Sodium ranged from 0.18% to 0.37% and Cl ranged from 0.35% to 0.67%. For Exp. 2, results of the chemical analysis indicated that Na concentration of the diets was slightly greater than formulated values (Table 2-2). Dietary Cl concentrations were similar to calculated values. For Exp. 3, chemical analysis indicated that the dietary Na and Cl concentrations of the treatment diets were similar to formulated values (Table 2-3).

Experiment 1

From day 0 to 14, pigs fed the 0.78% added salt-lactose diet had greater ($P < 0.05$) ADG than pigs fed the 0.35% added salt-lactose diet, with intermediate performance observed for pigs fed the 0.60% added salt-dried whey diet and 1.15% $NaHCO_3$ and 0.40% KCl-lactose diet (Table 2-4). Pigs fed the 0.60% added salt-dried whey diet had greater ADFI ($P < 0.05$) compared to those fed the 0.35% added salt-lactose diet, with the other treatments being intermediate. There was no evidence to indicate that dietary treatment influenced G:F or ending BW.

The NRC (2012) Na and Cl requirement estimate for 7 to 11 kg pigs is 0.35% and 0.45%, respectively. Based on these estimates, the 0.78% added salt-lactose diet (0.37% Na and 0.60% Cl) and 0.60% added salt-dried whey diet (0.37% Na and 0.67% Cl) met the NRC (2012) requirement estimate for Na (0.35%) and exceeded the Cl requirement estimate. The $NaHCO_3$ and KCl diet (0.37% Na and 0.35% Cl) would have met the NRC (2012) requirement estimate for Na (0.35%); however, it would be considered deficient in Cl (0.45%) based on the chemical analysis, even though the formulated target was to meet the NRC (2012) requirement estimate. The 0.35% added salt-lactose diet (0.18% Na and 0.36% Cl) was clearly deficient in both Na and Cl. Results of this trial suggest that only pigs fed the diet with 0.78% salt and lactose had greater ADG compared to pigs fed a diet that was deficient in Na. Mahan et al. (1996) evaluated Na from added Na_2PO_4 in corn-soybean meal diets with dried whey and observed improvement in ADG up to a dietary Na concentration of 0.34% in 7 to 8 kg pigs. A Na concentration of 0.34% would be similar to the Na concentration of the 0.78% added salt-lactose diet in the study herein. Surprisingly, pigs fed the dried whey diet with 0.60% added salt were only intermediate between the high and low Na diets though numerically their performance was similar to pigs fed the 0.78% added salt lactose diet. Based on the chemical analysis of Na and Cl, we would have expected no evidence of difference in ADG between pigs fed the 0.60% added salt dried whey diet and those fed 0.78% added salt-lactose diet. Interestingly, pigs fed the $NaHCO_3$ and KCl diet that was adequate in Na but deficient in Cl were also intermediate between the 0.78% salt-lactose diet and 0.35% salt-lactose diet. The intermediate ADG and ADFI of pigs fed the $NaHCO_3$ and KCl diet could be due to the Na and Cl source ($NaHCO_3$ and KCl) or because of a deficiency of Cl. In two separate studies, Mahan et al. (1999) noted improvements in ADG and N retention up to a dietary Cl concentration of 0.32% and 0.38% in corn-soybean meal diets with lactose, spray-dried animal plasma, and added HCl. However, in a different study, Mahan et al. (1999) observed improvements in ADG up to a dietary Cl concentration of 0.45% in corn-soy diets with lactose and spray dried animal plasma and added Na_2PO_4 and HCl. A Cl concentration of 0.45% would be considerably greater than the Cl concentration of $NaHCO_3$ and KCl (0.35%) diet, however, a Cl concentration of 0.32 and 0.38% would be similar and this may suggest the amount of Cl rather than source might be the reason for the intermediate ADG. Overall, results of this trial indicate pigs fed an added salt diet that contains a Na concentration of 0.35% and a Cl concentration of at least 0.60% had greater growth performance compared to pigs fed a diet deficient in Na and Cl based on the NRC (2012) requirement estimate. As long as these minimum requirements were met, source of Na and Cl did not influence performance.

Experiment 2

From d 0 to 14 (approximately 7 to 11 kg), ADG and ADFI improved (quadratic, $P < 0.05$) as dietary Na concentration increased from 0.13 to 0.35%, with no further benefits observed thereafter (Table 2-5). Day 14 BW tended ($P < 0.089$) to increase as dietary Na concentration increased from 0.13 to 0.35%, with no further benefits observed thereafter. Gain to feed was not influenced by the dietary Na concentration. There was no evidence to indicate differences in growth performance due to Na or Cl source.

From day 14 to 21 when pigs were fed a common diet, compensatory gain was observed with pigs previously fed low Na diets having increased (linear, $P < 0.05$) ADG and G:F compared with pigs previously fed higher Na diets regardless of Na source. Previous source and concentration of Cl did not affect subsequent ADG.

Overall, the most consistent response observed in this experiment was improvement in growth performance up to a Na concentration of 0.35%. Pigs fed a Na concentration of 0.35%, regardless of source, had improved ADG compared to pigs fed 0.13% or 0.57% Na. This would agree with the NRC (2012) requirement estimate of 0.35%. It would also agree with the findings of Exp. 1 in which pigs fed a diet containing a Na concentration of 0.37% had improved growth performance compared to pigs fed the deficient (0.13% Na) diet containing 0.35% added salt and lactose. It would also agree with observations of Mahan et al. (1996) who observed improvements in ADG up to a Na concentration of 0.34% in corn-soy diets with dried whey and added Na_2PO_4. In this experiment, there was no evidence to indicate that the source of Na and Cl ion influenced the growth performance of the pigs. This observation would suggest that dietary source of the Na and Cl ion does not influence growth. It also helps to explain the response to the $NaHCO_3$ and KCl diet in Exp. 1. The intermediate growth performance was likely due to the shortage of Cl in the diet rather than the source of Cl. However, the fact that there were no differences among the two added salt diets (0.13 and 0.35% Na) is not consistent with the results of Exp. 1 nor would it agree with the findings of Mahan et al. (1996, 1999) in which improvements in ADG was observed up to an added salt inclusion of 0.40%.

Experiment 3

From day 0 to 14 (approximately 7 to 12 kg), ADG, ADFI, G:F, and day 14 BW improved (quadratic, $P < 0.035$) as dietary Cl concentration increased from 0.09 to 0.32% with no further benefits observed thereafter (Table 2-6). Pigs fed the 0.55% Cl diet had similar ADG, increased ($P = 0.046$) ADFI, but a tendency for poorer ($P = 0.069$) G:F compared with pigs fed the control diet with 0.55% Cl from added salt. From d 14 to 21, when pigs were fed a common diet, compensatory gain was observed for pigs previously fed the low chloride diet. Average daily gain decreased (linear, $P = 0.045$), ADFI increased (linear, $P = 0.033$), and G:F decreased (quadratic, $P = 0.004$) with increasing dietary Cl previously fed from d 0 to 14. Pigs previously fed the 0.55% Cl from KCl diet had greater ($P = 0.009$) ADFI and tended ($P = 0.080$) to have poorer ($P = 0.080$) G:F than pigs previously fed the diet with 0.55% Cl from added salt.

From day 0 to 14, the broken line linear model was the best fitting model for ADG and ADFI and indicated a breakpoint of 0.23% Cl (Figure 2-4 and 2-5). For the ADG BLL model, ADG = 357.87 – 619.42 × (0.23 – Cl, %), when Cl < 0.23% and ADG =359.5 of Cl ≥ 0.23%. For the ADFI BLL model, ADFI = 494.45 – 415.5 × (0.23 – Cl, %), when Cl < 0.23% and ADFI =495.2 of Cl ≥ 0.23%. The best fitting model for G:F was the quadratic polynomial with the predicted response indicated as $G{:}F = 549.77 + 1{,}016.45 \times (Cl, \%) - 1{,}331.57 \times (Cl, \%)^2$ with maximum performance achieved with a Cl concentration of 0.38% (95% CI [0.26, 0.51%]) though a 0.23% Cl concentration could obtain 96% of the performance (Figure 2-6).

Maximum ADG could be obtained with a Cl concentration of 0.23%, however, this would only capture 96% of the G:F performance. Thus to maximize ADG and G:F, a Cl concentration of 0.38% would be needed. A Cl concentration of 0.38% would be slightly lower than the current NRC (2012) Cl requirement estimate of 0.45%. While titrating Cl with HCl in corn-soy diets with dried whey, Mahan et al. (1996) observed improvement in ADG up to a dietary Cl concentration of 0.50% in 6 to 9 kg pigs. Mahan et al. (1999) did not observe an interaction between Na and Cl, however, did note improvements in ADG up to a dietary Cl concentration of 0.45% in a corn-soy diet with lactose and plasma and added Na_2PO_4 and HCl. A Cl concentration of 0.45% and 0.50% would be significantly higher than the Cl concentration (0.38%) that maximized ADG and G:F in this trial; however, Cl in our experiment was titrated with KCl instead of HCl. In two separate studies, Mahan et al. (1999) noted improvements in ADG and N retention up to a dietary Cl concentration of 0.32% and 0.38% in corn-soy diets with lactose and plasma and added HCl. A Cl concentration of 0.32% and 0.38% would be similar to the Cl concentration (0.38%) that optimized ADG and G:F in this experiment.

In conclusion, results of these studies indicate that 0.35% Na (similar to NRC 2012 estimates) appears to optimize ADG in pigs from 7 to 11 kg. The optimal Cl concentration that maximizes both ADG and G:F was 0.38% which is slightly lower than NRC (2012) requirement estimate of 0.45%. Source of Na or Cl had minimal effect on growth performance.

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Table 2-1. Diet composition, Exp. 1 (as-fed basis)[1]

Lactose source:	Dried whey	Lactose		
Na source:	NaCl			$NaCO_3$
Cl source:	NaCl			KCl
Na, %	0.37	0.18	0.35	0.35
Cl, %	0.75	0.47	0.72	0.45
Ingredient %				
Corn	50.36	50.47	49.76	48.59
Soybean meal (48% CP)	29.65	29.67	29.66	29.65
Lactose	---	7.20	7.20	7.20
Dried whey	10.00	---	---	---
HP 300[2]	5.00	7.75	7.80	7.88
Choice white grease	1.00	0.90	1.15	1.55
Monocalcium P (21%P)	1.05	1.33	1.33	1.15
Limestone	1.05	1.05	1.05	1.15
Potassium chloride	---	---	---	0.40
Sodium bicarbonate	---	---	---	1.15
Salt	0.60	0.35	0.78	---
Zinc oxide	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15
Vitamin premix[4]	0.25	0.25	0.25	0.25
Phytase[5]	0.02	0.02	0.02	0.02
L-Lysine HCl	0.30	0.30	0.30	0.30
DL-Methionine	0.18	0.17	0.17	0.17
L-Threonine	0.15	0.16	0.16	0.16
TOTAL	100	100	100	100
Calculated analysis				
Standard ileal digestible (SID) AA, %				
Lysine	1.35	1.35	1.35	1.35
Isoleucine:lysine	63	63	63	63
Leucine:lysine	123	123	123	122
Methionine:lysine	35	35	35	34
Methionine and cystine:lysine	58	58	58	57
Threonine:lysine	66	65	65	65

Tryptopahn:lysine	19.0	19.0	19.0	19.0
Valine:lysine	67	68	68	68
Total lysine, %	1.49	1.49	1.49	1.49
Net energy, kcal/kg	2,447	2.448	2.448	2.447
Crude protein, %	22.8	23.2	23.1	23.1
Calcium, %	0.78	0.78	0.78	0.78
Phosphorus, %	0.68	0.69	0.69	0.65
Available Phosphorus, %	0.48	0.48	0.48	0.48
Sodium, %	0.37	0.18	0.35	0.35
Chloride, %	0.75	0.47	0.72	0.45
Potassium, %	1.14	1.02	1.01	1.22
Dietary electrolyte balance, mEq/kg[6]	240	205	207	337
Chemical analysis, %				
Dry matter	88.45	90.12	88.83	89.22
Crude protein	19.51	22.97	20.63	21.50
Sodium	0.37	0.18	0.37	0.37
Chloride	0.67	0.36	0.60	0.35

[1] Experimental diets were fed from d 7 to 21 after weaning.

[2] Hamlet Protein, Findlay, OH.

[3] Provided per kilogram of premix: 22 g Mn from manganese oxide; 73 g Fe from iron sulfate; 73 g Zn from zinc sulphate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

[4] Provided per kilogram of premix: 3,527,360 IU vitamin A; 881,840 IU vitamin D3; 17,637 IU vitamin E; 3,307 mg riboflavin; 1,764 mg menadione; 11,023 mg pantothenic acid; 33,069 mg niacin; and 15.4 mg vitamin B12.

[5] Ronozyme HiPhos 2700 (DSM Nutritional Products, Inc., Parsippany, NJ), providing 406.3 phytase units (FTU)/kg and an estimated release of 0.10% available P.

[6] Calculated as = (Na*434.98) + (K*255.74) – (Cl*282.06).

Table 2-2. Diet composition, Exp. 2 (as-fed basis)[1]

Na source:	NaCl		NaHCO$_3$				
Cl source:	NaCl		KCl			CaCl$_2$	Common Phase 3 diet[2]
Na, %	0.13	0.35	0.13	0.35	0.57	0.35	
Cl, %	0.35	0.68	0.50	0.50	0.50	0.50	
Corn	54.72	54.72	54.72	54.72	54.72	54.72	60.28
Soybean Meal (48% CP)[3]	23.36	23.36	23.36	23.36	23.36	23.36	34.65
Dried Whey[4]	10.00	10.00	10.00	10.00	10.00	10.00	---
HP 300[5]	5.00	5.00	5.00	5.00	5.00	5.00	---
Choice White Grease	0.95	0.95	0.95	0.95	0.95	0.95	1.30
Monocalcium P (21% P)	1.10	1.10	1.10	1.10	1.10	1.10	1.15
Calcium carbonate	0.81	0.81	0.81	0.81	0.81	0.50	0.88
L-Lysine HCl	0.50	0.50	0.50	0.50	0.50	0.50	0.35
DL-Methionine	0.24	0.24	0.24	0.24	0.24	0.24	0.16
L-Threonine	0.24	0.24	0.24	0.24	0.24	0.24	0.14
L-Tryptophan	0.03	0.03	0.03	0.03	0.03	0.03	0.00
L-Valine	0.12	0.12	0.12	0.12	0.12	0.12	0.04
Trace mineral premix[6]	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix[7]	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Phytase[8]	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25	---
Sodium bicarbonate	---	---	0.18	1.00	1.80	1.00	---
Potassium chloride	---	---	0.48	0.48	0.48	---	---
Calcium chloride	---	---	---	---	---	0.46	---
Salt	0.13	0.68	---	---	---	---	0.65
Sand	2.15	1.60	1.62	0.80	---	1.12	---
TOTAL	100	100	100	100	100	100	100
Calculated analysis							
Standardized ileal digestible (SID) AA, %							
Lysine	1.35	1.35	1.35	1.35	1.35	1.35	1.30
Isoleucine:lysine	55	55	55	55	55	55	61
Leucine:lysine	111	111	111	111	111	111	124
Methionine:lysine	37	37	37	37	37	37	35
Methionine and cystine:lysine	58	58	58	58	58	58	58

Threonine:lysine	65	65	65	65	65	65	62
Tryptopahn:lysine	18.7	18.7	18.7	18.7	18.7	18.7	18.5
Valine:lysine	68	68	68	68	68	68	69
Total lysine, %	1.47	1.47	1.47	1.47	1.47	1.47	1.45
Net energy, kcal/kg	2,447	2,447	2,447	2,447	2,447	2,447	2,451
Crude protein, %	20.5	20.5	20.5	20.5	20.5	20.5	22.1
Calcium, %	0.71	0.71	0.71	0.71	0.71	0.71	0.7
Phosphorus, %	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Available Phosphorus, %	0.48	0.48	0.48	0.48	0.48	0.48	0.43
Sodium, %	0.13	0.35	0.13	0.35	0.57	0.35	0.28
Chloride, %	0.35	0.68	0.50	0.50	0.50	0.50	0.50
Potassium, %	1.02	1.02	1.26	1.26	1.26	1.02	0.97
Dietary electrolyte balance, mEq/kg9	218	221	237	334	428	272	229
Chemical analysis, %							
Dry matter	91.07	87.89	90.26	89.22	88.85	89.34	---
Crude protein	21.52	21.71	22.44	20.88	21.01	19.73	---
Sodium	0.18	0.39	0.19	0.40	0.60	0.39	---
Chloride	0.34	0.61	0.49	0.47	0.47	0.56	---

[1] Experimental diets were fed to pigs from d 7 to 21 after weaning. Sand was removed and replaced with either sodium bicarbonate, potassium chloride, calcium chloride, or salt to create the treatment diets.

[2] Sodium and Cl values from NRC (1998) were used for soybean meal. Values for all other ingredients except for the Na and Cl values for dried whey are from NRC (2012).

[3] Common Phase 3 diet was fed 7 d following treatment feeding.

[4] Dried whey was analyzed for dietary Na (0.61%) and Cl (1.37%) and analyzed values were used in formulation.

[5] Hamlet Protein, Findlay, OH.

[6] Provided per kilogram of premix: 22 g Mn from manganese oxide; 73 g Fe from iron sulfate; 73 g Zn from zinc sulphate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

[7] Provided per kilogram of premix: 3,527,360 IU vitamin A; 881,840 IU vitamin D3; 17,637 IU vitamin E; 3,307 mg riboflavin; 1,764 mg menadione; 11,023 mg pantothenic acid; 33,069 mg niacin; and 15.4 mg vitamin B12.

[8] Ronozyme HiPhos 2700 (DSM Nutritional Products, Inc., Parsippany, NJ), providing 406.3 phytase units (FTU)/kg and an estimated release of 0.10% available P.

[9] Calculated as = (Na*434.98) + (K*255.74) – (Cl*282.06).

Table 2-3. Diet composition, Exp. 3 (as-fed basis)[1]

Item	Chloride, %					0.78% added salt	Common phase 3 diet[2]
	0.09	0.21	0.32	0.45	0.55		
Ingredient, %							
Corn	47.41	47.41	47.41	47.41	47.41	47.41	62.92
Soybean meal (48% CP)[3]	29.82	29.82	29.82	29.82	29.82	29.82	33.68
Lactose	7.20	7.20	7.20	7.20	7.20	7.20	---
HP 300[4]	7.80	7.80	7.80	7.80	7.80	7.80	---
Choice white grease	1.95	1.95	1.95	1.95	1.95	1.95	---
Monocalcium P (21% P)	1.10	1.10	1.10	1.10	1.10	1.10	1.15
Limestone	1.30	1.30	1.30	1.30	1.30	1.30	0.95
L-Lysine HCl	0.30	0.30	0.30	0.30	0.30	0.30	0.30
DL-Methionine	0.17	0.17	0.17	0.17	0.17	0.17	0.12
L-Threonine	0.16	0.16	0.16	0.16	0.16	0.16	0.12
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25	---
Trace mineral premix[5]	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix[6]	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Phytase[7]	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Sand	0.98	0.73	0.49	0.23	---	1.35	---
Potassium chloride	---	0.25	0.49	0.75	0.98	---	---
Sodium bicarbonate	1.15	1.15	1.15	1.15	1.15	---	---
Salt	---	---	---	---	---	0.78	0.35
TOTAL	100	100	100	100	100	100	100
Calculated analysis							
Standardized ileal digestible (SID) AA, %							
Lysine	1.35	1.35	1.35	1.35	1.35	1.35	1.24
Isoleucine:lysine	63	63	63	63	63	63	63
Leucine:lysine	122	122	122	122	122	122	129
Methionine:lysine	35	35	35	35	35	35	33
Methionine and cystine:lysine	58	58	58	58	58	58	57
Threonine:lysine	65	65	65	65	65	65	63
Tryptopahn:lysine	19	19	19	19	19	19	19
Valine:lysine	67	67	67	67	67	67	69
Total lysine, %	1.49	1.49	1.49	1.49	1.49	1.49	1.39

Net energy, kcal/kg	2,446	2,446	2,446	2,446	2,446	2,446	2,403
Crude protein, %	23.0	23.0	23.0	23.0	23.0	23.0	21.7
Calcium, %	0.82	0.82	0.82	0.82	0.82	0.82	0.70
Phosphorus, %	0.68	0.68	0.68	0.68	0.68	0.68	0.65
Available Phosphorus, %	0.51	0.51	0.51	0.51	0.51	0.51	0.43
Sodium, %	0.33	0.33	0.33	0.33	0.33	0.33	0.18
Chloride, %	0.09	0.21	0.32	0.45	0.55	0.55	0.49
Potassium, %	1.01	1.14	1.26	1.40	1.51	1.01	0.96
Dietary electrolyte balance, mEq/kg[8]	375	375	375	375	374	244	185
Chemical analysis, %							
Dry matter	88.31	88.38	89.31	88.89	89.06	88.63	---
Crude protein	21.21	20.14	22.72	22.28	22.07	21.96	---
Sodium	0.32	0.30	0.30	0.28	0.42	0.26	---
Chloride	0.15	0.24	0.32	0.46	0.45	0.47	---

[1] Experimental diets were fed from d 7 to 21 after weaning.

[2] Common Phase 3 diet was fed 7 d following treatment feeding.

[3] Sodium and Cl values from NRC (1998) were used for soybean meal. Values for all other ingredients are from NRC (2012).

[4] Hamlet Protein, Findlay, OH.

[5] Provided per kilogram of premix: 22 g Mn from manganese oxide; 73 g Fe from iron sulfate; 73 g Zn from zinc sulphate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

[6] Provided per kilogram of premix: 3,527,360 IU vitamin A; 881,840 IU vitamin D3; 17,637 IU vitamin E; 3,307 mg riboflavin; 1,764 mg menadione; 11,023 mg pantothenic acid; 33,069 mg niacin; and 15.4 mg vitamin B12.

[7] Ronozyme HiPhos 2700 (DSM Nutritional Products, Inc., Parsippany, NJ), providing 406.3 phytase units (FTU)/kg and an estimated release of 0.10% available P.

[8] Calculated as = (Na*434.98) + (K*255.74) – (Cl*282.06).

Table 2-4. Effects of Na and Cl source and concentration on nursery pig performance, Exp. 1[1]

Lactose source:	Dried whey	Lactose			
Na Source:	NaCl			$NaCO_3$	
Cl Source:	NaCl			KCl	
Na, %	0.37	0.18	0.35	0.35	
Cl, %	0.75	0.47	0.72	0.45	SEM
Day 0 to 14					
ADG, g	281[ab]	251[b]	287[a]	270[ab]	9.5
ADFI, g	445[a]	390[b]	427[ab]	408[ab]	11.2
G:F, g/kg	631	643	671	661	13.1
BW, lb					
d 0	6.9	6.9	6.9	6.9	0.06
d 14	10.9	10.5	11	10.7	0.15

[ab] Means with common superscripts differ $P < 0.05$.

[1] A total of 360 barrows (Line 241 × 600; DNA, Columbus, NE) were used in a 14-d study with 6 pigs per pen and 15 pens per treatment. Pigs were weaned at approximately 21 d, fed a common starter diet for 7 d post-weaning, then placed on experimental diets.

Table 2-5. Effects of Na, K and, Cl source and concentrations on nursery pig performance, Exp. 2[1]

Na source:	NaCl		$NaHCO_3$												
Cl source:	NaCl		KCl			$CaCl_2$		Probability, $P <$[2]							
Na, %	0.13	0.35	0.13	0.35	0.57	0.35		$NaHCO_3$ and KCl		Na					
Cl, %	0.35	0.68	0.50	0.50	0.50	0.50	SEM	Linear	Quadratic	Linear	Quadratic	1	2	3	4
Day 0 to 14[3]															
ADG, g	307	316	287	301	281	314	11.8	0.726	0.262	0.273	0.038	0.587	0.430	0.232	0.877
ADFI, g	403	410	382	398	378	404	10.8	0.785	0.163	0.259	0.039	0.654	0.706	0.159	0.682
G:F, g/kg	762	770	750	751	744	777	16.3	0.795	0.827	0.542	0.222	0.713	0.239	0.591	0.737
Day 14 to 21 (post treatment)															
ADG, g	556	487	540	507	494	518	14.6	0.021	0.554	0.002	0.159	0.001	0.549	0.420	0.115
ADFI, g	760	684	705	710	692	726	19.3	0.629	0.634	0.090	0.743	0.007	0.537	0.049	0.124
G:F, g/kg	736	715	767	715	712	714	14.0	0.006	0.154	0.021	0.148	0.290	0.941	0.112	0.945
BW, kg															
d 0	7.1	7.1	7.1	7.1	7.1	7.1	0.08	0.601	0.955	0.797	0.998	0.846	0.684	0.549	0.831
d 14	11.4	11.5	11.1	11.3	11.1	11.5	0.18	0.887	0.390	0.568	0.089	0.617	0.403	0.206	0.907
d 21	15.4	14.9	14.9	14.8	14.6	15.1	0.22	0.319	0.663	0.036	0.516	0.137	0.328	0.093	0.511

[1] A total of 360 barrows (Line 200 × 600; DNA, Columbus, NE) were used in a 14-d study with 5 pigs per pen and 12 pens per treatment. Pigs were weaned at approximately 21 d, fed a common starter diet for 7 d post-weaning, then placed on experimental diets.

[2] Contrasts were (1) 0.13% Na and 0.35% Cl provided by added salt vs 0.35% Na and 0.68% Cl provided by added salt (2) 0.35% Na and 0.45% Cl provided by $NaCHCO_3$ and KCl vs 0.35% Na and 0.45% Cl provided by $NaHCO_3$ and $CaCl_2$, (3) 0.13% Na and 0.50% Cl provided by $NaCHCO_3$ and KCl vs 0.13% Na and 0.35% Cl provided by NaCl, and (4) 0.35% Na and 0.45% Cl provided by $NaCHCO_3$ and KCl vs 0.35% Na and 0.45% Cl provided by $NaHCO_3$ and $CaCl_2$ vs 0.35% Na and 0.68% Cl provided by NaCl.

[3] Experimental diets were fed from d 0 to 14 and a common Phase 3 diet was fed from d 14 to 21.

Table 2-6. Effects of increasing chloride for 7 to 12 kg nursery pigs on growth performance, Exp. 3[1]

	Chloride, %[2]					0.78% added salt diet[3]		Probability, $P <$		
								0.78% added salt diet vs. 0.55% Cl diet	Cl	
Item	0.09	0.21	0.32	0.45	0.55		SEM		Linear	Quadratic
Treatment period (day 0 to 14)4										
ADG, g	273	348	372	349	356	351	10.0	0.676	0.001	0.001
ADFI, g	436	491	507	477	504	469	13.6	0.046	0.003	0.035
G/F, g/kg	627	712	734	733	708	749	15.8	0.069	0.001	0.001
Post treatment period (day 14 to 21)										
ADG, g	554	496	522	497	510	489	14.6	0.271	0.045	0.079
ADFI, g	789	818	848	817	860	782	20.9	0.009	0.033	0.652
G/F, g/kg	704	611	614	609	592	624	13.6	0.080	0.001	0.004
BW, kg										
d 0	7.0	7.1	7.1	7.1	7.1	7.1	0.11	0.997	0.913	0.756
d 14	10.9	12.0	12.3	12.0	12.1	12.0	0.20	0.674	0.001	0.001
d 21	14.7	15.4	15.9	15.5	15.6	15.4	0.24	0.362	0.004	0.006

[1] A total of 300 pigs (Line 241 × 600; DNA, Columbus, NE) were used in a 21-d study with 5 pigs per pen and 10 pens per treatment. Pigs were weaned at approximately 21 d, fed a common starter diet for 7 d post-weaning, then placed on experimental diets.

[2] Experimental diets were formulated to a dietary Na concentration of 0.33% with 1.15% sodium bicarbonate and dietary Cl concentrations were formulated with increasing added potassium chloride.

[3] The 0.78% added salt diet contained 0.33% Na and 0.55% Cl.

[4] Experimental diets were fed from d 0 to 14 and a common Phase 3 diet was fed from d 14 to 21.

Figure 2-1. Estimated optimal Cl concentration to maximize ADG for 7-12 kg nursery pigs, Exp. 3[1]

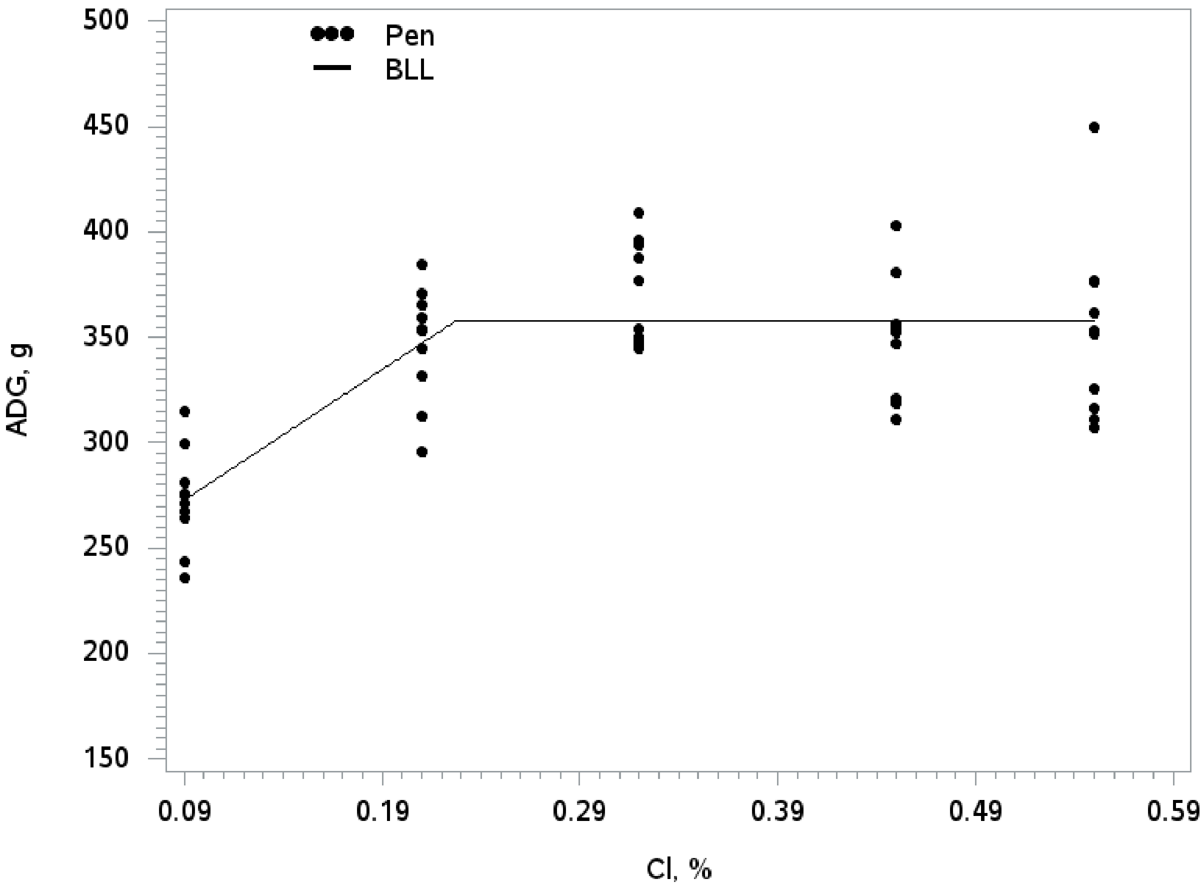
BLL BIC=491.5

Breakpoint 0.23% Cl

95% CI: [0.18, 0.27]

ADG = 357.87 – 619.42 × (0.23 – Cl, %), when Cl < 0.23%

ADG = 359.5, if Cl ≥ 0.23%



[1] A total of 300 pigs (Line 241 × 600; DNA, Columbus, NE) were used with 5 pigs per pen and 10 pens per treatment. Pigs were weaned at approximately 21 d, fed a common starter diet for 7 d post-weaning, then placed on experimental diets. Experimental diets were fed for 14 d. Linear polynomial, quadratic polynomial (QP), broken-line linear (BLL), and broken-line quadratic (BLQ) models were fit for the experimental period to estimate the optimal dietary Cl concentration for ADG. Bayesian Information Criterion (BIC) was used to determine the best fitting model.

Figure 2-2. Estimated optimal Cl concentration to maximize ADFI for 7-12 kg nursery pigs, Exp. 3[1]

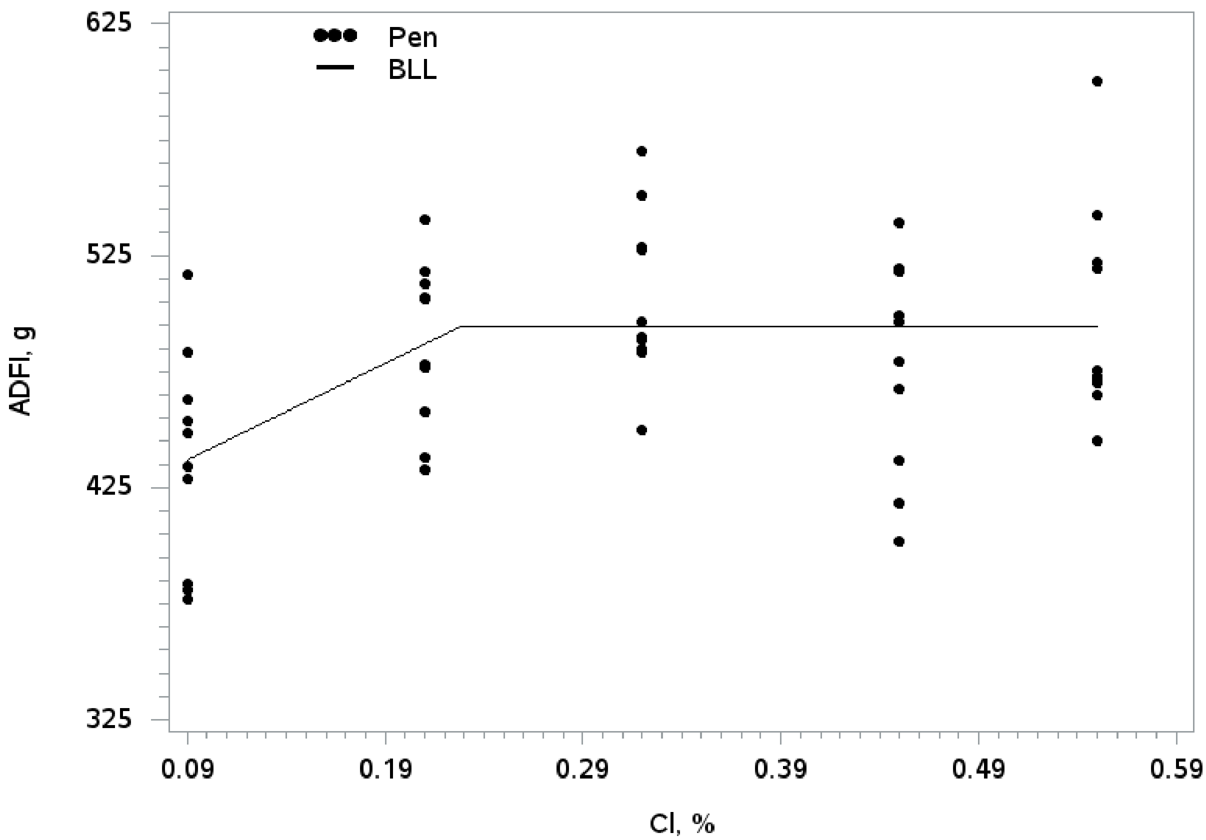
BLL BIC=524.5

Breakpoint 0.23% Cl

95% CI: [0.14, 0.31]

ADFI = 494.45 – 415.5 × (0.23 – Cl, %), when Cl < 0.23%

ADFI = 495.2, if Cl ≥ 0.23%

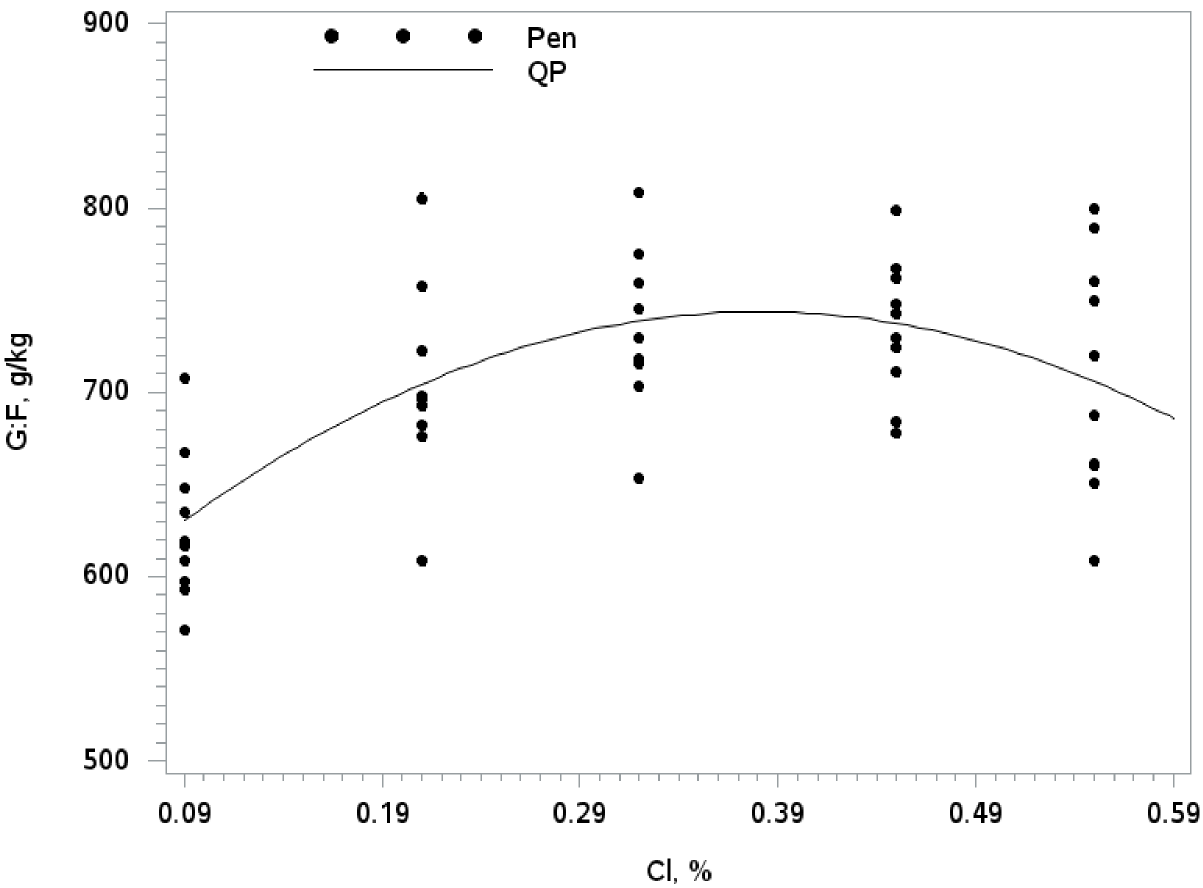


[1] A total of 300 pigs (Line 241 × 600; DNA, Columbus, NE) were used with 5 pigs per pen and 10 pens per treatment. Pigs were weaned at approximately 21 d, fed a common starter diet for 7 d post-weaning, then placed on experimental diets. Experimental diets were fed for 14 d. Linear polynomial, quadratic polynomial (QP), broken-line linear (BLL), and broken-line quadratic (BLQ) models were fit for the experimental period to estimate the optimal dietary Cl concentration for ADFI. Bayesian Information Criterion (BIC) was used to determine the best fitting model.

Figure 2-3. Estimated optimal Cl concentration to maximize G:F for 7-12 kg nursery pigs, Exp. 3[1]

QP BIC=523.4

Predicted maximum response at 0.38% Cl (95% CI: 0.26, 0.51)
96% of maximum at 0.23% Cl
$G:F = 549.77 + 1016.45 \times (Cl, \%) - 1331.57 \times (Cl, \%)^2$



[1] A total of 300 pigs (Line 241 × 600; DNA, Columbus, NE) were used with 5 pigs per pen and 10 pens per treatment. Pigs were weaned at approximately 21 d, fed a common starter diet for 7 d post-weaning, then placed on experimental diets. Experimental diets were fed for 14 d. Linear polynomial, quadratic polynomial (QP), broken-line linear (BLL), and broken-line quadratic (BLQ) models were fit for the experimental period to estimate the optimal dietary Cl concentration for G:F. Bayesian Information Criterion (BIC) was used to determine the best fitting model.

Chapter 3 - Effects of sodium metabisulfite additives on nursery pig growth

ABSTRACT

Three experiments were conducted to determine the efficacy of sodium metabisulfite-based feed additives on the growth performance of nursery pigs fed diets relatively low (< 1.5 mg/kg) in deoxynivalenol. Pigs were weaned at approximately 22 d of age and randomly allotted to pens with one pen of 27 gilts and one pen of 27 barrows per fence line feeder, thus feeder was the experimental unit. In experiment 1, 2,268 pigs were used in a 35-day trial with 21 feeders per treatment. Experimental treatments included a control diet or the control with 0.50% Product 1 (Provimi, Brooksville, OH) for phase 1 and 0.25% for phase 2 and 3, then all pigs were fed a control diet for the last week of the study. Pigs fed Product 1 had greater ($P < 0.05$) average daily gain (ADG), average daily feed intake (ADFI), and gain:feed ratio (G:F) compared to pigs fed the control diet from day 0 to 28. However, from day 28 to 35, the opposite response was observed with pigs fed the control diet having greater ADG and G:F than pigs previously fed Product 1. Despite this response, pigs fed Product 1 were heavier ($P < 0.05$) on day 35 than control-fed pigs. In experiment 2, 4,320 pigs were used in a 42-day trial with 8 or 16 feeders per treatment. Pigs were fed a control diet or diets with either Product 1 or Product 2 (Nutriquest, Mason City, IA) at different concentrations and durations. Among the various treatments, Product 1or Product 2 concentrations ranged from 0.50% initially to 0.25%, 0.15% or none the last week of the study. Overall, pigs fed either of the additives at the highest concentrations and for the longest period of time had greater ($P < 0.05$) ADG and ADFI compared to pigs fed the control diet, with those fed lower concentrations or shorter durations intermediate. Gain to feed was not influenced by dietary treatment. In experiment 3, 2,808 pigs were used in a 28-day trial

with 13 feeders per treatment. All pigs were fed a common diet for 7 days after weaning. Pigs were then either fed a control diet or diets containing Product 1 (0.50 and 0.25% from day 0 to 21 and 21 to 28 respectively) or sodium metabisulfate (SMB; 0.50 and 0.25% from day 0 to 21 and 21 to 28 respectively) or 0.25% SMB from day 0 to 28. Overall, pigs fed Product 1 or high SMB diets had greater ($P < 0.05$) ADG compared to pigs fed low SMB or control diets. Collectively these studies suggest that in diets with relatively low deoxynivalenol concentrations, these sodium metabisulfite-based products increased ADG compared to pigs fed control diets.

Key words: deoxynivalenol, nursery pig, preservative, sodium metabisulfite

INTRODUCTION

Deoxynivalenol (**DON**), or vomitoxin, is a mycotoxin found in cereal grains and is produced by the *Fusarium* genus. The DON concentration of cereal grains can vary from year to year, based on the degree of stress the plant is exposed to during the growing season, such as poor soil fertility, harsh weather conditions, and insect damage. Swine are sensitive to DON with exposure to concentrations greater than 1 mg/kg resulting in decreased feed intake and growth, while exposure to higher concentrations can result in complete feed refusal and vomiting (Rotter et al., 1996; Forysth et al., 1997; Eriksen and Pettersson, 2004). Preservatives, although not approved by U.S. Food and Drug Administration as DON detoxifying agents, have been used in diets with high DON concentrations with positive results. Defusion (Provimi, Brooksville, OH), is a commercially available preservative that is a blend of sodium metabisufite (**SMB**), organic acids, fermentation products, and supplemental vitamins and amino acids. Previous research has indicated a positive relationship between growth performance and the addition of Defusion in swine diets with greater than 3 mg/kg of DON (Mahan et al., 2010; Patience et al., 2014; Frobose et al., 2015). However, there is limited research available to document the effects of SMB-based preservatives on growth performance of nursery pigs fed diets with relatively little to no DON. Therefore, the objective of these experiments was to determine the effects of sodium metabsulfite-based feed additives in low-DON containing diets on the growth performance of nursery pigs weighing approximately 6 to 25 kg.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in these studies. The experiments were conducted at a commercial research-facility located in north central Ohio. Each pen (2.3 × 2.7 m) contained approximately 27 barrows or gilts and a double-sided 5-hole stainless steel fence line feeder. Therefore, the experimental unit was the feeder. Each pen also contained a cup-waterer and feed and water were provided ad libitum. Feed additions to each individual pen was made and recorded by an electronic feeding system (Dry Exact; Big Dutchman, Inc. Holland, MI). Experimental diets were manufactured at the Hord Elevator (Bucyrus, OH). Feed samples were collected from 6 feeders per treatment per phase, pooled, and subsampled for chemical analysis. Pens of pigs were weighed and feed disappearance was recorded every 7 days to determine ADG, ADFI, and G:F.

Experiment 1

A total of 2,268 pigs (PIC 337 × 1050; initial BW 6.8 kg) were used in a 35-d growth trial. Pigs were weaned at approximately 22 d of age and were randomly sorted into 1 of 84 pens (42 pens of barrows, 42 pens of gilts) with one pen of gilts and one pen of barrows per fence line feeder. A pair of pens (1 adjoining feeder) were blocked by body weight and weaning date and then randomly assigned to 1 of 2 dietary treatments in a randomized complete block design with 21 feeders per treatment. Dietary treatments included a control diet or the control with 0.50%

Product 1 in phase 1 and 0.25% in phase 2 and 3 (Table 3-1). From day 28 to 35, all pigs were fed a common diet without Product 1. Product 1 (Defusion; Provimi, Brooksville, OH), is a commercially available preservative that is a blend of SMB (92%), organic acids, fermentation products, and supplemental vitamins and amino acids. For phase 1, pigs were offered 0.68 kg of feed, which lasted from day 0 to approximately day 5. Then phase 2 diets were provided until day 21, phase 3 diets were fed from day 21 to 28 with all pigs receiving a control diet without preservative from day 28 to 35.

Experiment 2

A total of 4,320 pigs (PIC 337 × 1050; initial weight 6.2 kg) were used in a 42-d growth trial. Pigs were weaned at approximately 22 d of age and were randomly sorted into one of 160 pens (80 pens of barrows, 80 pens of gilts) with one pen of gilts and one pen of barrows per fence line feeder. A pair of pens (1 adjoining feeder) were blocked by body weight and weaning date and then randomly assigned to one of five dietary treatments that were fed for 35 d in a randomized complete block design. Dietary treatments including 1) a control diet; 2) the control diets with 0.50% Product 1 fed for seven days followed by 0.25% Product 1 from day 7 to 35; 3) control diet containing 0.50% Product 2 from day 0 to 7, 0.25% from day 7 to 28, and 0.15% from day 28 to 35; 4) control diet containing 0.50% Product 2 from day 0 to 7 and 0.25% from day 7 to 35; and 5) control diet containing 0.50% Product 2 from day 0 to 28 and 0.25% from day 28 to 35. Then on day 35, half of the pens receiving either Product 1 or Product 2 remained on those treatments and the other half were switched to the control diet. These combinations resulted in a total of nine treatments. There were 16 replications (feeders) for all treatments from day 0 to 35 and 8 replications per treatment from day 35 to 42 for all treatments except for the control, which continued to have 16 replications per treatment. Product 2 (NutriQuest, Mason

City, IA), is a custom made preservative and anti-caking agent that contains SMB (92%), bentonite, and mineral oil.

Experiment 3

A total of 2,808 pigs (PIC 337 × 1050; initial weight 7.0 kg) were used in a 28-d growth trial. Pigs were weaned at approximately 22 d of age and were randomly sorted into one of 104 pens (52 pens of barrows, 52 pens of gilts) with one pen of gilts and one pen of barrows per fence line feeder. All pigs were fed a common phase 1 diet for 7 days, then 7 days after weaning, considered d 0 of the trial, a pair of pens (1 adjoining feeder) were blocked by weight and randomly assigned to one of four dietary treatments with 13 feeders per treatment. Dietary treatments were fed for 28 d. The four treatments were: 1) a control diet; 2) control diet with 0.50% Product 1 from day 0 to 21 followed by 0.25% Product 1 from day 21 to 28; 3) control diet with 0.25% SMB from day 0 to 28; and 4) control diet with 0.50% SMB from day 0 to 21 followed by 0.25% SMB from day 21 to 28 (Table 3-3).

Chemical analysis

Feed samples for all three experiments were submitted to North Dakota Grain Inspection Service, Inc. (Bucyrus, OH) for DON analysis. Dietary DON concentrations for Exp. 1 were determined by the RIDASCREEN® FAST DON SC ELISA test kit (R-Biopharm AG, Darmstadt, Germany). Dietary DON concentration for Exp. 2 and 3 were determined by ROSA DONQ2 Quantitative Test (Charms Sciences, Inc., Lawrence, MA). North Dakota Grain Inspection Service, Inc. (Bucyrus, OH) follows the Federal Grain Inspection Service guidelines which considers the standard certification limits for these assays to be 0.5 to 5 mg/kg (FGIS, 2015). Thus, the minimum detection limit for both assays was 0.5 mg/kg.

Statistical analysis

For Exp. 1, means of the control and the Product 1 diet were separated using the least square mean method. For Exp. 2 and 3, individual treatment means were separated using the Tukey-Kramer multiple comparison test. Data for all experiments were analyzed as a randomized complete block design using PROC GLIMMIX in SAS version 9.4 (SAS Institute, Inc., Cary, NC) with feeder as the experimental unit (1 pen of barrows and 1 pen of gilts). Results were considered significant at $P \leq 0.05$ and marginally significant between $P > 0.05$ and $P \leq 0.10$.

RESULTS

Chemical Analysis

Chemical analysis of experiment 1 and 3 diets indicated that dietary DON concentrations of all diets, regardless of phase, were less than 0.5 mg/kg or below the detectable limit (Table 3-4, 3-6). For experiment 2 (Table 3-5), the control diet had DON concentrations ranging from 1.1 to 1.5 mg/kg. Both the Product 1-based diets had DON concentrations equal to or less than 1.3 mg/kg. Diets containing Product 2 had DON concentrations equal to or less than 1.1 mg/kg.

Experiment 1

From d 0 to 28, pigs fed diets containing Product 1 had greater ($P < 0.05$) ADG, ADFI, G:F, and d 28 body weight compared to those fed the control diet (Table 3-7). However, from d 28 to 35, when all pigs were fed a control diet, the opposite effect was observed. Pigs previously fed the diets containing Product 1 had decreased ($P < 0.05$) ADG, ADFI and G:F compared to pigs fed the control diet. Regardless, overall (day 0 to 35) ADG, ADFI, G:F, and day 35 body weight were greater ($P < 0.05$) for those pigs fed diets containing Product 1.

Experiment 2

From d 0 to 35, pigs fed the control had decreased (*P* < 0.05) ADG, ADFI, and d 35 body weight compared to pigs fed the Product 1 or Product 2 combinations (Table 3-8). The response to SMB products (Product 1 or Product 2) was in a dose dependent manner with pigs fed the highest level of Product 2 having greater (*P* < 0.05) performance than the other Product 2 diets. There was no evidence for difference between pigs fed similar levels of Product 1 and Product 2. Gain to feed was greater (*P* < 0.05) for pigs fed the highest levels of Product 2 compared with the lowest added Product 2 diets with pigs fed other diets intermediate.

On day 35, pigs either remained on their respective Product 1 or Product 2 diets or were switched to a diet without feed preservative. During this period, those pigs switched to a non-feed preservative containing diet had decreased (*P* < 0.05) ADG and ADFI compared with the pigs remaining on their respective feed preservative this those fed the control diet intermediate.

Overall, pigs fed the Product 1 at the highest level had greater (*P* < 0.05) ADG and ADFI compared to pigs fed the control, with pigs fed the other diets intermediate. There was no evidence to indicate dietary treatment influenced G:F. Pigs fed the control diet had lower (*P* < 0.05) day 42 body weight compared to the other dietary treatments. Pigs fed Product 1 at the highest level had greater (*P* < 0.05) day 42 body weight compared to pigs fed the two lowest levels of Product 1, with pigs fed the other preservative containing diets intermediate.

Experiment 3

From d 0 to 21, pigs fed 0.25% SMB had decreased (*P* < 0.05) ADG compared to pigs fed the other diets (Table 3-9). Pigs fed Product 1 or 0.50% SMB had greater (*P* < 0.05) ADG compared to pigs fed the other diets. Pigs fed Product 1 or 0.50% SMB had greater (*P* < 0.05) ADFI compared to pigs fed the control, with pigs fed 0.25% SMB intermediate. Pigs fed 0.25%

SMB had lower ($P < 0.05$) G:F than pigs fed the other dietary treatments. Pigs fed 0.50% SMB had greater ($P < 0.05$) G:F than pigs fed the control, with pigs fed Product 1 intermediate.

From d 21 to 28, pigs fed 0.25% SMB for the entire experiment had greater ($P < 0.05$) ADG compared to pigs fed the other diets. Pigs fed Product 1 had greater ($P < 0.05$) ADG compared to pigs fed the control diet, with pigs fed 0.50% SMB intermediate followed by 0.25% SMB. Pigs fed Product 1 had increased ($P < 0.05$) ADFI compared to pigs fed the control, with others intermediate. Pigs fed 0.25% SMB for the entire trial had greater ($P < 0.05$) G:F than pigs fed other diets.

From d 0 to 28, pigs fed Product 1 or 0.50% SMB had greater ($P < 0.05$) ADG compared to pigs fed 0.25% SMB or the control diet. Pigs fed Product 1 or 0.50% SMB had increased ($P < 0.05$) ADFI compared to pigs fed the control, with pigs fed the 0.25% SMB intermediate. Pigs fed 0.50% SMB had greater ($P < 0.05$) G:F than pigs fed the control diet, with those fed Product 1 intermediate. Pigs fed 0.25% SMB had lower ($P < 0.05$) G:F compared to pigs fed the other treatments. Pigs fed 0.50% SMB or Product 1 had greater ($P < 0.05$) d 28 BW than pigs fed the other dietary treatments.

DISCUSSION

Based on the Federal Grain Inspection Service guidelines, the lowest detection limit for the assays used in the analysis was 0.5 mg/kg (FGIS, 2015). Deoxynivalenol analysis indicated that DON concentrations in Exp.1 and 3 were less than the detection limit of the tests utilized. Diets with SBM-based products would be expected to have slightly lower analyzed concentrations of DON relative to the control diets because of the DON binding capacity of the products (Frobose et al. 2015). This was evident in DON analysis in experiment 2, where treated feed with higher concentrations of Product 1 or 2 had decreased DON concentrations compared to the control diet. Pigs fed the control diet in Exp. 2 were consistently exposed to DON concentrations greater than 1.1 mg/kg throughout the trial while pigs fed the Product 2 treatments were not exposed to DON concentration greater than 1.1 mg/kg. Pigs fed Product 1 were not exposed to DON concentrations greater than 0.9 mg/kg until the last 7 days of the trial.

Previous research has indicated that pigs fed DON concentrations greater than 1 mg/kg will have reduced ADG and ADFI compared to pigs fed diets with lower DON concentration (Rotter et al., 1996; Forsyth et al., 1997; Eriksen and Pettersson, 2004). Frobose et al. (2015) observed that pigs fed diets with either 0.5 or 1.5 mg/kg DON had greater ADG and ADFI compared to pigs fed diets with 3 mg/kg DON. In our experiments, ADG and ADFI should have been minimally influenced by the DON concentration of the diets because all dietary DON concentrations were less than 1.5 mg/kg.

In the studies conducted by Frobose et al. (2015) and Mahan et al. (2010), ADG was improved when pigs were fed diets containing Defusion with a dietary DON concentration of 3 or 4 mg/kg. Results of Exp. 1, 2, and 3 agree with these studies because in both experiments pigs fed Product 1 (Defusion) had improved ADG. However, in contrast to the earlier research, diets in Exp. 1 and 2 had DON concentrations that were less than 1.3 mg/kg. This is significant because it would suggest that Product 1 could improve growth performance of pigs fed low DON diets, even those that have DON concentrations below the detectable level of the assay.

In Exp. 2, pigs fed Product 2 for the longest duration and at the highest concentration had greater ADG compared to pigs fed Product 2 for a shorter duration and a lower concentration. This would also agree with the results of Exp. 3 in which pigs fed SMB at the higher concentration had improved ADG compared to pigs fed a lower concentration of SMB. Overall this would suggest that pigs fed a higher concentration of SMB for a longer duration have improved growth performance, though further research should be conducted to determine the optimal concentration.

To our knowledge there is currently no research available that documents the effects of transitioning pigs that were fed diets containing a SMB additive to a diet without a SMB additive. In Exp. 1, when pigs were transitioned to a common diet, pigs previously fed Product 1 had decreased ADG compared to pigs fed the control diet. In experiment 2, pigs previously fed Product 1 or 2, then switched to a control diet, had numerically lower ADG compared to pigs fed the control or pigs fed a diet that still contained Product 1 or Product 2. It is also interesting to note that pigs that were previously fed the highest inclusion of Product 2 numerically had the lowest ADG compared to pigs previously fed diets containing lower inclusions of Product 2. This reduction in ADG could be due to the transitioning pigs from a diet with less than 1 mg/kg DON to a diet with greater than 1 mg/kg DON. Further research should be conducted to evaluate the effects of transitioning pigs previously fed a SMB additive to a diet that does not contain a SMB additive.

In high DON diets the biological mechanism of SMB is suggested to be the chemical alteration of DON to a nontoxic DON-sulfonate adduct form (Frobose et al., 2015, 2017). However, in low DON diets the biological mechanism of SMB is unclear. Sodium metabisulfite is commonly used in the food industry as an antioxidant and antimicrobial agent, however, there is limited research available to document the effects of SMB on the microbiome of gut of the pig and feed. Previous research has indicated improvements in energy and protein utilization in broilers fed sorghum-based diets that was steam pelleted with SMB (Selle et al., 2013, 2014; Truong et al., 2016). The biological mechanism of this improvement in protein and energy utilization is suggested to be the oxidative-reductive depolymerization of starch polysaccharides and the reduction of disulfide cross linkages in proteins thus improving protein and starch availability (Truong et al., 2015). Sodium metabisulfite has also shown some potential in the ability to reduce trypsin in soybean meal by the reduction of disulfide cross linkages (Sessa and Ghantous., 1987; Wang et al., 2009). Overall, further research should be conducted to determine the biological mechanism of SMB in low DON diets.

In conclusion, in diets relatively low in DON, pigs fed SMB-based preservatives had improved ADG compared to pigs fed a control diet. Furthermore, at the dietary concentrations of the product tested, the greater the inclusion and longer the feeding duration resulted in the greatest benefit.

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Table 3-1. Diet composition, Exp. 1 (as-fed basis)[1]

Ingredient, %	Phase 1	Phase 2	Phase 3
Corn	35.8	50.77	48.27
Soybean meal	20.87	31.57	33.06
Wheat	3.00	---	---
Bakery meal	---	---	12.50
Milk, whey powder	25.00	---	---
Dairylac 80[2]	---	9.00	---
HP 300[3]	7.50	2.50	---
Corn oil	4.00	1.50	2.50
Limestone	0.85	0.85	1.00
Monocalcium phosphate, 21%	0.73	1.50	0.85
Sodium chloride	0.50	0.60	0.50
L-Lysine HCl	0.45	0.48	0.45
DL-Methionine	0.30	0.31	0.25
L-Threonine	0.21	0.27	0.22
L-Tryptophan	0.06	0.04	0.01
L-Valine	0.12	0.16	0.09
Vitamin and trace mineral premix[4]	0.15	0.15	0.18
Zinc oxide	0.38	0.25	---
Copper sulfate	---	0.03	0.03
Choline chloride, 60%	0.04	---	---
Quantum 5000 L[5]	0.05	0.05	---
Quantum Blue 2G[6]	---	---	0.10
Product 1[7]	---	---	---
TOTAL	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) AA, %			
Lysine	1.40	1.42	1.38
Isoleucine:lysine	58	58	60
Leucine:lysine	107	109	113
Methionine:lysine	40	41	38
Methionine and cystine:lysine	58	59	57
Threonine:lysine	63	63	62

Tryptopahn:lysine	21.2	20.4	18.5
Valine:lysine	67	70	68
Total lysine, %	1.56	1.57	1.53
Net energy, kcal/kg	2,420	2,474	2,487
Crude protein, %	21.0	21.4	21.3
Calcium, %	0.74	0.77	0.67
Phosphorus, %	0.66	0.76	0.59
Available Phosphorus, %	0.55	0.59	0.40

[1] Experimental diet were fed in three phases with dietary phases formulated for BW ranges of 5 to 7, 7 to 11, and 11 to 20 kg.

[2] International Ingredients, Inc., St. Louis, MO.

[3] Hamlet Protein, Findlay, OH.

[4] Provided per kilogram of premix: 26 g Mn from manganese oxide; 66 g Fe from iron sulfate; 88 g Zn from zinc sulphate; 11 g Cu from copper sulfate; 220 mg I from calcium iodate; and 198 mg Se from sodium selenite; 6,613,860 IU vitamin A; 1,468,277 IU vitamin D3; 44,092 IU vitamin E; 154 mg biotin; 1,102 mg folic acid; 2,205 mg pyridoxine; 6,614 mg riboflavin; 2,866 mg menadione; 22,046 mg pantothenic acid; 28,660 mg niacin; 6,614 mg thiamine; and 22 mg vitamin B12.

[5] Quantum 5000 (AB Vista, Plantation, FL) provided an estimated release of 0.14% available P.

[6] Quantum Blue 2G (AB Vista, Plantation, FL) provided an estimated release of 0.14% available P.

[7] Product 1 (Defusion; Provimi, Brooksville, OH).

Table 3-2. Diet composition, Exp. 2 (as-fed basis)[1]

Ingredient, %	Phase 1	Phase 2	Phase 3
Corn	35.80	50.77	48.27
Soybean meal	20.87	31.57	33.06
Wheat	3.00	---	---
Bakery meal	---	---	12.50
Milk, whey powder	25.00	---	---
Dairylac 80[2]	---	9.00	---
HP 300[3]	7.50	2.50	---
Corn oil	4.00	1.50	2.50
Limestone	0.85	0.85	1.00
Monocalcium phosphate, 21%	0.73	1.50	0.85
Sodium chloride	0.50	0.60	0.50
L-Lysine HCl	0.45	0.48	0.45
DL-Methionine	0.30	0.31	0.25
L-Threonine	0.21	0.27	0.22
L-Tryptophan	0.06	0.04	0.01
L-Valine	0.12	0.16	0.09
Vitamin and trace mineral premix[4]	0.15	0.15	0.18
Zinc oxide	0.38	0.25	---
Copper sulfate	---	0.03	0.03
Choline chloride, 60%	0.04	---	---
Quantum 5000 L[5]	0.05	0.05	---
Quantum Blue 2G[6]	---	---	0.10
Product 1[7]	-/+	-/+	-/+
Product 2[8]	-/+	-/+	-/+
TOTAL	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) AA, %			
Lysine	1.40	1.42	1.38
Isoleucine:lysine	58	58	60
Leucine:lysine	107	109	113
Methionine:lysine	40	41	38
Methionine and cystine:lysine	58	59	57

Threonine:lysine	63	63	62
Tryptopahn:lysine	21.2	20.4	18.5
Valine:lysine	67	70	68
Total lysine, %	1.56	1.57	1.53
Net energy, kcal/kg	2,420	2,474	2,487
Crude protein, %	21.0	21.4	21.3
Calcium, %	0.74	0.77	0.67
Phosphorus, %	0.66	0.76	0.59
Available Phosphorus, %	0.55	0.59	0.40

[1] Experimental diet were fed in three phases with dietary phases formulated for 5 to 7, 7 to 11, and 11 to 20 kg BW ranges.

[2] International Ingredients, Inc., St. Louis, MO.

[3] Hamlet Protein, Findlay, OH.

[4] Provided per kilogram of premix: 26 g Mn from manganese oxide; 66 g Fe from iron sulfate; 88 g Zn from zinc sulphate; 11 g Cu from copper sulfate; 220 mg I from calcium iodate; and 198 mg Se from sodium selenite; 6,613,860 IU vitamin A; 1,468,277 IU vitamin D3; 44,092 IU vitamin E; 154 mg biotin; 1,102 mg folic acid; 2,205 mg pyridoxine; 6,614 mg riboflavin; 2,866 mg menadione; 22,046 mg pantothenic acid; 28,660 mg niacin; 6,614 mg thiamine; and 22 mg vitamin B12.

[5] Quantum 5000 (AB Vista, Plantation, FL) provided an estimated release of 0.14% available P.

[6] Quantum Blue 2G (AB Vista, Plantation, FL) provided an estimated release of 0.14% available P.

[7] Product 1(Defusion; Provimi, Brooksville, OH) was included at the expense of corn.

[8] Product 2 (NutriQuest, Mason City, IA) was included at the expense of corn.

Table 3-3. Diet composition, Exp. 3 (as-fed basis)[1]

Ingredient, %	Phase 1	Phase 2
Corn	50.77	57.43
Soybean meal	31.57	33.10
Dairylac 80[2]	9.00	---
HP 300[3]	2.50	---
Corn oil	1.50	1.50
Limestone	0.85	1.05
Monocalcium phosphate, 21%	1.50	0.85
Sodium chloride	0.60	0.50
L-Lysine HCl	0.48	0.43
DL-Methionine	0.31	0.26
L-Threonine	0.27	0.22
L-Tryptophan	0.04	0.01
L-Valine	0.16	0.09
Vitamin and trace mineral premix[4]	0.15	0.18
Zinc oxide	0.25	0.25
Copper sulfate	0.03	0.03
Quantum 5000 L[5]	0.05	---
Quantum Blue 2G[6]	---	0.10
Product 1[7]	-/+	-/+
Sodium metabisulfite[8]	-/+	-/+
TOTAL	100	96
Calculated analysis		
Standardized ileal digestible (SID) AA, %		
Lysine	1.42	1.37
Isoleucine:lysine	58	60
Leucine:lysine	109	115
Methionine:lysine	41	39
Methionine and cystine:lysine	59	58
Threonine:lysine	63	62
Tryptopahn:lysine	20.4	18.6
Valine:lysine	70	68
Total lysine, %	1.57	1.53

Net energy, kcal/kg	2,386	2,422
Crude protein, %	21.4	21.2
Calcium, %	0.77	0.68
Phosphorus, %	0.76	0.62
Available Phosphorus, %	0.59	0.41

[1] Experimental diet were fed in three phases with dietary phases formulated for 7 to 11, and 11 to 20 kg BW ranges.

[2] International Ingredients, Inc., St. Louis, MO.

[3] Hamlet Protein, Findlay, OH.

[4] Provided per kilogram of premix: 26 g Mn from manganese oxide; 66 g Fe from iron sulfate; 88 g Zn from zinc sulphate; 11 g Cu from copper sulfate; 220 mg I from calcium iodate; and 198 mg Se from sodium selenite; 6,613,860 IU vitamin A; 1,468,277 IU vitamin D3; 44,092 IU vitamin E; 154 mg biotin; 1,102 mg folic acid; 2,205 mg pyridoxine; 6,614 mg riboflavin; 2,866 mg menadione; 22,046 mg pantothenic acid; 28,660 mg niacin; 6,614 mg thiamine; and 22 mg vitamin B12.

[5] Quantum 5000 (AB Vista, Plantation, FL) provided an estimated release of 0.14% available P.

[6] Quantum Blue 2G (AB Vista, Plantation, FL) provided an estimated release of 0.14% available P.

[7] Product 1 (Defusion; Provimi, Brooksville, OH) was included at the expense of corn.

[8] Sodium metabisulfite was included at the expense of corn.

Table 3-4. Deoxynivalenol analysis of experimental diets, Exp. 1 (as-fed basis)[1]

Item	Control	Product 1[2]
DON, mg/kg		
Phase 1 diets	< 0.5	< 0.5
Phase 2 diets	< 0.5	< 0.5
Phase 3 diets	< 0.5	< 0.5

[1] Multiple samples were collected from each diet throughout the study, homogenized, and submitted to North Dakota Grain Inspection Service, Inc. (Bucyrus, OH) for analysis of DON as determined by the RIDASCREEN® FAST DON SC ELISA test kit (R-Biopharm AG, Darmstadt, Germany).

[2] Product 1 (Defusion; Provimi, Brooksville, OH).

Table 3-5. Deoxynivalenol analysis of experimental diets, Exp. 2 (as-fed basis)[1]

		Product added, %			
	Control	Product 1[2]	Product 2[3]		
d 0 to 7[4]	---	0.50	0.50	0.50	0.50
d 7 to 21	---	0.25	0.25	0.25	0.50
d 21 to 28	---	0.25	0.25	0.25	0.50
d 28 to 35	---	0.25	0.15	0.25	0.25
d 35 to 42	---	--- 0.25	--- 0.15	--- 0.25	--- 0.25
DON, mg/kg					
d 0 to 7	---[4]	< 0.5	< 0.5	< 0.5	< 0.5
d 7 to 21	1.4	< 0.5	0.5	< 0.5	< 0.5
d 21 to 28	1.1	0.9	1.0	0.9	1.1
d 28 to 35	1.5	0.9	1.0	0.9	1.0
d 35 to 42	1.3	1.3 1.3	1.3 1.0	1.3 0.8	1.3 0.9

[1] Multiple samples were collected from each diet throughout the study, homogenized, and submitted to North Dakota Grain Inspection Service, Inc. (Bucyrus, OH) for analysis of DON as determined by the ROSA DONQ2 Quantitative Test (Charms Sciences, Inc., Lawrence, MA).

[2] Product 1 (Defusion; Provimi, Brooksville, OH).

[3] Product 2 (NutriQuest, Mason City, IA).

[4] Missing sample.

Table 3-6. Deoxynivalenol analysis of experimental diets, Exp. 3 (as-fed basis)[1]

		Product added, %		
	Control	Product 1[2]	Sodium metabisulfite	
d 0 to 14	---	0.50	0.25	0.50
d 14 to 21	---	0.50	0.25	0.50
d 21 to 28	---	0.25	0.25	0.25
DON, mg/kg				
d 0 to 14	< 0.5	<0.5	< 0.5	< 0.5
d 14 to 21	< 0.5	< 0.5	< 0.5	< 0.5
d 21 to 28	< 0.5	<0.5	< 0.5	< 0.5

[1] Multiple samples were collected from each diet throughout the study, homogenized, and submitted to North Dakota Grain Inspection Service, Inc. (Bucyrus, OH) for analysis of DON as determined by ROSA DONQ2 Quantitative Test (Charms Sciences, Inc., Lawrence, MA).

[2] Product 1 (Defusion; Provimi, Brooksville, OH).

Table 3-7. Effects of Product 1 on growth of nursery pigs, Exp. 1[1]

Item	Control	Product 1[2]	SEM	Probability, *P* <
Day 0 to 28				
ADG, g	303	365	4.7	0.001
ADFI, g	403	443	5.0	0.001
G:F, g/kg	751	822	6.0	0.001
Day 28 to 35 (Post Test)				
ADG, g	645	548	13.0	0.001
ADFI, g	853	817	11.4	0.002
G:F, g/kg	757	670	11.8	0.001
Day 0 to 35				
ADG, g	371	401	4.9	0.001
ADFI, g	492	517	5.5	0.001
G:F, g/kg	753	775	5.3	0.001
BW, kg				
d 0	6.8	6.8	0.04	0.921
d 28	15.4	17.1	0.16	0.001
d 35	20.0	20.9	0.20	0.001

[1] A total of 2,268 pigs (Line 337 × 1050; PIC) were used in a 35-d study. Pigs were weaned at approximately 22 days. Upon entry into the nursery, pigs were randomly sorted into 1 of 84 pens (42 pens of barrows, 42 pens of gilts), with one pen of gilts and one pen of barrows per fence line feeder. Pigs were blocked by BW and then randomly assigned to 1 of 2 dietary treatments in a completely randomized block design with 21 feeders per treatment. Experimental diets were fed from d 0 to 28 and a common diet was then fed from d 28 to 35.

[2] Product 1 (Defusion; Provimi, Brooksville, OH).

Table 3-8. Effects of added Product 1 or 2 on growth of nursery pigs, Exp. 2[1]

		Product added, %								
	Control	Product 1[2]		Product 2[3]						
Day 0 to 7	-	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
Day 7 to 21	-	0.25	0.25	0.25	0.25	0.25	0.25	0.50	0.50	
Day 21 to 28	-	0.25	0.25	0.25	0.25	0.25	0.25	0.50	0.50	
Day 28 to 35	-	0.25	0.25	0.15	0.15	0.25	0.25	0.25	0.25	
Day 35 to 42	-	-	0.25	-	0.15	-	0.25	-	0.25	SEM
Day 0 to 35										
ADG, g	342^{d}	382^{ab}		365^{c}		371^{bc}		394^{a}		7.8
ADFI, g	446^{c}	490^{ab}		478^{b}		484^{b}		502^{a}		10.9
G:F. g/kg	766^{ab}	780^{ab}		765^{b}		767^{ab}		786^{a}		5.7
Day 35 to 42										
ADG, g	728^{abcd}	663^{d}	780^{ab}	672^{cd}	770^{abc}	684^{bcd}	777^{ab}	649^{d}	794^{a}	24.4
ADFI, g	1,027^{bcd}	976^{d}	1,089^{ab}	969^{d}	1,060^{abc}	986^{cd}	1,092^{ab}	982^{d}	1,127^{a}	22.7
G:F. g/kg	709	679	718	694	726	697	709	660	709	20.3
Day 0 to 42										
ADG, g	404^{d}	429^{bc}	447^{ab}	415^{cd}	429^{bc}	422^{bcd}	437^{abc}	436^{abc}	460^{a}	9.0
ADFI, g	540^{d}	568^{bcd}	592^{ab}	558^{cd}	568^{bc}	567^{bcd}	582^{abc}	579^{abc}	608^{a}	12.2
G:F. g/kg	749	757	755	746	756	744	752	755	758	8.0
BW, kg										
d 0	6.2	6.2		6.2		6.2		6.2		0.09
d 35	18.3^{d}	19.7^{ab}		19.1^{c}		19.3^{bc}		20.1^{a}		0.33
d 42	23.5^{f}	24.3^{de}	25.2^{ab}	24.1^{e}	24.4^{de}	24.1^{e}	24.9^{bc}	24.7^{cd}	25.6^{a}	0.34

[abcde] Means within a row with different superscripts differ $P < 0.05$.

[1] A total of 4,320 pigs (Line 337 × 1050; PIC) were used in a 35-d study. Pigs were weaned at approximately 22 days. Upon entry into the nursery, pigs were randomly sorted into 1 of 160 pens (80 pens of barrows, 80 pens of gilts), with one pen of gilts and one pen of barrows per fence line feeder. A pair of pens (feeders) were blocked by weight and then randomly assigned to one of five dietary treatments that were fed for 35 d in a completely randomized block design. Then on day 35, half of the pens receiving either Product 1or Product 2 remained on those treatments and the other half were switched to the control diet. These combinations resulted in a total of nine treatments. There were 16 replications (feeders) for all treatments from day 0 to 35 and 8 replications per treatment from day 35 to 42 for all treatments except for the control, which continued to have 16 replications per treatment.

[2] Product 1 (Defusion; Provimi, Brooksville, OH).

[3] Product 2 (NutriQuest, Mason City, IA).

Table 3-9. Effects of added sodium metabisulfite or Product 1 on growth of nursery pigs, Exp. 3[1]

		Product added, %			
	Control	Product 1[2]	Sodium metabisulfite		
Day 0 to 21	-	0.50	0.25	0.50	
Day 21 to 28	-	0.25	0.25	0.25	SEM
Day 0 to 21					
ADG, g	457[b]	482[a]	431[c]	483[a]	5.5
ADFI, g	589[b]	609[a]	592[ab]	608[a]	6.7
G:F, g/kg	776[b]	792[ab]	727[c]	796[a]	5.4
Day 21 to 28					
ADG, g	679[c]	700[b]	728[a]	697[bc]	6.1
ADFI, g	971[b]	1,000[a]	996[ab]	995[ab]	8.2
G:F, g/kg	700[b]	700[b]	731[a]	700[b]	4.9
Day 0 to 28					
ADG, g	512[b]	536[a]	505[b]	536[a]	4.6
ADFI, g	684[b]	706[a]	693[ab]	704[a]	6.2
G:F, g/kg	749[b]	759[ab]	729[c]	762[a]	3.3
BW, kg					
d 0	7.0	7.0	7.0	7.0	0.07
d 21	16.8[b]	17.3[a]	16.2[c]	17.3[a]	0.14
d 28	21.6[b]	22.2[a]	21.3[b]	22.2[a]	0.16

[abc] Means within a row with different superscripts differ $P < 0.05$.

[1] A total of 2,808 pigs (Line 337 × 1050; PIC) were used in a 28-d study. Pigs were weaned at approximately 22 days. Upon entry into the nursery, pigs were randomly sorted into 1 of 104 pens (52 pens of barrows, 52 pens of gilts), with one pen of gilts and one pen of barrows per fence line feeder. Pigs were blocked by BW and then randomly assigned to 1 of 4 dietary treatments in a completely randomized block design with 13 feeders per treatment. Experimental diets were fed from d 0 to 28.

[2] Product 1 (Defusion; Provimi, Brooksville, OH).