THE EFFECTS OF FEED ADDITIVES, SODIUM METABISULFITE AND PROCESSING CONDITIONS ON NURSERY PIGS FED DIETS CONTAINING DEOXYNIVALENOL; AND THE IMPACT OF FEED WITHDRAWAL AND DIET BLENDING ON FINISHING PIG GROWTH, CARCASS COMPOSITION AND ECONOMICS

by

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B.S., Kansas State University, 2009

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

2012

Approved by:

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Abstract

Thirteen experiments using a total of 7,589 nursery and finishing pigs were conducted to evaluate the effects of deoxynivalenol (DON), feed additives and processing conditions on nursery pig growth performance. In addition, feed withdrawal and diet blending were evaluated in finishing pigs. Experiment 1 tested 3 feed additives in DON-contaminated diets with only Defusion Plus improving performance. Experiment 2 evaluated Biofix in both low- and high-DON diets and showed no effects on growth. Experiments 3 and 4 further evaluated levels of Defusion and the effects of pelleting and supplemental nutrients in DON-contaminated diets. Defusion improved growth in low-DON diets, but had variable effects in high DON diets. Pelleting DON-contaminated diets resulted in comparable growth to pigs fed positive control diets in meal form. In Exp. 5 and 6, pilot studies evaluated DON-detoxification using sodium metabisulfite (SMB) with hydrothermal treatment in both an autoclave and a pellet mill. These conditions reduced analyzed DON by as much as 89 and 75% for the autoclave and pellet mill, respectively. In Exp. 7 and 8, pelleting DON-contaminated diets with SMB improved growth. Experiments 9 and 10 evaluated feed-withdrawal time on carcass composition and economic returns. These experiments showed that pre-slaughter fasting for up to 36 h prior can be used to avoid weight discounts in heavyweight pigs without negatively impacting carcass composition and maintaining overall revenue. However, these advantages come with a potential reduction in carcass weight and increased incidence of leaking ingesta, which can result in condemned heads. Experiments 11, 12, and 13 compared phase-feeding to blending diets using an automated feed delivery system. These studies showed that corn-supplement blending is not economical and feeding diets blended to a Lys curve results in lower feed costs compared to phase-feeding, but due to reductions in growth and carcass weight, these savings do not translate into higher income over feed cost. Finally, Exp. 13 showed that over- and under-budgeting situations do not significantly influence overall returns, but pigs fed under-budgeted diets performed more closely to those fed correctly estimated feed budgets.

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Acknowledgements

This is an exciting point as a young professional, where I can not only look back on the past two and a half years, but also look forward to the challenges of pursuing a doctoral degree. I cannot say enough to my family for their love and support as I have moved 850 miles away from our family farm to pursue my education. My parents have been very understanding to encourage me to blaze my own path over the past seven years and I wouldn't be where I am today without the continuous support of my three sisters and the rest of my family as well.

Secondly, I would like to express my gratitude to the K-State Swine Team. I've seen other graduate students struggle and I have to commend our swine group for the culture and environment in which we work. It is a wonderful blend of hard work and collaboration in a fun, entertaining setting that makes it such an appealing place to work and learn. Drs. Nelssen, Tokach, Dritz and Goodband have all played an important role throughout my time here and I've learned an immense amount from each of you. I would be remiss not to individually thank my advisor Dr. Joel DeRouchey. Upon meeting you as an undergraduate looking for an Honors project, I knew I had found someone who loved to teach and expand the knowledge of others. The countless hours of assistance you've provided throughout my education are greatly appreciated and I've learned many life lessons from our discussions.

Aside from this group, there are a myriad of others who deserve a much longer thank you than I will provide. I cannot express how much I have learned from my year as a Fulbright Scholar at the University of Melbourne and having the opportunity to work with Dr. Frank Dunshea as well as Maree, Vickey, Kristy, Fahri and Henny has been a real privilege. At KSU, the graduate students I have had the opportunity to work with are second to none. To Nick, Jon, Mandy, Julie, Jeremiah, Chad, Matt, Megan, Kelly, Eric, Rommel, Jay, Alan, Eddie, Sureemas, Kazu, Josh, Devin, Jon, Amanda, Bryce, Brandon, Andy, Aaron and Randell, thanks for being great friends and colleagues, I look forward to more great times together.

Finally, I have an amazing wife who has supported and encouraged me along the way. Although we've both had some stressful experiences in graduate school and moving halfway around the world, we've also learned how important we are to each other's success. Thank you Brandi for your patience, love and support.

Chapter 1 - The effects of deoxynivalenol-contaminated corn distillers dried grains with solubles in nursery pig diets and the effectiveness of commercially available feed additives to mitigate these effects

Abstract

Four experiments were conducted to investigate the effects of deoxynivalenol (DON) from naturally-contaminated distillers dried grains with solubles (DDGS) and the efficacy of feed additives in nursery pig diets. In Exp. 1, 180 pigs (10.3 ± 0.2 kg BW) were fed 1 of 5 diets for 21 d. The diets were: 1) Positive control (PC; < 0.5 mg/kg DON), 2) Negative control (NC; 4 mg/kg DON), 3) NC + 0.10% Biofix Plus, 4) NC + 0.15% Cel-can and 0.50% bentonite clay, or 5) NC + 0.25% Defusion Plus. Pigs fed the NC diet had poorer ($P < 0.001$) ADG than the PC. Pigs fed Defusion Plus had improved ($P < 0.03$) ADG over the NC while pigs fed Biofix Plus or Cel-can with bentonite clay had reduced ADG ($P < 0.001$) compared to the PC. In Exp. 2, 340 pigs (11.7 ± 0.1 kg BW) were fed 1 of 8 diets for 21 d. The diets were: 1) Positive control (< 0.5 mg/kg DON), 2) Low negative control (Low NC; 1.5 mg/kg DON), 3) Low NC + 0.15% Biofix Select, 4) Low NC + 0.30% Biofix Select, 5) High negative control (High NC; 3.0 mg/kg DON), 6) High NC + 0.30% Biofix Select, 7) High NC + 0.45% Biofix Select, and 8) Diet 7 with 5% added water. Increasing DON level reduced (linear; $P < 0.05$) ADG, ADFI and pig BW. Biofix did not improve performance. In Exp. 3, 1,008 pigs (12.5 ± 0.3 kg BW) were fed 6 treatments for 24 d. Diets were: 1) Positive control (PC; < 0.5 mg/kg DON), 2) Negative control (NC; 3 mg/kg DON), 3) NC + 0.25% Defusion, 4) NC + 0.50% Defusion, 5) Diet 3, with supplemental nutrients, and 6) Diet 5, pelleted. Pigs fed the NC had decreased ($P < 0.01$) ADG and ADFI, but adding Defusion improved (linear; $P < 0.04$) ADG and ADFI over the NC. Pelleting improved ($P < 0.001$) both ADG and G:F, resulting in ADG above PC pigs. In Exp. 4, 980 pigs (12.0 ± 0.3 kg BW) were fed 1 of 7 diets in a 28 d trial in a 2 × 3 + 1 factorial arrangement. The 7 treatments were based on 3 diets fed in meal or pellet form: 1) Positive control (PC; < 0.5 mg/kg DON), 2) Negative control (NC; 3 mg/kg DON), and 3) NC + 0.25% Defusion. Treatment 7 was Diet 3

with supplemental nutrients in pellet form. There were no interactions between pelleting and Defusion. Pigs fed the NC had decreased ($P < 0.01$) ADG and ADFI and pelleting improved ($P < 0.001$) ADG to PC levels, driven by improved ($P < 0.001$) G:F. Adding nutrients or Defusion had no effect. Overall, these studies show that Defusion and pelleting can help overcome some of the negative effects of DON while other feed additives and additional nutrients do not.

Keywords: deoxynivalenol, detoxifying agents, nursery pigs, pelleting, vomitoxin

Introduction

Deoxynivalenol (DON), colloquially known as vomitoxin, is one of the most important mycotoxins because it occurs frequently in cereal grains and at levels of toxicological relevance. In a survey by Côté et al. (1984) evaluating swine health problems during "Fusarium years", DON levels averaged 3 mg/kg in corn and DON-contaminated feed was linked to 75% of the cases of mycotoxicosis. Pigs are the most susceptible livestock species, reacting primarily with decreased feed intake, immune suppression and at high concentrations emesis and complete feed refusal (Forsyth et al., 1986; Rotter et al., 1996b; Eriksen and Pettersson, 2004).

While the traditional method of diluting DON concentrations during diet formulation is effective (Patterson and Young, 1993), the habitually regional distribution of DON-affected areas may rule out dilution as a viable option. Consequently, swine producers often must utilize DON-contaminated grains that elicit negative effects on growth, characterized as >1 mg/kg in growing pigs (Dänicke et al., 2001). Corn distiller's dried grains with solubles (DDGS), an ethanol industry by-product, also presents significant problems because the DON level in DDGS are generally 3 times more concentrated than the corn source. In order to mitigate the effects of DON, many types of detoxification have been proposed. These strategies are typically categorized as: technical treatments where contaminated feed is manipulated chemically, physically or biologically prior to feeding; or *in situ* treatments where adsorbents, probiotics or enzymes are used to limit DON effects during digestion. However, Dänicke (2002) summarized that to date, both *in vitro* models (Avantaggio et al., 2007; Sabater-Vilar et al., 2007) and *in vivo* growth studies have proven largely ineffective against DON (Friend et al., 1984; Danicke et al., 2004; Doll et al., 2005).

While no DON-detoxifying agents are currently approved by the U.S. Food and Drug Administration, there are products reported to be of benefit that are approved for other purposes. These experiments were designed to evaluate the effectiveness of three commercially-available feed additives as well as the influence of these additives and pelleting in diets containing DON on nursery pig performance.

Materials and Methods

All experimental procedures and animal care were approved by the Kansas State Institutional Animal Care and Use Committee. All diets were corn-soybean meal based and both a clean and naturally-contaminated source of corn DDGS were provided by Hubbard Feeds (Mankato, MN). The DDGS were analyzed for mycotoxin concentrations and the analyzed values were used during diet formulation to incorporate DON into the test diets at desired concentrations. Diets were formulated to meet or exceed all nutrient requirement estimates (NRC, 1998).

Experiment 1

A total of 180 mixed-sex pigs (TR4 × 1050; PIC, Hendersonville, TN), initially 10.3 ± 0.2 kg BW and 34 d of age, were used in a 21 d growth experiment to evaluate the ability of 3 feed additives to ameliorate the negative effects associated with DON-contamination in nursery pig diets. Pigs were allotted to pens by initial BW and pens assigned to 1 of 5 dietary treatments in a randomized complete block design (RCBD), with both initial BW and location in the barn serving as blocking factors. There were 6 replicate pens per treatment with 6 pigs per pen. Five dietary treatments were formulated to contain: 1) Positive control (PC; < 0.5 mg/kg DON), 2) Negative control (NC; 4 mg/kg DON), 3) NC + 0.10% Biofix Plus (Biomin Inc., Herzogenburg, Austria), 4) NC + 0.15% Cel-can (VAST Inc., Mason City, IA) and 0.50% bentonite clay, or 5) NC + 0.25% Defusion Plus (Cargill Animal Nutrition, Minneapolis, MN). Biofix Plus contains a constituent of yeast cell walls designed to adsorb specific areas of the DON molecule thereby making it non-toxic as well as by enzymatically degrading the DON molecule. Cel-can is a mixture of yeast components that supplies fermentation metabolites in combination with bentonite clay aimed at binding and adsorbing mycotoxins. Defusion Plus is a combination of preservatives, antioxidants, amino acids, and direct-fed microbials which is thought to mitigate some of the toxic effects of DON. Experimental diets were presented in meal form and were fed

from d 0 to 21. All diets were formulated to be identical in nutrient composition and contained a total of 17% DDGS (Table 1-1).

This experiment was conducted at the Kansas State University Swine Teaching and Research Center. Each pen (1.22 × 1.52 m) contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pig weight and feed disappearance were measured on d 0, 3, 7, 10 and 21 of the trial to determine ADG, ADFI and G:F (Table 1-3).

Diets were all manufactured at the Kansas State University Animal Science Feed Mill. Samples of each diet were collected from feeders between each weigh day, blended and sub-sampled before sending to the Veterinary Diagnostic Laboratory at North Dakota State University (NDSU; Fargo, ND) for 17-component mycotoxin analysis (Table 1-2). Samples of the NC diet and the diet containing Defusion Plus were also collected at the end of the trial to determine if DON levels changed over time. All samples were sent for analysis at the conclusion of the trial.

Experiment 2

A total of 340 barrows (1050; PIC, Hendersonville, TN; initially 11.7 ± 0.1 kg BW and 35 d of age) were used in a 21 d growth experiment. Pigs were allotted to pens by BW, and pens were assigned to 1 of 8 treatments in a RCBD, with location in the barn serving as the blocking factor. There were 9 replicate pens per treatment with 4 to 5 pigs per pen. All pigs were initially fed common commercial diets for the first 14 d. On d 14 post-weaning (d 0 of the experiment), diets comprising the 8 experimental treatments (Table 1-6) were fed to the pigs. All diets contained 20% corn DDGS. Based on the initial mycotoxin analysis of base ingredients, the 8 experimental diets were formulated to contain: 1) Positive control (< 0.5 mg/kg DON), 2) Low negative control (Low NC; 1.5 mg/kg DON), 3) Low NC + 0.15% Biofix Select, 4) Low NC + 0.30% Biofix Select, 5) High negative control (High NC; 3.0 mg/kg DON), 6) High NC + 0.30% Biofix Select, 7) High NC + 0.45% Biofix Select, and 8) High NC + 0.45% Biofix Select and 5% water added to the diet.

It was hypothesized that adding water to diets with Biofix Select may enhance the ability of the yeast cell wall constituents to absorb and degrade the mycotoxin molecule. Therefore, water was added at 5%, which diluted nutrient concentrations in the remainder of the diet.

This experiment was conducted at the Kansas State University Segregated Early Weaning Research Facility in Manhattan, KS. Each pen (1.22 × 1.22 m) contained a 4-hole dry self-feeder and 1 cup waterer to provide ad libitum access to feed and water. Base corn, soybean meal, and the two sources of DDGS were sent to Romer Labs (Union, MO) and tested for mycotoxin content (Table 1-4). These results were used in diet formulation before diets were manufactured at the Kansas State University Animal Science Feed Mill.

After diet manufacturing, each diet was sampled and tested at Romer Labs as well as NDSU Veterinary Diagnostic Laboratory (Table 1-5). Experimental diets were presented in meal form and were fed from d 0 to 21. Average daily gain, ADFI, and G:F were determined by weighing pigs and measuring feed disappearance on d 4, 7, 14 and 21 of the trial (Table 1-7).

Experiment 3

A total of 1,008 mixed sex pigs (Fast/PIC × TR4; Fast Genetics, Saskatoon, SK, CAN; PIC, Hendersonville, TN) initially 12.5 ± 0.3 kg BW were used in a 24 d growth experiment to evaluate the effect of adding levels of Defusion higher than used previously along with supplemental nutrients and pelleting on the growth performance of nursery pigs fed DON-contaminated diets. There were 6 dietary treatments in a RCBD with 6 replicate pens per treatment and average initial pig BW as the blocking factor. Pen served as the experimental unit. Pens were allotted to treatment based on initial pen weight, with an average of 28 pigs per pen (14 barrows, 14 gilts). The 6 dietary treatments were formulated to contain: 1) Positive control (PC; < 0.5 mg/kg DON), 2) Negative control (NC; 3 mg/kg DON), 3) NC + 0.25% Defusion, 4) NC + 0.50% Defusion, 5) NC + 0.25% Defusion with supplemental nutrients, and 6) Diet 5, pelleted. Diets 1 to 5 were fed in meal form. For treatments 5 and 6, the added nutrients included supplemental choice white grease, monocalcium phosphate, L-Lys, methionine hydroxy analog and L-Thr. Treatments 1 to 4 were medicated with chlortetracycline (CTC) at 441g/t while treatments 5 and 6 with supplemental nutrients were medicated with CTC at 485g/t. Due the high sodium content in Defusion (23.73% Na), diets with added Defusion contained a lower inclusion rate of salt.

Distiller's dried grains with solubles originated from a clean (0.7 mg/kg DON) and DON-contaminated (15.8 mg/kg DON) source and both were sub-sampled 10 times and samples were homogenized before being sent to the NDSU Veterinary Diagnostic Laboratory for a 17-

component mycotoxin analysis (Table 1-8), which was then used for diet formulation. Based on these results, corn DDGS was incorporated at 15.85% to achieve desired DON concentrations (Table 1-9). All diets were manufactured at the Hubbard Feeds mill in Mankato, MN. Treatment 6 was pelleted using a CPM 7800 (California Pellet Mill, Crawfordsville, IN) through a stainless steel 32 mm pellet die that was 635 mm thick with conditioning temperature of 54.4 °C. Following diet manufacturing, a sample of each diet was collected and analyzed for DON levels using an ELISA test kit (Neogen, 2007) at MVTL Laboratories (New Ulm, MN).

This experiment was conducted at the New Fashion Pork Research Nursery (Buffalo Center, IA). Each pen (1.75 × 4.05 m) contained a 5-hole, dry self-feeder and provided ad libitum access to feed and water. Pig weights and feed disappearance were measured on d 0, 7, 14, and 24 to determine ADG, ADFI and G:F (Table 1-10).

Experiment 4

A total of 980 mixed sex pigs (Fast/PIC × TR4; Fast Genetics, Saskatoon, SK, CAN; PIC, Hendersonville, TN) initially 12.0 ± 0.3 kg were used in a 28 d growth experiment. This experiment was designed as a follow-up to Exp. 3 to further evaluate the impact of adding Defusion in combination with pelleting on the growth performance of nursery pigs fed DON-contaminated diets. There were 7 dietary treatments in a RCBD with a 2 × 3 + 1 factorial arrangement with 5 replicate pens per treatment and average initial pig BW was used as the blocking factor. Pens were allotted to treatments based on initial pen weight with an average of 28 pigs per pen (14 barrows, 14 gilts). Seven experimental treatments were formulated based on 4 experimental diets fed in meal (M) or pellet (P) form: 1) Positive control (PC; < 0.5 mg/kg DON), 2) Negative control (NC; 3 mg/kg DON) and 3) NC + 0.25% Defusion. Treatment 7 was Diet 3 (NC + 0.25% Defusion) with supplemental nutrients fed only in pellet form. The added nutrients included Choice white grease, monocalcium phosphate, L-Lys, methionine hydroxy analog and L-Thr. Diets 1 to 6 were medicated with chlortetracycline (CTC) at 441 g/t while the treatment 7 with supplemental nutrients used CTC at 485 g/t. Due the high sodium content in Defusion (23.73% Na), diets with added Defusion contained a lower inclusion level of added salt.

Distiller's dried grains with solubles originated from the same source as in Exp. 3 and were analyzed in the same fashion. Based on these results (Table 1-11), corn DDGS were

incorporated into diets at 23.5% to achieve desired DON concentrations (Table 1-12). All diets were manufactured at the Hubbard Feeds feed mill in Mankato, MN. Diets were pelleted using a CPM 7800 (California Pellet Mill, Crawfordsville, IN) through a stainless steel 32 mm pellet die 635 mm thick with conditioning temperatures averaging 57.0 ± 3.1 °C. Particle sizes averaged 636 µ for the diets fed in meal form. Mycotoxin analyses were conducted at NDSU using a full 17-component toxin screen (Table 1-11).

This experiment was conducted at the New Fashion Pork Research Nursery in Buffalo Center, IA. Each pen (1.75 × 4.05 m) contained a 5-hole, dry self-feeder and provided ad libitum access to feed and water. Pig weights and feed disappearance were measured on d 0, 7, 14, and 24 of the trial to determine ADG, ADFI and G:F (Table 1-13).

Mycotoxin Analysis

In Exp. 1 to 4, samples of the base corn and DDGS were sent to the NDSU Veterinary Diagnostic Laboratory for a 17-component mycotoxin analysis. In Exp. 1, 2 and 4, complete diet samples were also sent to NDSU for analysis. The analysis for tricothecene mycotoxins (DON, 15-acetyldeoxynivalenol (15-ADON), 3-Acetyl DON, nivalenol and T-2 toxin) along with zearalenone and zearalenol is conducted according to a modified version of Groves et al. (1999), using gas chromatography coupled with mass spectrometry. Aflatoxins and fumonisins are analyzed by HPLC. Samples were tested on an as-fed basis and the practical quantitation limit for all mycotoxins was 0.5 mg/kg. In Exp. 2, complete diet samples were initially tested for mycotoxin levels at Romer Labs using an HPLC extraction method (Romer Labs, 2012) with a minimum quantitation limit of 0.15 mg/kg. In Exp. 3, complete diet samples were tested at MVTL Labs and tested for DON levels using an ELISA test kit (Neogen, 2007) with a range of quantitation between 0.5 and 5.0 mg/kg.

Statistical Analysis

For all four experiments, data were analyzed as a RCBD using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. In Exp. 1, when treatment effect was a significant source of variation, means were separated using the PDIFF option of SAS. In Exp. 2 to 4, treatment means were analyzed using the LSMEANS statement and pre-planned CONTRAST statements in SAS, with block as the random component. In Exp. 2, the fixed factors in the model included DON level and Biofix inclusion. Pre-planned contrasts in

Exp. 2 included low vs. high DON, the effect of adding 5% water to high-DON diets with 0.45% Biofix Select and the linear and quadratic effects of both increasing levels of DON and increasing levels of Biofix Select in low and high-DON diets. The coefficients for the unequally spaced linear and quadratic contrasts were derived using the PROC IML procedure in SAS. In Exp. 3, the pre-planned contrasts included 1) DON vs. non-contaminated; 2) linear and quadratic effects of levels of Defusion; 3) effect of supplemental nutrients in NC diets with 0.25% Defusion and 4) diet form (pellet vs. meal) in NC diets containing 0.25% Defusion and supplemental nutrients. For Exp. 4, the model included pelleting and the inclusion of Defusion as fixed factors. Pre-planned contrasts in Exp. 4 were: 1) the two-way interaction between pelleting and adding 0.25% Defusion in NC diets; 2) DON vs. non-contaminated; 3) diet form (pellet vs. meal); 4) the addition of Defusion in NC diets and 5) effect of supplemental nutrients in NC diets with 0.25% Defusion (pellet form). In all four experiments, least square means were calculated for each independent variable and means were considered significant at $P < 0.05$ and trends at $P < 0.10$.

Results

Experiment 1

The analyzed dietary DON concentration for the PC diet was 0.8 mg/kg. In addition, analyzed dietary DON concentration for the NC, Biofix Plus, Cel-can with clay bentonite, and Defusion Plus treatments were 4.6, 4.4, 4.3, and 5.1 mg/kg, respectively. Also, 3-Acetyl DON, 15-ADON, fumonisin B_1, and zearelenone were detected in diets at or below cautionary dietary limits.

Overall (d 0 to 21), pigs fed the PC diet had greater ($P < 0.001$) ADG and ADFI compared to pigs fed DON-contaminated diets. The addition of Biofix Plus or Cel-can with bentonite clay had no effect on ADG, ADFI or G:F in NC diets. However, pigs fed diets containing Defusion Plus had greater ADG ($P < 0.03$) then pigs fed the NC as well as diets containing Biofix Plus or Cel-can with bentonite clay. Pigs fed the PC diet had improved G:F ($P < 0.03$) compared to pigs fed the NC diet and diets containing Biofix plus or Cel-can with bentonite clay. Also, pigs fed Defusion Plus had improved G:F ($P < 0.04$) compared to pigs fed NC diets and tended to have improved ($P < 0.08$) G:F compared to pigs fed diets containing Biofix Plus.

Pig BW did not differ between treatments at d 0, but at d 3 and 7 pigs fed the positive control diet were heavier ($P < 0.02$) than pigs fed the other diets. At d 10 and d 21, pigs fed the PC diet remained heavier ($P < 0.01$) than pigs fed other diets. However, at d 10 the pigs fed diets containing Defusion Plus tended ($P < 0.07$) to be heavier than those fed NC diets or diets containing Biofix Plus, while at d 21 pigs fed Defusion Plus diets were heavier ($P < 0.05$) than pigs fed the remaining treatment diets.

Experiment 2

After diet sampling, the analyzed DON concentrations from Romer Labs were higher and more variable between diets than expected. Therefore, the samples at Romer Labs were tested a second time. Romer Labs indicated that their analysis procedures are less accurate when DON concentrations exceed 5 mg/kg (such as with the high-DON DDGS used in the diets). A separate set of ingredient and diet samples were then sent to the North Dakota State University Veterinary Diagnostic Laboratory (NDSU) for comparative analysis. The NDSU results for the contaminated DDGS were approximately 50% higher (15.8 mg/kg) than the results reported by Romer Labs (10.1, 12.1 mg/kg), which explains why the test diets formulated to be 1.5 (low-DON) and 3.0 mg/kg (high-DON) actually averaged approximately 2.0 and 4.1 mg/kg, respectively. Based on variability between labs and analyses, a composite level of DON and Total DON for each diet was generated representing an average of the 3 separate analyses (Table 1-5).

For the overall trial period (d 0 to 21), increasing DON from 1.5 to 3.0 ppm decreased (linear; $P < 0.05$) ADG and ADFI, which was primarily due to a decrease in ADFI when DON levels increased from 1.5 to 3.0 mg/kg. Concentration of DON did not influence G:F. Within DON-contaminated diets, pigs fed high-DON had poorer ($P < 0.001$) ADG than those fed low-DON diets, driven by a reduction in ADFI ($P < 0.001$) as G:F was not affected. Within low-DON diets, ADFI increased (quadratic, $P < 0.01$) with the addition of 0.15% Biofix, but at 0.30% Biofix ADFI dropped to a similar level of the low NC. Conversely, G:F worsened (quadratic, $P < 0.01$) when 0.15% Biofix was added, which recovered when 0.30% Biofix was added. This fluctuation in ADFI and G:F explains why adding 0.15 or 0.30% Biofix did not influence ADG in low-DON diets. Within high-DON diets, there were no differences in ADG or G:F when pigs were fed 0.30 or 0.45% Biofix, although pigs fed increasing levels of Biofix

tended (quadratic, $P < 0.08$) to have lower ADFI than pigs fed the high NC diet. The addition of 5% water to high-DON diets with 0.45% Biofix did not influence ADG, ADFI or G:F.

Pigs fed increasing levels of DON weighed less (linear; $P < 0.02$) at d 4 and d 7 compared to the PC pigs, with similar responses on d 14 (quadratic; $P < 0.05$) and on d 21 (linear; $P < 0.04$). Within DON-contaminated diets, pigs fed high-DON levels had lower BW ($P < 0.001$) than pigs fed diets containing low-DON concentrations. When Biofix concentrations increased in high-DON diets, pig BW decreased (quadratic, $P < 0.04$) at d 14 and those pigs tended to weigh less (quadratic, $P < 0.07$) at d 21, but increasing Biofix in low-DON diets did not affect pig BW at any time point. Adding 5% water to high-DON diets with 0.45% Biofix did not impact pig BW at any of the weigh dates.

Experiment 3

Analyzed DON concentration for the PC diet was 0.6 mg/kg, below orientation values for critical concentrations of DON in nursery pig diets (> 1 mg/kg; Danicke et al. 2001). The analyzed dietary DON concentrations for NC, NC + 0.25% Defusion, NC + 0.50% Defusion and the NC + 0.25% Defusion with increased nutrients (meal form) were collectively lower than formulated levels (3 mg/kg) at 2.6, 2.0, 2.0 and 2.1 mg/kg, respectively. Also, when the NC + 0.25% Defusion with increased nutrients was pelleted, analyzed DON levels decreased to 1.1 mg/kg.

Overall (d 0 to 24), pigs fed NC diets containing DON had decreased ($P < 0.01$) ADG than those fed PC diets, driven by a decrease ($P < 0.01$) in ADFI, while G:F was not affected. Within NC diets, increasing Defusion improved (linear; $P < 0.01$) ADG by increasing (linear; $P < 0.04$) ADFI, but did not influence G:F. Adding supplemental nutrients to DON-contaminated diets with 0.25% Defusion fed in meal form improved ($P < 0.01$) G:F, but due to the simultaneous reduction ($P < 0.001$) in ADFI, there was no difference in ADG. Pelleting DON-contaminated diets with 0.25% Defusion improved ($P < 0.001$) ADG, driven by a typical pelleting response where G:F was improved ($P < 0.001$) and ADFI was not affected.

Regarding pig BW, there were no differences on d 7 across treatments. Additionally, feeding 3 mg/kg DON did not impact pig BW on d 14, but pigs fed DON-contaminated diets tended ($P < 0.08$) to weigh less at the conclusion of the trial on d 24. Within DON-contaminated diets, increasing Defusion tended to increase (linear; $P < 0.10$) pig BW at d 14 and 24. Although

adding supplemental nutrients to DON-contaminated diets with 0.25% Defusion did not alter pig BW, pelleting the diet improved ($P < 0.01$) final BW on d 21 within treatments where supplemental nutrients were fed.

Experiment 4

Analyzed Total DON was reported as a combination of DON and 15-ADON, which have been shown to have similar toxicity in the pig (Pestka 1987). In PC diets, DON concentrations were < 0.5 mg/kg and 0.5 mg/kg for the meal and pelleted forms, respectively. Negative control DON levels analyzed at 3.3 mg/kg in both meal and pelleted form. When 0.25% Defusion was added to NC diets, DON levels were 2.9 mg/kg in meal diets and 1.7 mg/kg in pelleted diets. Diet samples from the NC diet with 0.25% Defusion where supplemental nutrients were added were not available for mycotoxin analysis.

Overall, (d 0 to 28), there were no interactions between main effects of pelleting and adding Defusion to DON-contaminated diets. Pigs fed NC diets had reduced ($P < 0.01$) ADG and ADFI compared to those fed the PC, but did not differ in G:F. Pelleting the diet increased ($P < 0.001$) ADG, stimulated by an improvement ($P < 0.001$) in G:F, but there was no difference in ADFI compared to diets fed in meal form. The addition of 0.25% Defusion to DON-contaminated nursery pig diets did not affect ADG, ADFI, or G:F. Furthermore, adding supplemental nutrients to DON-contaminated pelleted diets with 0.25% Defusion did not influence nursery pig performance.

For pig BW, pigs fed diets containing 3 mg/kg DON weighed less ($P < 0.05$) at d 7, 14 and 28 and tended to weigh less ($P < 0.07$) at d 21 compared to those fed PC diets. Additionally, pigs fed pelleted diets were heavier ($P < 0.05$) each week than those fed diets in meal form. Finally, agreeing with the growth performance results, neither Defusion nor supplemental nutrients influenced pig BW at any of the weekly time points during the experiment.

Discussion

While the informal name “vomitoxin” suggests that feeding DON commonly results in vomiting, there are very few studies which confirm this (Etienne and Waché, 2008). While DON concentrations as high as 20 mg/kg can elicit emesis in young pigs (Young et al., 1983), during “Fusarium years”, typical DON concentrations are much lower, with regionally-affected corn averaging 3.1 mg/kg (Coté et al., 1984). For DON concentrations below 20 mg/kg in cereal

grains, Etienne and Waché (2008) described a 4% reduction in ADFI and 7% reduction in ADG for each additional mg/kg of DON when final diet concentrations exceed 1 mg/kg. However, in the current trials, DON was incorporated into negative control diets using naturally DON-contaminated DDGS, for which DON-related reductions in growth performance had not been previously quantified. In Exp. 2, when low DON levels (1.5 mg/kg) were tested, neither ADFI (564 vs. 560 g) nor ADG (896 vs. 911) were different from pigs fed PC diets, while in pigs fed DON levels above 1.5 mg/kg in Exp. 1 to 4, ADFI was reduced by 4% and ADG by 5% for each additional mg/kg of DON in the final diet. However, in Exp. 2, even when feeding high-DON diets (4.1 mg/kg) growth reductions were not as marked as in the other 3 experiments (Figure 1-1;Figure 1-2), for reasons that are unknown. The variation in DON effects seen both within and between experiments may be associated with the presence of low-levels of other DON metabolites (e.g., 15-ADON, 3-Acetyl DON) in naturally-contaminated feedstuffs, which can further exacerbate DON effects (EFSA, 2009). Finally, it is also noteworthy that Exp. 2 used castrated males only, while the other 3 experiments used both castrated males and gilts. Although less significant effects were seen in Exp. 2, if sex-related, these results would contrast with Côté et al. (1985), who reported lower and more variable weight gains in castrated males than in gilts fed the same DON-contaminated diets.

In all 4 experiments, high DON levels affected pig growth most markedly during the initial period, reducing ADG in the NC diet to approximately 33 and 76% of pigs fed the PC diet on d 3 (126 vs. 386 g/d; Exp. 1) and d 4 (288 vs 377 g/d; Exp. 2). Reductions in performance due to DON continued throughout the entire trial in Exp. 1 and 4, which contained higher concentrations than Exp. 2 and 3. In Exp. 2 and 3, after the decrease in performance during the initial period, pigs fed low-DON NC diets performed similarly to pigs fed the PC. This agrees with a review of the dose-dependent DON effects on feed intake by Etienne and Waché (2008), who suggested that the suppression of feed intake usually persists for the duration of the experiment when DON concentrations exceed 3 mg/kg (Côté et al. 1985; Lun et al., 1985), but normal intake usually recovers after 1 to 2 weeks for lower DON concentrations (Grosjean et al., 2002).

While DON effects were primarily driven by decreased feed intake, feed efficiency during the initial periods also worsened during the initial period in all four experiments. After the initial decrease, feed efficiency for pigs fed DON-contaminated diets was generally similar to

those fed the PC diet. This reduction in G:F may be associated with immune system stimulation during the initial exposure to low to moderate levels of DON. Pestka et al. (2004) described a DON-stimulated up-regulation of the expression of cytokines, chemokines and inflammatory genes; though in high doses DON promotes leukocyte apoptosis with concurrent immune system suppression (Pestka et al., 2004; Oswald, 2007).

When the 3 commercially available feed additives were tested at their recommended levels in diets containing an average of 4.6 mg/kg DON in Exp. 1, the growth performance of pigs fed these products remained lower than pigs fed the PC (0.8 mg/kg DON). Adding 0.25% Defusion Plus increased ADG by 12% compared to negative controls, driven by an 9% improvement in G:F and a numeric increase (3%) in ADFI. This agrees with reports by D. C. Mahan (personal communication) and Patience (2011), who also saw improvements in ADG when adding a similar product, Defusion, to pigs fed DON-contaminated diets. In contrast, Biofix Plus and Cel-can were ineffective against dietary DON at the inclusion rated used in the present experiments. It is unclear if higher rates than 0.10% of Biofix would be more effective, but in a study by D.C. Mahan (personal communication), feeding 0.40% Biofix did not affect the performance of nursery pigs fed diets containing 2 or 7 mg/kg DON.

In Exp. 2, Biofix Select, a product similar to Biofix Plus, was tested at varying levels in nursery pig diets containing an average of 2.0 and 4.1 mg/kg DON, respectively. While adding 0.15% Biofix Select improved ADFI in low-DON diets, in this experiment pigs fed the low-DON diets (2.0 mg/kg) did not differ in overall growth performance compared to the PC. Moreover, adding 0.30 or 0.45% Biofix Select to high-DON diets tended to reduce pig weights, although similar levels of Biofix in previous research had also shown no improvements in performance due to Biofix (D. C. Mahan, personal communication). It was theorized that Biofix may be more effective in diets containing added moisture by potentially enhancing the microbial activity of the *saccharomyces cerevisiae* yeast culture. In the present experiment, adding 5% water to a diet containing 0.45% Biofix Select had no effect on growth performance. There was also a buildup of heat and a stale odor over time in this diet, which may have contributed to the lack of response. Based on the accumulation pattern of DON during grain storage described by Langseth et al. (1993), samples from this diet were collected on d 0, 7, 14 and 21 and analyzed to evaluate any change in DON level, which increased slightly (3.0 to 3.8 mg/kg) during the experimental period. Overall, the results of Exp. 1 and 2 reaffirm previous *in vivo* research,

where the use of enzymes and adsorbent materials aimed at binding to the DON molecule in the gastrointestinal tract have been largely ineffective (Dänicke et al., 2004; Awad et al., 2010).

In Exp. 3, adding Defusion to diets containing 2 mg/kg DON improved ADG by approximately 4% and 6% when 0.25 or 0.50% Defusion was added, respectively, agreeing with previous research where Defusion responses have primarily been driven by ADFI improvements (D.C. Mahan, personal communication; Patience 2011). Overall, pigs fed 0.50% Defusion performed similarly to pigs fed PC diets. Furthermore, pelleting the same diet elicited a typical pelleting response, improving ADG by 7.5%, primarily through enhanced feed efficiency, surpassing the growth performance of pigs fed positive control diets (637 vs. 617 g/day). While adding Defusion in low-DON diets improved growth performance in Exp. 3, when DON levels were elevated to approximately 3 mg/kg in Exp. 4, Defusion had no effect on overall growth performance. Even so, pelleting DON-contaminated diets with and without Defusion increased ADG by over 9% in Experiment 4, offsetting the approximate 7% reduction caused by feeding diets containing 3 mg/kg DON. In both experiments, supplementing additional nutrients within DON-contaminated diets containing 0.25% Defusion had no effect on ADG. While no interactions were present between pelleting and adding Defusion on pig growth performance, it is notable that pelleting diets containing Defusion resulted in analyzed DON levels 91 and 71% lower for Exp. 3 (2.2 vs. 1.1 mg/kg) and Exp. 4 (2.9 vs. 1.7 mg/kg), respectively.

Defusion contains a variety of ingredients including preservatives, organic acids, fermentation products and supplemental vitamins and amino acids. Consequently, there are many possible mechanisms that independently or in some combination could improve growth performance of pigs fed DON-contaminated diets. One specific ingredient in Defusion is sodium metabisulfite which, when mixed in combination with heat and moisture, chemically alters the structure of DON to a non-toxic DON-sulfonate adduct form (Young et al., 1987). Therefore, the pelleting process in the presence of Defusion in Exp. 3 and 4 may have provided the hydrothermal action necessary to convert DON and thereby reduce analyzed DON levels, which may in part be responsible for the increased feed intake seen. However, Defusion-related improvements in feed efficiency as well as the growth performance improvements seen when diets were fed in meal form cannot be explained by sodium metabisulfite alone, which suggests that additional ingredients in Defusion might also have an effect. Defusion contains L-Trp, which may play a role, as increasing the Trp:Lys ratio above 0.18 has shown some improvement

in feed conversion (Vinyeta et al., 2010). However, a study by Rotter et al. (1996a) showed no evidence that supplemental tryptophan could modulate DON toxicity. Regarding fermentation products, a recent study by Li et al. (2011) reported improvements in pig growth in DON-contaminated diets when *Bacillus* sp. LS 100 was isolated from chicken digesta and mixed into the diet, suggesting that the addition of *Bacillus* cultures to Defusion may be able to initiate some microbial detoxification of DON.

The variation in response to Defusion seen in the present study may also be attributed to the fact that in Exp. 1, Defusion Plus was the product used, which contains additional flow agents; whereas in Exp. 3 and 4, the standard Defusion product was used. In Exp. 1, adding Defusion Plus at an inclusion rate of 0.25% resulted in increased ADG, driven primarily by an improvement in G:F. However, in Exp. 3 and 4 Defusion was the product used, and at 0.25% did not improve ADG, although in Exp. 3 the addition of 0.50% Defusion did increase ADG. In this case, the improvement in ADG was driven primarily by improvements in ADFI. The variability in DON or the presence of low levels of other mycotoxins between experiments may have influenced the response to Defusion, but it may also indicate that the different ingredients between products may also influence nursery pig growth performance.

In summary, DON from naturally-contaminated corn DDGS caused similar reductions in performance in pigs as other researchers have found with DON from other cereal grains. The use of adsorbent materials (e.g., Biofix & Cel-can with bentonite clay) in DON-contaminated diets was ineffective in the present study. Nevertheless, Defusion showed promise as it improved nursery pig growth performance in 2 of 3 experiments. The addition of 0.25 to 0.50% Defusion may lessen the impact of DON in nursery pig diets when dietary DON levels are below 5 mg/kg, although the mechanism by which performance is improved remains unclear. Finally, the present experiments suggest that pelleting DON-contaminated diets may serve as a way to mitigate DON-related reductions in performance.

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Tables and Figures

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

Item	Positive Control	Deoxynivalenol (DON; 4 mg/kg) Negative Control
Corn	51.36	51.36
Soybean meal, 46.5%	28.29	28.29
DDGS	17.00	---
High-DON DDGS[1]	----	17.00
Monocalcium phosphate, 21% P	0.65	0.65
Limestone	1.20	1.20
Salt	0.35	0.35
Copper sulfate	0.05	0.05
Vitamin premix[2]	0.25	0.25
Trace mineral premix[3]	0.15	0.15
L-Lys HCl	0.40	0.40
DL-Met	0.08	0.08
L-Thr	0.10	0.10
Phytase[4]	0.13	0.13
Feed additive[5]	---	---
Total	100	100
Calculated analysis		
SID[6] amino acids, %		
Lys	1.27	1.27
Ile:Lys	63	63
Met:Lys	32	32
Met & Cys:Lys	59	59
Thr:Lys	63	63
Trp:Lys	17	17
Val:Lys	72	72
Total Lys, %	1.43	1.43
ME, kcal/kg	3,320	3,320
SID Lys:ME, g/Mcal	3.83	3.83
CP, %	22.64	22.64
Ca, %	0.69	0.69
P, %	0.60	0.60
Available P, %	0.42	0.42

[1] Analyzed DON concentration in DDGS was 23.5 mg/kg.

[2] Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.
[3] Provided per kg of premix: 26.5 g Mn from manganese oxide; 110 g Fe from iron sulfate; 110 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.
[4] Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided 750 phytase units phytase/kg and 0.13% available P released.
[5] Three feed additives were tested in the negative control diet: 0.15% Biofix Plus, 0.25% Defusion Plus, and 0.15% Cel-can with 0.50% bentonite clay. In each diet, additives were included at the expense of corn.
[6] Standardized ileal digestible.

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

	Composite[2]					d 21[3]	
Item, mg/kg	Positive Control	Negative Control	Biofix Plus[4]	Cel-can[5]/ bentonite clay	Defusion Plus[5]	Negative Control	Defusion Plus[5]
DON	0.8	4.6	4.4	4.3	5.1	6.1	4.6
15-ADON	< 0.5	1.0	1.0	1.0	1.1	1.3	1.0
Total DON	0.8	5.6	5.4	5.3	6.2	7.4	5.6
Fumonisin B_1	2.0	2.0	2.0	1.0	2.0	2.0	1.0
Zearalenone	< 0.5	0.5	0.5	0.5	0.5	0.6	0.5

[1] Samples were sent for 17-component mycotoxin analysis at the NDSU Veterinary Diagnostic Laboratory, Fargo, ND. Samples were analyzed using a variety of mass spectrometry, ELISA, and HPLC methods. Included are those mycotoxins found at levels above detection limits.
[2] Values are a mean of 6 samples collected on d 2, 5, 8, 12, 14, and 19 that were blended before being analyzed at the conclusion of the experiment.
[3] Collected at the end of the experiment and analyzed in a separate run from other samples.
[4] Biofix Plus (Biomin Inc., Herzogenburg, Austria).
[5] Cel-can (VAST Inc., Mason City, IA).
[6] Defusion Plus (Cargill Animal Nutrition, Minneapolis, MN).

Table 1-3. Effect of deoxynivalenol (DON) level and commercial feed additives on nursery pig performance[1]

		DON (4.0 mg/kg)[2]				
Item	Positive Control	Negative Control	Biofix Plus	Cel-can + bentonite clay	Defusion Plus	SEM
d 0 to 21						
ADG, g	585[a]	419[c]	409[c]	418[c]	469[b]	22.7
ADFI, g	895[a]	719[b]	687[b]	699[b]	739[b]	29.6
G:F	0.655[a]	0.587[c]	0.597[bc,x]	0.601[bc]	0.637[ab,y]	0.0162
Pig BW, kg						
d 0	10.31	10.34	10.39	10.37	10.34	0.190
d 3	11.47	10.72	10.75	10.74	10.76	0.201
d 7	13.48[a]	12.23[b]	12.13[b]	12.24[b]	12.16[b]	0.216
d 10	17.32[a]	15.24[b,x]	15.19[b,x]	15.54[b]	16.10[b,y]	0.320
d 21	22.60[a]	19.15[c]	18.97[c]	19.15[c]	20.35[b]	0.397

[a,b, x,y] Within a row, means without a common superscript differ $P < 0.05$ and $P < 0.10$, respectively.

[1] A total of 180 pigs (PIC TR4 × 1050, initially 10.3 ± 0.2 kg) were used in a 21-d trial with 6 pigs per pen and 9 pens per treatment.

[2] The analyzed average DON level was 4.6 mg/kg and the average total DON was 5.6 mg/kg.

Table 1-4. Mycotoxin analysis of base ingredients, Exp. 2 (as-fed basis)

Item, mg/kg	Ground corn	Soybean meal	Control DDGS	High-DON DDGS
Romer Labs[1]				
DON	< 0.2	< 0.2	0.9	8.1
15-ADON	< 0.2	< 0.2	< 0.2	3.4
Total DON[2]	< 0.2	< 0.2	0.9	11.5
NDSU[3]				
DON	---	---	0.7	11.1
15-ADON	---	---	< 0.5	4.7
Total DON[2]	---	---	0.7	15.8

[1] Romer Labs, Union, MO. Samples analyzed using a combination of gas chromatography, high-pressure liquid chromatography and mass spectrometry with a practical quantitation limit of 0.2 mg/kg. Reported value is an average of two separate analyses.

[2] Total DON levels as a combination of DON and 15-ADON, as these two compounds have similar toxicity (Pestka, 1987).

[3] NDSU Veterinary Diagnostic Laboratory, Fargo, ND. Samples were sent for 17-component mycotoxin analysis and analyzed using a variety of mass spectrometry, ELISA, and HPLC methods. Included in the table are mycotoxins found at levels above detection limits.

Table 1-5. Deoxynivalenol (DON) analysis of experimental diets, Exp. 2

		Low DON (1.5 mg/kg)			High DON (3.0 mg/kg)			5% Water[1]
Item, mg/kg	Positive Control	Low NC	0.15% Biofix	0.30% Biofix	High NC	0.30% Biofix	0.45% Biofix	0.45% Biofix
Romer Labs[2]								
DON	0.6	1.5	2.2	1.8	4.4	3.9	3.7	3.7
15-ADON	<0.2	0.6	0.8	0.7	1.4	1.3	1.2	1.2
Total DON	0.6	2.1	3.0	2.5	5.8	5.2	4.9	4.9
NDSU[3]								
DON	0.7	2.2	2.5	2.2	4.1	4.9	4.1	3.6
15-ADON	< 0.5	0.5	0.5	0.5	0.9	1.0	0.9	0.8
Total DON	0.7	2.7	3.0	2.7	5.0	5.9	5.0	4.4
Overall[4]								
DON	0.6	1.7	2.3	1.9	4.3	4.2	3.8	3.7[5]
Total DON	0.6	2.3	3.0	2.6	5.5	5.4	4.9	4.7

[1] The 5% water treatment is a duplicate of the high-DON, 0.45% Biofix treatment diluted with 5% water (2.85 mg/kg DON, 0.427% Biofix).
[2] Romer Labs, Union, MO. Samples analyzed using a combination of gas chromatography, high-pressure liquid chromatography and mass spectrometry with a practical quantitation limit of 0.2 mg/kg. Reported value is an average of two separate analyses.
[3] NDSU Veterinary Diagnostic Laboratory, Fargo, ND. Samples were sent for 17-component mycotoxin analysis and analyzed using a variety of mass spectrometry, ELISA, and HPLC methods. Included in the table are mycotoxins found at levels above detection limits.
[4] Reported value is an average of the three analyses conducted (two analyses at Romer Labs and one at NDSU).
[5] Additional samples were collected at d 0, 7, 14, and 21 and sent to NDSU for DON analysis. Results: d 0 (3.0 mg/kg), d 7 (3.4 mg/kg), d 14 (3.8 mg/kg) and d 21 (3.8 mg/kg).

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

		Low deoxynivalenol (DON; 1.5 mg/kg)[2]			High DON (3.0 mg/kg)[2]			5% Water[3]
Item	Positive Control	Low Negative Control	0.15% Biofix	0.30% Biofix	High Negative Control	0.30% Biofix	0.45% Biofix	0.45% Biofix
Ingredient, %								
Corn	49.06	49.06	48.89	48.73	49.06	48.73	48.57	46.16
Soybean meal, 46.5% CP	27.63	27.63	27.65	27.66	27.63	27.66	27.67	26.27
Control DDGS, 29% CP	20.00	10.00	10.00	10.00	---	---	---	---
High-DON DDGS, 28.5% CP	---	10.00	10.00	10.00	20.00	20.00	20.00	19.00
Monocalcium phosphate, 21% P	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.57
Limestone	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.19
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.33
Copper sulfate	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Vitamin premix[4]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.24
Trace mineral premix[5]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.14
L-Lys HCl	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.39
DL-Met	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
L-Thr	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07
Phytase[6]	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.12
Biofix Select[7]	---	---	0.15	0.30	---	0.30	0.45	0.43
Water	---	---	---	---	---	---	---	5.00
Total	100	100	100	100	100	100	100	100
Calculated composition, %								
SID[8] amino acids, %								
Lys	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.21
Ile:Lys	63	63	63	63	63	63	63	63
Leu:Lys	148	148	148	148	148	148	147	147
Met:Lys	30	30	30	30	30	30	30	30
Met & Cys:Lys	58	58	58	58	58	58	58	58
Thr:Lys	62	62	62	62	62	62	62	62
Trp:Lys	17	17	17	17	17	17	17	17
Val:Lys	72	72	72	72	72	72	72	72
Total Lys, %	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.37
ME, kcal/kg	3,320	3,320	3,313	3,309	3,320	3,309	3,305	3,139
SID Lys:ME, g/Mcal	3.83	3.83	3.83	3.84	3.83	3.84	3.84	3.84

CP, %	22.9	22.9	22.9	22.9	22.9	22.9	22.9	21.8
Ca, %	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.67
P, %	0.60	0.60	0.60	0.60	0.60	0.60	0.59	0.57
Available P, %	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.40

[1] Diets were fed for 21 d with d 14 postweaning as d 0 of the experiment. Diets were fed in meal form.

[2] The analyzed average DON content for the low- and high-DON diets was 2.0 and 4.1 mg/kg, respectively.

[3] The 5% water treatment is a duplicate of the high-DON, 0.45% Biofix treatment diluted with 5% water (2.85 mg/kg DON, 0.427% Biofix).

[4] Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[5] Provided per kg of premix: 26.5 g Mn from manganese oxide; 110 g Fe from iron sulfate; 110 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

[6] Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided 750 phytase units phytase/kg and 0.13% available P released.

[7] Biofix Select (Biomin, Herzogenberg, Austria).

[8] Standardized ileal digestible.

Table 1-7. Effects of Biofix Select and deoxynivalenol (DON) on nursery pig growth performance, Exp. 2[1]

		Low-DON (1.5 mg/kg)[2]			High-DON (3.0 mg/kg)[2]					Probability, *P* <						
								5% Water[3]		DON effect[4]		Low vs	Biofix Low-DON[4]		Biofix High-DON[4]	
Item	Positive Control	Low NC	0.15% Biofix	0.30% Biofix	High NC	0.30% Biofix	0.45% Biofix	0.45% Biofix	SEM	Lin	Quad	High DON[4]	Lin	Quad	Lin	Quad
d 0 to 21																
ADG, g	560	564	574	558	530	506	518	517	11.8	0.05	0.16	0.001	0.70	0.32	0.32	0.24
ADFI, g	911	896	949	895	850	813	851	861	19.1	0.01	0.45	0.001	0.94	0.01	0.79	0.08
G:F	0.615	0.629	0.607	0.623	0.624	0.623	0.608	0.600	0.007	0.31	0.21	0.77	0.52	0.01	0.11	0.23
Pig BW, kg																
d 0	11.73	11.63	11.71	11.64	11.63	11.57	11.63	11.58	0.077	0.22	0.45	0.31	0.93	0.28	0.84	0.39
d 4	13.24	13.13	13.24	13.03	12.78	12.57	12.66	12.86	0.139	0.01	0.39	0.001	0.53	0.25	0.35	0.37
d 7	14.57	14.57	14.65	14.45	14.08	13.87	13.96	14.22	0.175	0.02	0.16	0.001	0.55	0.42	0.45	0.47
d 14	18.54	18.92	18.84	18.48	18.33	17.68	18.15	18.26	0.202	0.46	0.05	0.001	0.12	0.57	0.29	0.04
d 21	23.49	23.47	23.77	23.35	22.85	22.19	22.63	22.61	0.255	0.04	0.27	0.001	0.71	0.18	0.29	0.07

[1] A total of 340 pigs (1050, PIC; Hendersonville, TN; initial BW 11.6 ± 0.1 kg) were used in a 21-d trial with 4 to 5 pigs per pen and 9 pens per treatment.

[2] The analyzed average DON content for the low- and high-DON diets were 2.0 and 4.1 mg/kg, respectively.

[3] The 5% water treatment is a duplicate of the high-DON, 0.45% Biofix treatment diluted with 5% water (2.85 mg/kg DON, 0.427% Biofix).

[4] Each contrast compared the following treatments: (1) 'DON effect' evaluated the linear and quadratic effects of the positive control vs. Low- and High-DON NC treatments; (2) 'Low vs High DON' compared the 3 Low-DON treatments to the 3 High-DON treatments; (3) 'Biofix Low-DON' and (4) 'Biofix High-DON' evaluated the linear and quadratic effects of increasing Biofix levels in Low-DON or High-DON diets, respectively. The effect of adding 5% water to High-DON diets with 0.45% Biofix was not significant ($P > 0.20$).

Table 1-8. Mycotoxin analysis of diets, Exp. 3 (as-fed basis)[1]

	DDGS source[1]		Experimental diets[2]					
Item, mg/kg	Control	High-DON[3]	Positive Control	Negative Control (NC)	NC + 0.25% DEF[4]	NC + 0.50% DEF[4]	NC + 0.25% DEF & nutrients[5] (meal)	NC + 0.25% DEF & nutrients[5] (pellet)
DON	0.70	15.80	0.60	2.60	2.00	2.00	2.10	1.10
15-ADON	< 0.50	3.10	---	---	---	---	---	---
Zearalenone	< 0.50	1.00	---	---	---	---	---	---

[1] DDGS samples sent to the NDSU Veterinary Diagnostic Laboratory, Fargo, ND for a full 17-component toxin screen. Samples were analyzed using a variety of mass spectrometry, ELISA, and HPLC methods with a practical quantitation limit of 0.5 mg/kg. Included in the table are mycotoxins found above detection limits.
[2] Diet samples analyzed for DON using a Neogen (Lansing, MI) Veratox test kit. Positive control diet formulated to contain < 0.5 mg/kg DON and all remaining diets formulated to contain 3 mg/kg DON.
[3] Deoxynivalenol (DON).
[4] Defusion (Cargill Animal Nutrition, Minneapolis, MN).
[5] Supplemental nutrients included additional soybean meal, choice white grease, minerals, synthetic amino acids and medication.

Table 1-9. Composition of diets, Exp. 3

Item	Positive Control	Deoxynivalenol (3 mg/kg) Negative Control	NC + 0.25% DEF[1]	NC + 0.50% DEF[1]	NC + 0.25% DEF[1] + nutrients[2]
Ingredient, %					
Rolled corn	53.31	53.61	53.38	53.15	43.67
Soybean meal, 46.5% CP	26.00	26.00	26.00	26.05	30.50
DDGS	15.85	---	---	---	---
High-DON DDGS[3]	---	15.85	15.85	15.85	15.85
Choice white grease	1.30	1.00	1.10	1.15	5.95
Limestone	1.02	1.02	1.02	1.02	1.01
Monocalcium phosphate, 21% P	0.65	0.65	0.65	0.65	0.80
Salt	0.50	0.50	0.38	0.26	0.38
L-Lys HCl	0.43	0.43	0.43	0.43	0.46
Methionine hydroxy analog	0.11	0.11	0.11	0.11	0.16
L-Thr	0.08	0.08	0.08	0.08	0.10
Trace mineral premix[4]	0.08	0.08	0.08	0.08	0.08
Vitamin premix[5]	0.03	0.03	0.03	0.03	0.03
Medication[6]	0.40	0.40	0.40	0.40	0.44
Mold inhibitor[7]	0.10	0.10	0.10	0.10	0.10
Copper sulfate	0.07	0.07	0.07	0.07	0.07
Selenium, 0.06%	0.05	0.05	0.05	0.05	0.05
Phytase[8]	0.04	0.04	0.04	0.04	0.04
Defusion	---	---	0.25	0.50	0.25
TOTAL	100	100	100	100	100
Calculated analysis					
SID[9] amino acids, %					
Lys	1.20	1.20	1.20	1.20	1.32
Ile:Lys	60	60	60	60	58
Met:Lys	33	33	33	33	35
Met & Cys:Lys	58	58	58	58	58
Thr:Lys	60	60	60	60	60
Trp:Lys	18	18	18	18	18
Val:Lys	72	72	72	72	70
ME, Kcal/kg	3,307	3,296	3,296	3,296	3,488
CP, %	20.39	20.42	20.40	20.41	21.79
SID Lys:ME, g/Mcal	3.63	3.64	3.64	3.64	3.78
Total Lys, %	1.36	1.36	1.36	1.36	1.50
Ca, %	0.66	0.66	0.66	0.66	0.70
P %	0.58	0.58	0.58	0.58	0.61
Available P, %	0.30	0.30	0.30	0.30	0.34
Fat, %	4.92	4.63	4.73	4.77	9.29

[1] Defusion (Cargill Animal Nutrition, Minneapolis, MN).

[2] Fed in both meal and pellet form.
[3] Analyzed DON concentration in DDGS was 15.8 mg/kg.
[4] Trace mineral premix provided per kg of premix: 13.3 mg of Cu, 1.40 mg of I, 134 mg of Fe, 53.3 mg of Mn, and 160 mg of Zn.
[5] Vitamin premix provided per kg of premix: 22,046,000 IU of vitamin A, 5,291,000 IU of vitamin D_3, 97,002 IU of vitamin E, 10,288 mg of vitamin K, 88.2 mg of vitamin B_{12}, 79,366 mg of niacin, 61.7 mg of pantothenic acid, and 13,228 mg of riboflavin.
[6] To provide chlortetracycline at 441 or 485 g/t.
[7] Ammo Curb (Kemin Industries, Des Moines, IA).
[8] Phyzyme 2500 (Danisco Animal Nutrition, St. Louis, MO) provided 1,000 phytase units/kg which provided 0.13% available P.
[9] Standardized ileal digestible.

Table 1-10. Effects of Defusion (DEF) in combination with supplemental nutrients and pelleting on growth performance of nursery pigs fed deoxynivalenol (DON)-contaminated diets, Exp. 3[1]

		DON (3.0 mg/kg)[2]						Probability, *P* <			
									Defusion			
Item	Positive Control	Negative Control (NC)	NC + 0.25% DEF[3]	NC + 0.50% DEF[3]	NC + 0.25% DEF[3] & nutrients (meal)	NC + 0.25% DEF[3] & nutrients (pellet)	SEM	DON	Linear	Quad	Added Nutrients	Pellet vs. Meal
d 0 to 24												
ADG, g	617	575	597	612	583	637	9.5	0.01	0.01	0.71	0.29	0.001
ADFI, g	892	850	863	883	798	818	13.8	0.01	0.04	0.80	0.001	0.21
G:F	0.692	0.676	0.692	0.693	0.731	0.780	0.009	0.24	0.20	0.50	0.01	0.001
Pig weights, kg												
d 0	12.44	12.59	12.53	12.48	12.57	12.58	0.27	0.51	0.61	1.00	0.86	0.97
d 7	15.83	15.48	15.58	15.67	15.74	16.08	0.27	0.17	0.44	0.99	0.52	0.17
d 14	20.18	19.73	19.96	20.30	20.03	20.56	0.33	0.14	0.06	0.82	0.80	0.08
d 24	27.38	26.65	26.99	27.33	26.69	27.87	0.40	0.08	0.10	0.99	0.46	0.01

[1] A total of 1,008 mixed sex pigs (Fast/PIC × TR4; initially 12.5 ± 0.3 kg BW) were used in a 24-d growth experiment with 28 pigs per pen and 6 replicate pens per treatment.

[2] The analyzed average DON content for the Negative Control diets was 2.0 mg/kg.

[3] Defusion (Cargill Animal Nutrition, Minneapolis, MN).

[4] Each contrast compared the following treatments: (1) 'DON' compared positive control to negative control; (2) 'Defusion' compared the linear and quadratic effects of adding 0, 0.25% or 0.50% Defusion to negative control diets; (3) 'Added Nutrients' compared NC + 0.25% Defusion with and without nutrients, both in meal form; and (4) 'Pellet vs. Meal' evaluated treatments 6 and 7 where NC + 0.25% Defusion with nutrients was fed in meal vs pellet form.

Table 1-11. Mycotoxin analysis of diets, Exp. 4 (as-fed basis)[1]

	DDGS source[2]		Experimental diets[2,3]						
	Control	High-DON[4]	Positive Control		Negative Control		NC + 0.25% Defusion[5]		NC + 0.25% Defusion & nutrients[6]
Item, mg/kg			Meal	Pellet	Meal	Pellet	Meal	Pellet	Pellet
DON	0.60	11.70	< 0.5	0.50	3.30	3.30	2.90	1.70	---
15-ADON	< 0.50	2.40	< 0.5	< 0.5	0.80	0.70	0.70	0.60	---
Total DON	0.60	14.10	< 0.5	0.50	4.10	4.00	3.60	2.30	---
Zearalenone	< 0.50	1.70	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	---

[1] A total of 980 mixed sex pigs (Fast/PIC × TR4; initially 12.0 ± 0.3 kg) were used in a 28 d growth experiment with 28 pigs per pen and 5 replicate pens per treatment.

[2] DDGS and diet samples were sent to the NDSU Veterinary Diagnostic Laboratory, Fargo, ND for a full 17-component toxin screen. Samples were analyzed using a variety of mass spectrometry, ELISA, and HPLC methods with a practical quantitation limit of 0.5 mg/kg. Included in the table are mycotoxins found above detection limits.

[3] Positive control diet formulated to contain < 0.5 mg/kg DON and all remaining diets formulated to contain 3 mg/kg DON.

[4] Deoxynivalenol (DON).

[5] Defusion (Cargill Animal Nutrition, Minneapolis, MN).

[6] Supplemental nutrients included additional soybean meal, choice white grease, minerals, synthetic amino acids and medication. Diet samples for mycotoxin analysis were not available.

Table 1-12. Composition of diets, Exp. 4

Item	Positive Control	Deoxynivalenol (3 mg/kg) Negative Control	NC + 0.25% Defusion[1]	NC + 0.25% Defusion & nutrients[2]
Ingredient, %				
Rolled corn	46.28	46.14	45.99	36.55
Soybean meal, 46.5% CP	25.45	25.50	25.50	30.00
DDGS	23.50	23.50	23.50	23.50
Pork fat	1.40	1.35	1.40	6.00
Limestone	1.19	1.05	1.04	1.00
Monocalcium phosphate, 21% P	0.45	0.60	0.60	0.70
Salt	0.46	0.46	0.31	0.31
L-Lys HCl	0.41	0.44	0.44	0.48
Methionine hydroxy analog	0.06	0.13	0.13	0.30
L-Thr	0.04	0.08	0.08	0.10
Trace mineral premix[3]	0.08	0.08	0.08	0.08
Vitamin premix[4]	0.03	0.03	0.03	0.03
Medication[5]	0.40	0.40	0.40	0.44
Mold inhibitor[6]	0.10	0.10	0.10	0.10
Copper sulfate	0.07	0.07	0.07	0.07
Selenium, 0.06%	0.05	0.05	0.05	0.05
Phytase[7]	0.04	0.04	0.04	0.04
Defusion	---	---	0.25	0.25
TOTAL	100	100	100	100
Calculated analysis				
SID[8] amino acids, %				
Lys	1.20	1.20	1.20	1.32
Ile:Lys	55	55	55	55
Met:Lys	28	28	28	28
Met & Cys:Lys	58	58	58	58
Thr:Lys	60	60	60	60
Trp:Lys	18	18	18	18
Val:Lys	65	65	65	65
ME, Kcal/kg	3,304	3,304	3,304	3,492
CP, %	21.63	21.53	21.52	22.92
SID Lys:ME, g/Mcal	3.63	3.63	3.63	3.78
Total Lys, %	1.38	1.39	1.39	1.52
Ca, %	0.69	0.67	0.67	0.70
P %	0.58	0.58	0.58	0.61
Available P, %	0.30	0.30	0.30	0.33
Fat, %	5.54	5.57	5.62	9.94

[1] Defusion (Cargill Animal Nutrition, Minneapolis, MN).
[2] Fed in both meal and pellet form.
[3] Trace mineral premix provided per kg of premix: 13.3 mg of Cu, 1.40 mg of I, 134 mg of Fe, 53.3

mg of Mn, and 160 mg of Zn.
[4] Vitamin premix provided per kg of premix: 22,046,000 IU of vitamin A, 5,291,000 IU of vitamin D_3, 97,002 IU of vitamin E, 10,288 mg of vitamin K, 88.2 mg of vitamin B_{12}, 79,366 mg of niacin, 61.7 mg of pantothenic acid, and 13,228 mg of riboflavin.
[5] To provide chlortetracycline at 441 or 485 g/ t.
[6] Ammo Curb (Kemin Industries, Des Moines, IA).
[7] Phyzyme 2500 (Danisco Animal Nutrition, St. Louis, MO) supplied 1,000 phytase units/kg which provided 0.13% available P release.
[8] Standardized ileal digestible.

Table 1-13. Effects of pelleting, Defusion and supplemental nutrients on growth performance of nursery pigs fed deoxynivalenol (DON)-contaminated diets, Exp. 4[1]

	DON (3.0 mg/kg)[2]								Probability, *P* <			
	Positive Control		Negative Control		NC + 0.25% Defusion[3]		NC + 0.25% Defusion[3] & nutrients	SEM	DON[4]	Pellet vs. Meal[4]	Defusion[4]	Added Nutrients[4]
Item	Meal	Pellet	Meal	Pellet	Meal	Pellet	Pellet					
d 0 to 28												
ADG, g	641	666	589	649	603	655	654	10.6	0.01	0.001	0.35	0.94
ADFI, g	995	988	912	950	934	938	937	16.0	0.001	0.35	0.73	0.93
G:F	0.645	0.674	0.646	0.684	0.646	0.698	0.699	0.007	0.50	0.001	0.31	0.98
Pig BW, kg												
d 0	11.93	12.01	11.98	12.08	11.94	12.03	11.93	0.29	0.56	0.30	0.67	0.52
d 7	15.38	15.65	15.05	15.17	14.94	15.47	15.48	0.29	0.03	0.05	0.59	0.96
d 14	19.69	19.97	18.92	19.41	18.56	19.87	19.24	0.39	0.05	0.02	0.88	0.19
d 21	24.66	25.33	23.97	25.01	24.04	25.34	25.02	0.41	0.07	0.001	0.46	0.41
d 28	29.88	30.64	28.46	30.37	28.82	30.58	30.25	0.45	0.02	0.001	0.37	0.46

[1] A total of 980 mixed sex pigs (Fast/PIC × TR4; initially 12.0 ± 0.3 kg) were used in a 28 d growth experiment with 28 pigs per pen and 5 replicate pens per treatment.

[2] In negative control diets, the analyzed DON and Total DON levels were 2.8 and 3.5 mg/kg, respectively.

[3] Defusion (Cargill Animal Nutrition, Minneapolis, MN).

[4] Each contrast compared the following treatments: (1) 'DON' compared positive control to negative control (NC) in both meal and pellet form; (2) 'Pellet vs. Meal' compared final diet form in the first 6 treatments; (3) 'Defusion' compared negative control to NC + 0.25% Defusion in both meal and pellet form; and (4) 'Added Nutrients' compared treatments 6 & 7, where nutrients were added to diet specifications. The interaction between pelleting and adding 0.25% Defusion was not significant ($P > 0.22$), therefore it is not included in the table.

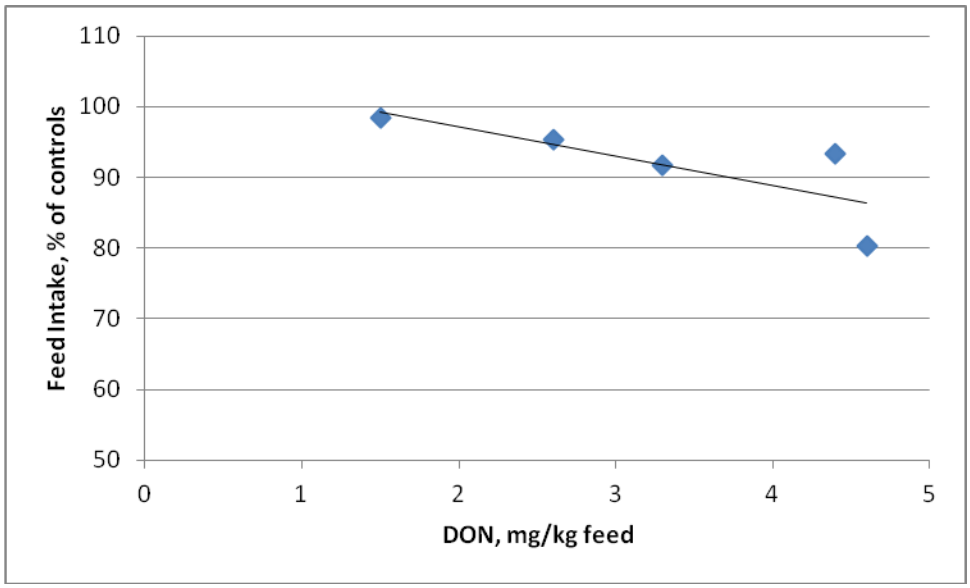

Figure 1-1. Effects of deoxynivalenol (DON) level from naturally-contaminated corn distillers dried grains on feed intake of 10 to 30 kg nursery pigs. Based on feed intake of pigs fed negative control diets compared to pigs fed positive control diets in Exp. 1 to 4 ($y = -4.1464x + 105.39$, $r^2 = 0.60$).

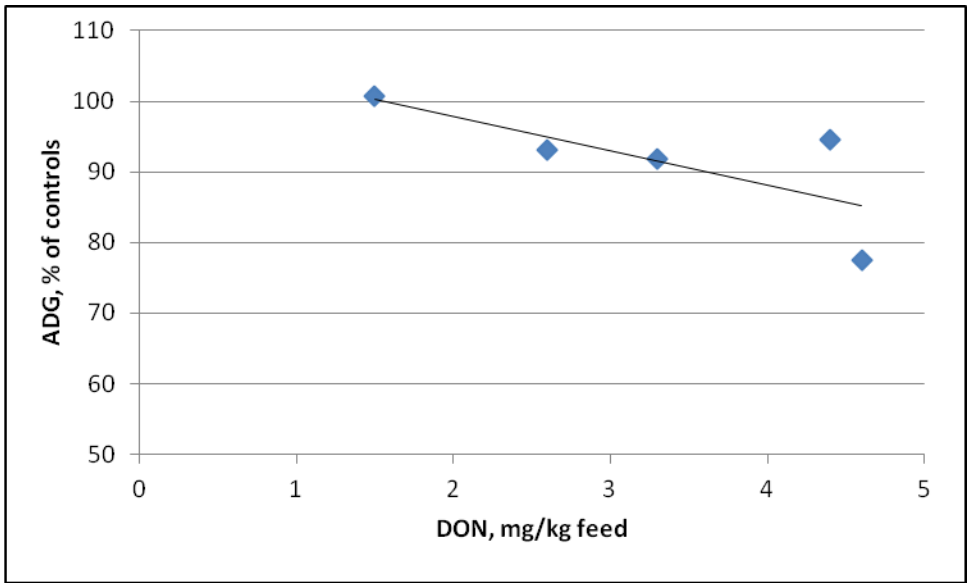

Figure 1-2. Effects of deoxynivalenol (DON) level from naturally-contaminated corn distillers dried grains on ADG of 10 to 30 kg nursery pigs. Based on ADG of pigs fed negative control diets compared to pigs fed positive control diets in Exp. 1 to 4 w ($y = -4.8932x + 107.65$, $r^2 = 0.580$).

Chapter 2 - The influence of pelleting and supplementing sodium metabisulfite ($Na_2S_2O_5$) on nursery pigs fed diets contaminated with deoxynivalenol

Abstract

Four experiments were conducted to ascertain the effects of hydrothermal treatment and sodium metabisulfite (SMB) on deoxynivalenol (DON)-contaminated corn distiller's dried grains with solubles (DDGS). Experiment 1 evaluated SMB and heat (autoclaving) on high-DON DDGS (20.6 mg/kg). Six levels of SMB were tested: 0.0% (control), 0.5%, 1%, 2.5%, 5%, or 5% with 100 mL/kg distilled water. Autoclaving after 1 h at 121°C alone elicited a 9.8% reduction in DON while an 82% reduction was achieved when 5% SMB was added prior to autoclaving. Experiment 2 tested pelleting high-DON DDGS under varying conditions with SMB. Four batches of DDGS (20.5 mg/kg DON) were tested: 0 (control), 1.0, 2.5, and 5.0% SMB. Pelleted samples were collected at conditioning temperatures of 66 and 82°C and retention times of 30 and 60 s within each temperature. Pelleting conditions had no effect on DON levels but pelleting DDGS reduced (quadratic; $P < 0.001$) DON as SMB inclusion increased. Experiments 3 and 4 evaluated the effect of pelleting and SMB on nursery pig growth. Both trials were arranged in a 2 × 3 + 1 factorial with 5 replicate pens per treatment. In Exp. 3, 987 pigs (13.0 ± 0.2 kg) were used for 27 d with main effects of 1) diet form: meal or pellet, and 2) SMB level: negative control (NC), NC + 0.25% SMB, or NC + 0.50% SMB. Negative control diets were formulated to contain 3 mg/kg DON. Treatment 7 was a positive control (PC; < 0.5 mg/kg DON) fed in meal form. Pigs fed high-DON diets had reduced ($P < 0.001$) ADG and ADFI while pelleting improved ($P < 0.001$) ADG and G:F. Adding SMB increased (linear; $P < 0.03$) ADG and tended to increase ($P < 0.10$) ADFI. In Exp. 4, 1,180 pigs (11.1 ± 0.32 kg) were used in a 21 d trial with main effects of 1) Diet form: meal or pellet, and 2) DDGS source: PC (< 0.5 mg/kg DON), NC (5 mg/kg DON), or NC + DDGS pelleted and crumbled before mixing into the final diet. Treatment 7, in meal form, included 2.5% SMB prior to pelleting DDGS (final diet contained 0.77% SMB). Overall, there was a 2-way interaction ($P < 0.04$) within NC diets where pelleting the final diet improved G:F by a greater margin in high-DON diets than when the DDGS was pelleted, crumbled, and then re-pelleted. DON reduced ($P < 0.002$) ADG and ADFI and pelleting

the diet improved ($P < 0.01$) ADG and G:F. Inclusion of SMB prior to pelleting DDGS increased ($P < 0.01$) ADG and ADFI. The use of SMB combined with thermal processing is a means to mitigate DON in diets for nursery pigs.

Keywords: deoxynivalenol, growth, pelleting, sodium metabisulfite, swine, vomitoxin

Introduction

Deoxynivalenol (DON), also known as vomitoxin, is produced by fungi of the *Fusarium* genus and is one of the key contaminants of cereal grains because it often occurs at levels high enough to cause adverse effects in farm animals. Among livestock species, pigs are the most sensitive, primarily because DON is rapidly absorbed and poorly metabolized (Etienne and Waché, 2008). The most obvious effect in pigs is reduced feed intake, which may be attributed to irritation of stomach mucosa (Rotter et al., 1994; Trenholm et al., 1994) and changes in brain transmitters (Prelusky, 1993; Swamy et al., 2004).

Levels of DON that elicit negative effects on growth (>1 mg/kg; Dänicke et al., 2001) can be relatively common in diets. Ethanol by-products are especially concerning because DON levels are approximately 3 times more concentrated in corn dried distillers grains (DDGS) than in the corn source. Because DON cannot be consistently removed, many types of detoxification have been evaluated. The majority of these treatments are either ineffective (Friend et al., 1984; Dänicke et al., 2004; Döll et al., 2005) or currently impractical in large-scale production (He et al., 1993; Li et al., 2011).

However, Young et al. (1987) showed that DON is converted to a 10-sulfonate adduct (DON-S) in the presence of sodium bisulfite and heat (autoclave). The resulting DON-S is non-toxic when fed to pigs. Furthermore, research by Dänicke et al. (2005) reported similar DON-transformation using sodium metabisulfite (SMB) and hydrothermal treatment using a laboratory conditioner. Therefore, we hypothesized that pelleting, particularly conditioning, could provide detoxification of DON-contaminated feedstuffs. Using DON-contaminated DDGS, the aims of this study were to evaluate: 1) the ability of SMB to transform DON using an autoclave; 2) pelleting under varying conditions with SMB on the reduction in DON; and 3) the effects of pelleting either DDGS or final diets with SMB on nursery pig performance.

Materials & Methods

General

All experimental procedures and animal care were approved by the Kansas State Institutional Animal Care and Use Committee. Corn DDGS were provided by Hubbard Feeds (Mankato, MN) and the clean (POET Bio-refining, Bingham Lake, MN) and naturally DON-contaminated (POET Bio-refining, North Manchester, IN) DDGS originated from the same plants across all four experiments.

Experiment 1

The objective of this pilot study was to verify that naturally DON-contaminated DDGS can be converted to a 10-sulfonate adduct (DON-S) using SMB (Samirian Chemical, Campbell, CA) in an autoclave. All samples used in this study were prepared at the Kansas State University Swine Nutrition Laboratory, with the samples autoclaved at the K-State Food Science Laboratory. Samples were prepared from a previously identified, uniform source of DDGS with a known DON concentration of 20.6 mg/kg. The DDGS were homogenized thoroughly prior to sample preparation to eliminate variation in DON content across samples.

This experiment used 6 treatments with DDGS containing either: 1) No SMB (control); 2) 0.5% SMB; 3) 1.0% SMB; 4) 2.5% SMB; 5) 5.0% SMB, or 6) 5.0% SMB with 100 mL/kg distilled water added to evaluate the role of water in the potential change in DON. Each treatment had a final weight of 500 g per sample, except treatment 6 (550g with water). Samples were split into two replicates and placed in covered aluminum trays, but were not sealed airtight to allow steam interaction and gas release during the autoclave process. Samples were autoclaved at 121°C for 60 min. After autoclaving, samples were dried in a 55°C drying oven to convert to a DM basis before replicates were combined, homogenized and sent for a full 17-component mycotoxin analysis at the North Dakota State University Veterinary Diagnostic Laboratory (NDSU; Fargo, ND). Analyzed mycotoxin levels were adjusted by the proportion of DDGS in the original sample and were then converted to an as-fed basis.

Experiment 2

The objective of this experiment was to evaluate the extent of DON reduction due to SMB when DDGS were pelleted under varying conditions. This experiment was conducted at the

Kansas State University Grain Sciences and Industry Feed Mill. All personnel involved were required to wear respirators and safety goggles during the pelleting process because sodium metabisulfite releases sulfur dioxide gas in the presence of heat and moisture and can be an irritant to the eyes and respiratory tract.

Treatments were comprised of 205 kg batches of DDGS after the addition of SMB. The DDGS were sourced from naturally DON-contaminated DDGS (averaging 20.5 ± 0.5 mg/kg). There were 4 DDGS treatments containing either: 1) 0.0% (control); 2) 1.0% SMB; 3) 2.5% SMB, or 4) 5.0% SMB. Prior to the addition of SMB, each batch was mixed for 4 min in a paddle mixer (Forberg 500 L double-shaft) to homogenize the DDGS and eliminate any variation in initial DON concentration. After adding SMB, each batch was mixed for an additional 3 min before pelleting. The pellet mill (CPM Master Model 1000HD, Crawfordsville, IN) was set to a production rate of 454 kg/h so conditioning temperature and retention time could be controlled within each batch of DDGS. Within each treatment, the pellet conditioner was adjusted to conditioning temperatures of 66 and 82°C and retention times of 30 and 60 s within each temperature and 2 kg samples were collected at each temperature × retention time combination. Pellets were cooled prior to sampling, and the 4 corresponding samples from each batch were ground and individually sent for mycotoxin analysis at NDSU.

Experiment 3

A total of 987 mixed sex pigs (Fast/PIC × TR4; Fast Genetics, Saskatoon, SK, CAN; PIC, Hendersonville, TN) initially 13.0 ± 0.2 kg BW were used in a 27 d growth experiment to evaluate the effects of supplementing SMB and pelleting on the performance of nursery pigs fed naturally DON-contaminated diets. There were 5 replicate pens per treatment and average initial pig BW was used as the blocking factor. Pens were allotted to treatments based on initial pen weight with 28 pigs per pen (14 barrows and 14 gilts).

Based on results of mycotoxin analysis (Table 2-3) of the high-DON DDGS (11.7 mg/kg) at NDSU, DDGS were incorporated into experimental diets at 25.0% to achieve desired DON concentrations (Table 2-4). The study was arranged in a randomized complete block design with a 2 × 3 + 1 factorial. The main effects were diet form (meal or pellet) and SMB (0, 0.25 and 0.50%). Therefore, the 7 experimental diets consisted of 4 diets which were: 1) Positive control (PC; < 0.5 mg/kg DON) in meal form only, 2) Negative control (NC; 3.0 mg/kg DON) in pellet

and meal form, 3) NC + 0.25% SMB (3.0 mg/kg DON) in pellet and meal form and 4) NC + 0.50% SMB (3.0 mg/kg DON) in pellet and meal form. All diets were also medicated with chlortetracycline 400 at a rate of 441 mg/kg. Diets were formulated to meet or exceed all nutrient requirement estimates (NRC, 1998).

Feed manufacturing took place at the Hubbard Feeds mill in Mankato, MN. Diets were pelleted using a CPM 7800 (California Pellet Mill, Crawfordsville, IN) through a stainless steel 32 mm pellet die 635 mm thick at a conditioning temperature of 61.4 ± 3.8°C. Corn was ground using a roller mill and the particle size for diets fed in meal form averaged 616 µ. Following diet manufacturing, a sample of each diet was collected, homogenized, and sent to NDSU for mycotoxin analysis. Diets were also analyzed for sodium and sulfur content at MVTL Laboratory (New Ulm, MN) due to concerns that incorporating SMB at high levels may negatively affect performance due to the effects of high dietary sodium or sulfur.

This experiment was conducted at the New Fashion Pork Research Nursery in Buffalo Center, IA. Each pen (1.75 × 4.05 m) contained a 5-hole, dry self-feeder and provided ad libitum access to feed and water. Pig weights and feed disappearance were measured on d 0, 7, 14, 21 and 27 to determine ADG, ADFI and G:F (Table 2-5).

Experiment 4

A total of 1,180 mixed sex pigs (Fast/PIC × TR4; Fast Genetics, Saskatoon, SK, CAN; PIC, Hendersonville, TN) initially 11.2 ± 0.3 kg BW were used to evaluate the effects of pelleting, pelleting DON-contaminated DDGS, and supplementing SMB on nursery pig performance. There were a combined total of 9 or 10 replications per treatment in a completely randomized design in a 2 × 3 +1 arrangement. The experiment was conducted concurrently at two sites to evaluate these effects in both university and commercial conditions. The research sites were: 1) Kansas State University (KSU) Swine Teaching and Research Center in Manhattan, KS, and 2) New Fashion Pork (NFP) Research Nursery in Buffalo Center, IA. All diets were manufactured simultaneously at the Hubbard Feeds mill in Mankato, MN, and diets for both sites were bagged and transported to the research locations.

At the KSU site, a total of 238 mixed sex pigs (337 × 1050; PIC, Hendersonville, TN; initially 11.5 ± 0.2 kg BW) were used in a 21-d growth trial with 5 replicates per treatment (pens) and 7 pigs (4 barrows, 3 gilts) per pen. However, based on limited pen availability, 1

treatment (positive control, meal) only had 4 replicate pens. Pigs were allotted to pens by initial BW at weaning, and when pigs reached approximately 11.5 kg they were re-weighed with average pig BW within pen balanced across 7 treatments. Each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water.

At the NFP site, a total of 942 pigs (Fast/PIC × TR4, initially 10.9 ± 0.3 kg BW) were used in a 21-d growth trial with 5 replications per treatment and 28 pigs (14 barrows, 14 gilts) per pen. Pens of pigs were allotted to 1 of 7 treatments based on initial pen weight. Each pen (1.75 × 4.05 m) contained a 5-hole, dry self-feeder and provided ad libitum access to feed and water.

The 7 experimental treatments consisted of 3 diets fed in meal or pellet form. Diets were: 1) Positive control (PC; < 0.5 mg/kg DON); 2) Negative control (NC; 4.8 mg/kg DON) and 3) NC + crumbled DDGS (4.8 mg/kg DON). In the seventh treatment, high-DON DDGS were mixed with 2.5% SMB prior to pelleting. After pelleting, DDGS were crumbled and mixed into the diet (4.8 mg/kg DON) with a final dietary concentration of 0.77% SMB. Treatment 7 was fed in meal form and due to concerns regarding the high sodium content in SMB, supplemental salt was removed.

Naturally-contaminated DDGS with a known DON concentration (Table 2-6, 16.0 mg/kg) were incorporated at 30% to produce diets with the desired DON concentration. Ten subsamples of corn and the clean and contaminated source of DDGS were collected and homogenized into a composite sample for a 17-component mycotoxin analysis at NDSU prior to diet formulation and manufacturing. Apart from DON and SMB content, diets were formulated to be identical in nutrient composition (Table 2-7). Because of the SMB addition, the inclusion rate of DDGS for the seventh treatment was increased to 31%, such that the final DDGS content was equivalent to the level in other diets. Diets were formulated to meet or exceed all nutrient requirement estimates (NRC, 1998). Diets were analyzed for sodium and sulfur content at MVTL Laboratory due to concerns that incorporating SMB at high levels may negatively affect performance due to the effects of high dietary sodium or sulfur. To prevent segregation of final diet ingredients, diets with pelleted DDGS were crumbled before incorporating into the final diet.

Diets were pelleted at the same pellet mill as in Exp. 3 with conditioning temperatures averaging 63.2 ± 1.8 °C. Dietary corn was processed using a roller mill and the particle size for

diets fed in meal form averaged 650 µ. For treatment 7, DDGS were pelleted using the same pellet mill and then crumbled before adding prior to final diet preparation. Samples of each diet were collected, blended and sub-sampled before sending to NDSU. Experimental diets were fed for 21 d with ADG, ADFI, and G:F determined by weighing pigs and measuring feed disappearance on d 7, 14, and 21.

Mycotoxin Analysis

In Exp. 1, 2 and 4, feed samples were sent to the NDSU Veterinary Diagnostic Laboratory for a 17-component mycotoxin analysis. The analysis for tricothecene mycotoxins (DON, 15-acetyldeoxynivalenol (15-ADON), 3-Acetyl DON, nivalenol and T-2 toxin) along with zearalenone and zearalenol is conducted according to a modified version of Groves et al. (1999) , using gas chromatography coupled with mass spectrometry. Aflatoxins and fumonisins were analyzed by HPLC. Samples were tested on an as-fed basis and the practical quantitation limit for all mycotoxins was 0.5 mg/kg. In Exp.3, feed samples were sent to MVTL Labs and tested for DON levels using an ELISA test kit (Neogen 2007) with a range of quantitation between 0.5 and 5.0 mg/kg.

Statistical Analysis

Because replications were combined for analysis in Exp. 1, there was no statistical analysis for this pilot study. In Exp. 2, data were analyzed using sample within batch as the experimental unit. Analysis evaluated the linear and quadratic effects of SMB and interactions with conditioning temperature and retention time using Genstat (Release 11.1, VSN International Ltd., Hemel Hempstead, UK). Data collected from Exp. 3 and 4 were analyzed using the MIXED procedure of SAS 9.1 (SAS Inst., Inc., Cary, NC, USA). Treatment effects were assessed within each experimental period using pen as the experimental unit. In Exp. 3, the model included pelleting and SMB inclusion as fixed factors and block as the random factor. The preplanned contrasts in Exp. 3 were: 1) DON versus non-contaminated; 2) diet form (pellet versus meal); 3) linear and quadratic effects of increased levels of SMB, and 4) pelleting-SMB interaction. For Exp. 4, data from the two research sites were pooled and analyzed for location by treatment interactions. Due to no significant interactions, the data was combined and analyzed with research location included in the model as a random effect. The fixed factors in the model were

pelleting and DDGS source (non-contaminated, contaminated, or contaminated, pelleted and crumbled). The planned contrasts in Exp. 4 included: 1) DON versus non-contaminated: 2) diet form (pellet versus meal); 3) pelleting versus un-pelleted DDGS in NC diets; 4) interactions between pelleting final diets and DDGS source, and 5) interaction between pelleting and pelleting DDGS within NC diets. Finally, a pair-wise comparison contrast evaluated the effects of SMB when DON-contaminated DDGS were pelleted, crumbled and incorporated into the final diet fed in meal form. For all statistical tests, significance and tendencies were set at $P < 0.05$ and $P < 0.10$, respectively.

Results

Experiment 1

The DON-contaminated DDGS used in the autoclave pilot study had mycotoxin levels above the practical detection limit for DON (20.6 mg/kg), 15-ADON (3.3 mg/kg) and zearalenone (1.1 mg/kg), while the levels of all other mycotoxins screened were not detected above 0.5 mg/kg. The effects of autoclaving with SMB on levels of DON are shown in Figure 2-1. Autoclaving without SMB addition reduced DON by 9.8% and 15-ADON by 26.6%. The addition of SMB further reduced DON, with 5.0% SMB reducing DON by 81.6%. The addition of 10% water to the 5.0% level of SMB created an additive effect, reducing DON by 93.4%, a 10.8% increase from the 5.0% level alone. The effects of added SMB on 15-ADON were not as clear, but at 5.0% SMB, 15-ADON levels were 12.0% lower than by autoclaving alone and the addition of 10% water further reduced 15-ADON by 10.8%.

Experiment 2

The DON-contaminated DDGS averaged 20.5 mg/kg DON and 3.0 mg/kg of 15-ADON prior to pelleting. The effects of pelleting with SMB and conditioning temperature on DON reduction are shown in Figure 2-2. There were no significant two or three-way interactions between temperature, retention time and SMB. Altering the retention time from 30 to 60 s had no effect on DON or 15-ADON. The effect of increasing temperature 51 to 68 °C was also non-significant for both DON and 15-ADON. Pelleting DDGS reduced (quadratic; $P < 0.001$) analyzed DON levels as the inclusion rate of SMB increased with up to 83% reduction at 5.0% SMB. Nevertheless, pelleting with SMB had no effect on 15-ADON concentrations.

Experiment 3

Mycotoxin analyses found that the PC diet did not contain any mycotoxins above the PQL (< 0.5 mg/kg). Negative control diets averaged 3.3 mg/kg DON, 0.7 mg/kg 15-ADON and 0.5 mg/kg zearalenone. When 0.50% SMB was added to the diet, DON was reduced by 26 and 75% for the meal and pelleted forms, respectively. However, the addition of SMB did not impact the concentrations of other mycotoxins in test diets. Mineral analyses showed considerable variation in sodium and sulfur content in experimental diets (Table 2-3), but in general, sodium and sulfur levels were higher in diets containing SMB, as expected.

During the trial period (d 0 to 27), there were no significant pellet × SMB interactions for growth performance or pig BW. Dietary DON levels of 3.3 mg/kg negatively impacted ($P < 0.001$) ADG and ADFI, but did not influence G:F; whereas pelleting the diet improved ($P < 0.001$) ADG and G:F without influencing ADFI. When SMB was added to the diet, pigs had increased (linear; $P < 0.03$) ADG and tended to have increased (linear; $P < 0.08$) ADFI, but had no impact on G:F. For pig BW, responses were consistent from d 7 through d 27 for DON and pelleting effects, with pigs fed DON-contaminated diets weighing less ($P < 0.001$) and pigs fed pelleted diets being heavier ($P < 0.001$). However, the effects of SMB on pig BW were non-significant on d 7, 14 and 21, but pigs fed diets containing SMB tended (linear; $P < 0.10$) to be heavier at the end of the trial.

Experiment 4

Mycotoxin analysis of the PC diets found no mycotoxin concentrations above the PQL. Although NC diets were formulated to contain 4.8 mg/kg DON based on the analysis of the contaminated DDGS (16.0 mg/kg), analyzed DON levels in NC diets averaged 3.4 mg/kg (Table 2-6). Nevertheless, these analyzed DON levels were adequate to cause an approximate 10% reduction in growth performance based on previous research. Interestingly, the treatment 7 diet, which contained 0.77% SMB, had a lower DON level at 1.6 mg/kg. This suggests that the conversion from DON to DON-S transformed over 50% of DON in the presence of SMB during the DDGS pelleting process. As in Exp. 3, the addition of SMB did not alter 15-ADON levels. For the mineral analyses, sodium and sulfur levels were relatively constant, except for treatment 7. In treatment 7, where no salt was added, analyzed sodium levels were slightly lower (0.23 vs.

0.29%) and sulfur levels were higher (0.57 vs. 0.44%) than pigs fed NC diets using the same DDGS.

Overall (d 0 to 21), there was a two-way interaction within NC diets where pelleting only the final diet improved G:F ($P < 0.04$) by a greater margin in high-DON diets than in treatments where the DDGS was pelleted, crumbled, and then re-pelleted in the final diet. No other 2-way interactions were detected for ADG, ADFI or BW. Pigs fed diets containing high DON (3.4 mg/kg average) had decreased ($P < 0.002$) ADG and ADFI and pig BW throughout the test period, but there were no differences in feed efficiency. Conversely, pigs fed pelleted diets had increased ($P < 0.01$) ADG, BW, and improved ($P < 0.001$) G:F. Throughout the trial period, pelleting the DDGS prior to final diet manufacturing (meal or pellet form) had no effect on growth performance or pig BW. Finally, the inclusion of SMB prior to pelleting DDGS and feeding diets in meal form increased ($P < 0.01$) ADG and ADFI; however, feed efficiency was not affected by the addition of SMB. Sodium metabisulfite inclusion did not affect pig BW at d 7, but incorporating SMB to negative control diets (meal form) prior to pelleting DDGS resulted in heavier ($P < 0.03$) pig BW at d 14 and d 21.

Discussion

Previous research has shown that DON, when combined with SMB or its aqueous form, sodium bisulfite, in a hydrothermal environment, is readily converted to DON-S in corn (Young 1986) and wheat (Dänicke et al., 2005). Using a combination of hydrophilic interaction chromatography and tandem-mass spectrometry, a more recent study by Beyer et al. (2010) verified that the decrease in DON concentration was directly correlated to an increase in DON-S. This conversion is especially important from a toxicological point of view, as Young et al. (1987) saw no acute toxic effects when DON-S was fed to pigs at levels equivalent to those of DON that eliciting emesis.

Young et al. (1987) showed that in an autoclave environment, DON levels in corn could be reduced using aqueous sodium bisulfite. Experiment 1 of the present study was completed to validate this research using naturally-contaminated DDGS and confirmed that DON concentrations could also be reduced by adding SMB in an autoclave. Compared to the results of Young et al. (1987), the level of reduction seen in the current study was comparable when no SMB was added (10 vs. 12%), and showed a similar decline with increasing SMB levels, with a

greater overall reduction at 5% SMB (81 vs 65%). Although SMB alone effectively detoxified a large proportion of DON, the addition of water further reduced DON levels with 5% SMB, suggesting that structural modification of the DON-molecule occurs more rapidly in the presence of water.

The variability in pig growth response to DON has previously been associated with the presence of additional tricothecenes. The compound 15-ADON, which differs from DON only by an acetyl group, is a common tricothecene in North America, usually present at 10 to 20% of DON. As a precursor in DON biosynthesis (Miller et al., 1983; Pestka et al., 1985), 15-ADON has been shown to be as toxic as DON both at the cellular level (Eriksen et al., 2004) and on pig performance (Pestka et al., 1987). In an autoclave, 15-ADON levels were reduced in the presence of SMB, but the extent of reduction was not as marked as for DON. However, autoclaving alone reduced 15-ADON by a greater extent than DON (27 vs. 10%) and the addition of water to 5% SMB elicited further reduction. Zearalenone was also present in the DDGS used in Exp. 1, but levels of zearalenone were not affected by autoclaving with SMB. While autoclaving DON-contaminated DDGS did reduce its concentration, pelleting alone did not alter DON or 15-ADON levels in naturally-contaminated DDGS, suggesting that the reductions seen in the autoclave may be related to the increased duration or the added heat present in the autoclave. Earlier research on the effects of hydrothermal treatment alone on DON have been inconclusive, as Dänicke et al. (2005) saw no effect in a laboratory conditioner at 100°C with naturally-contaminated wheat, but when DON-inoculated corn flour was cooked in an extruder (150°C, 15% moisture), DON was reduced by 98% (Cazzaniga et al., 2001). In Exp. 2, pelleting alone did not alter DON or 15-ADON levels in naturally contaminated DDGS, suggesting that reductions seen in the autoclave and previous extrusion research may be related to the length of treatment or the additional heat and moisture present. However, DON levels in pelleted DDGS decreased by approximately 50% with 1.0% SMB, and reduced further at higher levels, but the response seemed to plateau somewhere between 2.5 and 5.0% SMB. Although the two conditioning temperatures (61 and 82°C) did not significantly impact DON reduction, results suggest that at 82°C, DON levels were lower than at 61°C when intermediate levels of SMB were added. Dänicke et al. (2005) effectively reduced 7.5 mg/kg DON wheat to below 1 mg/kg within 3 minutes (the earliest data point) using a laboratory conditioner at 98 to 102°C with a 1.0% addition of SMB. Discovering that retention time did not influence DON reduction in the

present study, results of Dänicke et al. (2005) and Cazzaniga et al. (2001) suggest that if higher conditioning temperatures could be achieved in a pellet mill, further DON detoxification may take place. While DON was reduced to a greater extent during pelleting than in an autoclave, 15-ADON levels were not affected by pelleting with SMB, for reasons that remain unclear. A final consideration that needs to be taken into account is the release of sulfur dioxide gas when SMB is hydrothermally treated. When levels of 2.5% and 5.0% SMB were used, air quality in the feed mill was concerning such that safety goggles and respirators were worn by all personnel involved. Future research where SMB is hydrothermally treated should take this gaseous release into account.

Feeding DON-contaminated feedstuffs treated with SMB has improved piglet growth in previous studies (Young et al., 1987; Dänicke et al. 2005), but these studies used a limited number of animals. Yet, to the author's knowledge, the present study is the first to incorporate SMB in final diet manufacturing and to evaluate the effects of SMB and pelleting together on pig growth in a commercial environment. The present data is in agreement with Dänicke et al. (2005), who observed improvements in ADG and ADFI using a final dietary SMB concentration of 0.25%, but in the present study the improvement was more pronounced with 0.50% added SMB. While SMB improved nursery pig growth in both meal and pelleted form compared to NC pigs in Exp. 3, growth was not restored to levels of positive control. This may be attributed to the remaining DON levels in Exp. 3, as adding only 0.25% and 0.50% SMB to final diets did not reduce DON greatly. When these diets were pelleted, analyzed DON levels were decreased by 48% and 75%; but surprisingly, there were no two-way interactions with pelleting and SMB on piglet growth. These results may be related to when hydrothermal SMB treatment is applied, as in this experiment it was applied only to final diets. By contrast, both Young et al. (1987) and Dänicke et al. (2005) reduced DON by over 90% by treating only the contaminated grain, which in both cases resulted in growth performance that was similar to pigs fed uncontaminated grain. We hypothesize that there were additional factors that may have limited the effectiveness of SMB in Exp. 3, including any effects that SMB may have on diet palatability as well as the influence of higher levels of sulfur in the diet. However, in this experiment, pelleting alone improved ADG and G:F by 10 and 13%, which was higher than for pigs fed PC diets in meal form. These results suggest that pelleting DON-contaminated diets without SMB may be able offset DON-associated effects on performance.

Experiment 4 was designed to further validate the effect of pelleting DON-contaminated diets as well as to evaluate pelleting the contaminated DDGS with and without SMB as a potentially commercially-applicable rapid method for detoxifying DON. Although diets were formulated to contain higher levels of DON (5 mg/kg), due to what we conclude was an initial inaccurate analysis of the contaminated DDGS, dietary levels of DON averaged 3.4 mg/kg in NC diets, which was still sufficient to reduce pig growth rate by 11% and 7.5% for diets fed in meal and pellet form, respectively. As in previous research (Etienne and Waché, 2008) and Exp. 3 of the present study, the biggest reduction in performance due to DON was during the initial 7 day period (16%) although from d 7 to 21 pigs fed NC diets still grew 7% slower than pigs fed the PC. In accordance with the findings of Döll et al. (2007) and Trigo-Stockli et al. (2000) using DON-contaminated wheat, as well as the results of Exp. 2 and 3 of the present study, the pelleting process did not alter the concentration of DON in the feed. This was true whether the DON-contaminated DDGS were pelleted first and then re-ground and fed in either meal or pellet form, or if the pelleting occurred only in the final diet. Pelleting DON-contaminated diets did improve growth performance to the level of pigs fed uncontaminated diets in meal form, but there were no two-way interactions where pelleting affected the way piglets responded to diets containing DON. However, there was a two-way interaction for feed efficiency when high-DON DDGS were pelleted before adding to a meal diet, but not when added to a pelleted diet. Pigs fed DDGS that were crumbled back into a meal diet may have had enhanced feed efficiency from pelleting the DDGS, which could enhance nutrient digestibility. Additionally, Döll et al. (2007) suggested that because *Fusarium* infections in wheat causes other effects besides mycotoxin contamination, namely decreasing starch content (Matthäus et al., 2004), it is possible that altering the grain composition by pelleting could lead to differences in the effect of DON. Although the effects of DON-contamination on nutrient composition in DDGS were largely not considered in the present study, the lack of interaction for diet form and the inclusion of DON for both the DDGS alone and final diets make it unlikely that any variation in the effects of DON were related to changes in DDGS nutrient profile. In Exp. 4, SMB was added at a higher level (2.5%) than in Exp. 3, and was added prior to DDGS pelleting, rather than during final diet manufacturing. Final diet DON levels were decreased (3.4 vs. 1.6 mg/kg) in this experiment by using 2.5% SMB when pelleting the DDGS, but only by 53%, which is less than the 75% detoxification seen with 0.5% SMB in Exp. 3 and by 75% when 2.5% SMB was added in Exp. 2.

While the reason for the limited reduction is unknown, it may be an indicator that while pelleting with SMB can effectively reduce DON concentrations, there may be considerable variation in the extent of DON reduction that can take place in commercial pellet mills. Nevertheless, adding SMB prior to pelleting DDGS, re-grinding and offering in meal form resulted in a 6% improvement in piglet growth rate, which was similar to pigs fed PC diets in meal form.

This data shows that a large proportion of DON appeared to be detoxified into DON-S by pelleting the diet in the presence of SMB. This was indicated by both mycotoxin analysis as well as improvements in growth performance. In a similar study (Dänicke et al., 2005), blood serum DON levels were also used as an indicator for true DON detoxification. Although not analyzed in the present study, this reduction is an important indicator of the stability of the DON-S molecule, as it suggests that DON-S is not hydrolyzed back into DON during transit through the gastrointestinal tract. Young (1986) proved *in vitro* that DON-S is stable under acidic conditions but hydrolyzes back to DON under alkaline conditions, such as when sodium bicarbonate is added during the making of bakery products (Young et al., 1986). The acidic environment in the stomach should maintain DON-S stability, but the neutral or weak alkaline environment in the small intestine may elicit hydrolysis back to DON in certain conditions, although this was not seen by Dänicke et al. (2005). Additional research is needed to gain a better understanding of how DON-S is metabolized and absorbed in the pig.

The introduction of additional sulfite and sodium into pig diets is an additional consideration that must be taken into account when interpreting utilizing SMB. Although sodium levels were not balanced in Exp. 3, analyzed sodium content of the diets (Table 2-3) showed only minimal increases in total sodium level when 0.25 or 0.50% SMB was added to the diet. Interestingly, when diets were balanced for sodium level during Exp. 4, analyzed sodium levels were slightly lower (0.23 vs. 0.30%) in pigs fed diets with SMB compared to all other treatments. Nevertheless, this level is still above the 0.15% Na requirement of 10 to 20 kg pigs (NRC, 1998) therefore an influence of sodium on piglet performance in both studies appears to be unlikely in either study. Although not taken into account in the present growth experiments, the effect of additional sulfite in the diet when adding SMB is of greater concern. Til et al. (1972) conducted long-term studies on the toxicity of sulfite in pigs using SMB as the source, reporting that at 0.83 and 1.72% SMB, growth performance was reduced. It is also noteworthy that Til et al. (1972) reported rapid losses of sulfite when SMB was prepared in wet diets prior to

feeding. Sulfite has been shown to destroy thiamine (Hermus 1969; Joslyn and Leichter, 1968) and sulfur-induced thiamine deficiency has been implicated in reduced growth performance in pigs (Gibson et al., 1987). Although the previous studies were much longer in duration, additional research is needed to evaluate thiamine status of pigs fed diets using SMB for DON-detoxification in order to develop recommended feeding levels and duration of inclusion in swine diets. In the present study, analyzed sulfur content did not exceed 0.57%, which is likely insufficient to cause thiamine deficiency. However, high levels may affect feed intake, as Til et al. (1972) reported decreased feed intake due to palatability issues when 0.83% SMB was fed in a pair-feeding study. A similar decrease in ADFI was seen by Dänicke et al. (2005), but only in the pigs fed 2.5% SMB in uncontaminated wheat-based diets, whereas in a second experiment pigs fed uncontaminated wheat with 1.0% SMB performed similarly to controls. Although in the present study SMB was not added to PC diets, SMB levels in diets did not exceed 0.77%, therefore it is unlikely that SMB-related palatability-issues were a factor during the present study. However, based on the results of Dänicke et al. (2005) and Til et al. (1972), feeding levels above 1.0% SMB for short periods or above 0.83% over long periods with supplemental thiamine may result in growth performance reductions.

In conclusion, DON from naturally-contaminated DDGS can be greatly reduced when treated with SMB in a commercial pellet mill, although processing conditions have negligible influence on the level of DON detoxification. Adding 0.25 to 0.50% SMB to final diets improved growth performance in both meal and pelleted form. Pelleting 16 mg/kg DON-contaminated DDGS with SMB resulted in reductions in analyzed DON and, when fed at 30% of the diet prepared in meal form (3.4 mg/kg), pigs performed similarly to those fed uncontaminated diets. However, SMB did not affect other tricothecenes (15-ADON or zearalenone) present in naturally-contaminated DDGS and additional research needs to be conducted to evaluate the effects of SMB on sulfur-induced thiamin deficiency and palatability of diets. Overall, when feeding high-DON diets, the use of pelleting to improve feed efficiency can help reduce DON-related losses in growth performance. Furthermore, the inclusion of low levels of sodium metabisulfite combined with pelleting may serve as a management practice to utilize DON-contaminated feedstuffs without sacrificing growth performance.

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Figures and Tables

Table 2-1. Effects of sodium metabisulfite (SMB) on deoxynivalenol (DON) concentration in corn dried distillers grains with solubles (DDGS) within an autoclave, Exp. 1 (as-fed basis)[1]

		Mycotoxin, mg/kg[3]				
Sample	SMB[2], %	DON	15-ADON	Zearalenone	% DON remaining[4]	% 15-ADON remaining[4]
No	---	20.6	3.3	1.1	---	---
Yes	0	16.7	2.2	0.8	90.2	73.4
Yes	0.5	15.7	2.2	1.0	84.7	72.8
Yes	1.0	13.6	1.9	0.9	73.7	62.7
Yes	2.5	7.3	1.9	1.1	39.4	64.7
Yes	5.0	3.6	1.8	1.1	19.4	61.4
Yes + 10% water	5.0	1.2	1.5	1.1	6.6	50.6

[1] DDGS samples were autoclaved for 60 min at 121°C. After autoclaving, samples were dried in a 55°C drying oven. Mycotoxin analysis took place at the North Dakota State University Veterinary Diagnostic Laboratory (Fargo, ND) and used a combination of mass spectrometry, ELISA, and HPLC methods.
[2] Sodium metabisulfite (Samirian Chemicals, Campbell, CA); 100% by weight.
[3] Levels adjusted back to an as-fed basis (90.1% DM) after drying.
[4] Percentage of mycotoxin relative to amount prior to autoclaving.

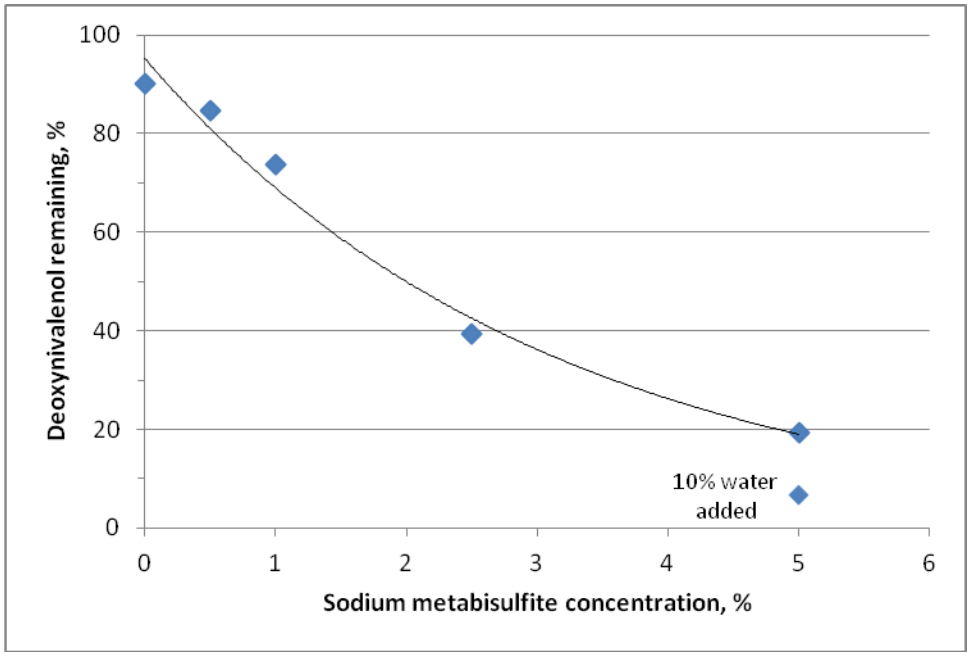

Figure 2-1 Dose-dependent deoxynivalenol reduction in corn dried distillers grains with solubles autoclaved for 60 min at 121°C in the presence of sodium metabisulfite (Exp. 1; $y = 95.224e^{-0.032x}$, $r^2 = 0.99$).

Table 2-2. Effect of pelleting temperature (Temp) and level of sodium metabisulfite (SMB) on deoxynivalenol (DON) and acetyl-DON in diets containing corn distillers dried grains with solubles (DDGS) naturally contaminated with DON, Exp. 2 (as-fed basis)[1]

		SMB, %					Probability, $P <$[2]		
Item, mg/kg[5]	Temp, ºC	0	1.0	2.5	5.0	SED[3]	Temp	Linear[4]	Quad[4]
DON[6]	66	20.5	10.2	5.6	3.3	1.29	0.15	0.001	0.001
	82	18.7	9.0	4.2	3.6				
15-ADON[6]	66	2.7	2.6	2.7	2.8	0.42	0.74	0.45	0.64
	82	2.8	2.5	2.8	3.0				

[1] No significant effect ($P > 0.40$) for retention time in pellet conditioner, thus data are not shown.
[2] No significant interactions ($P > 0.69$) between Temp × SMB.
[3] Standard error of the difference for the Temp × SMB interaction. For SED for effect of Temp and SMB multiply by 0.50 and 0.71, respectively.
[4] Linear and quadratic effects of SMB.
[5] Samples analyzed at North Dakota State University Veterinary Diagnostic Laboratory (Fargo, ND) using a variety of mass spectrometry, ELISA, and high-pressure liquid chromatography methods.
[6] DDGS batches, prior to pelleting averaged 20.5 and 3.0 mg/kg for DON and 15-ADON, respectively.

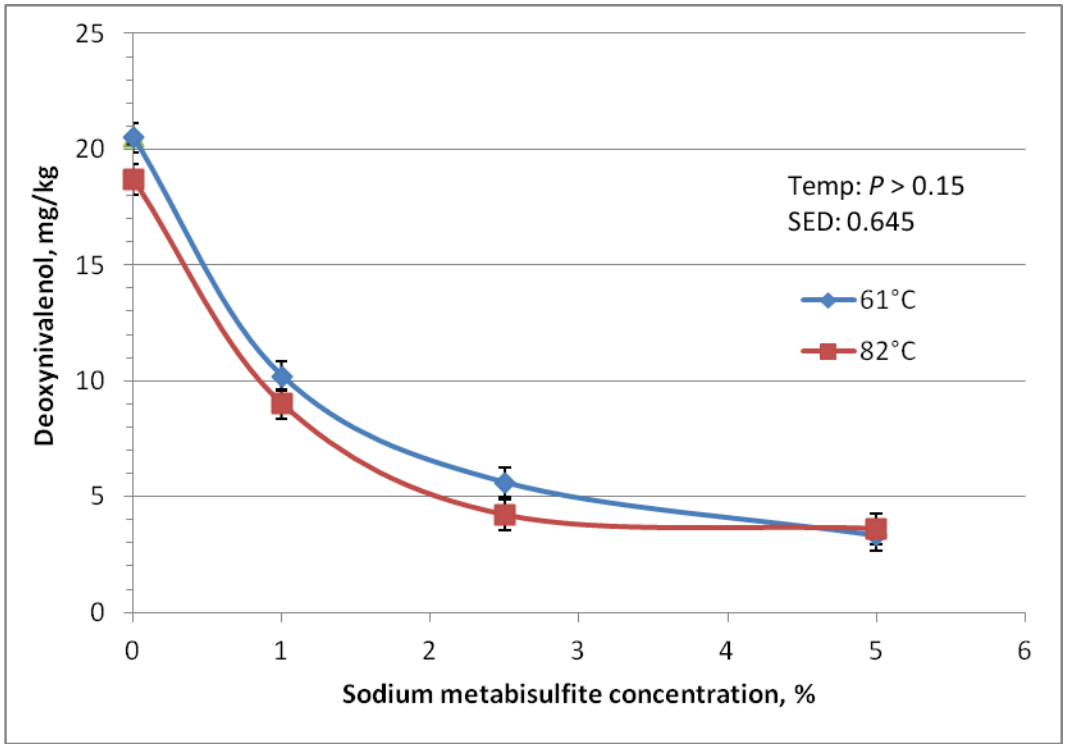

Figure 2-2. Dose-dependent deoxynivalenol reduction in corn dried distillers grains with solubles pelleted (61 and 82 °C conditioning temperature) in the presence of sodium metabisulfite (Exp. 2; DDGS prior to pelleting = 20.5 mg/kg DON).

Table 2-3. Mycotoxin and mineral analysis of diets, Exp. 3 (as-fed basis)

	DDGS source[1]		Experimental diets[1,2]						
			Positive Control	Negative Control		NC + 0.25% SMB[4]		NC + 0.50% SMB[4]	
Item	Control	High-DON[3]	Meal	Meal	Pellet	Meal	Pellet	Meal	Pellet
Mycotoxin, mg/kg									
DON	< 0.5	11.7	< 0.5	3.2	3.3	3.1	1.7	2.4	0.8
15-ADON	< 0.5	2.0	< 0.5	0.6	0.7	0.7	0.6	0.6	0.6
Total DON[5]	< 0.5	14.0	< 0.5	3.8	4.0	3.8	2.3	3.0	1.4
Zearalenone	< 0.5	2.0	< 0.5	0.5	0.5	0.5	0.5	0.5	0.5
Mineral, %[6]									
Na	---	---	0.24	0.28	0.37	0.32	0.30	0.36	0.37
S	---	---	0.41	0.38	0.56	0.45	0.44	0.56	0.56

[1] DDGS and diet samples were sent to the NDSU Veterinary Diagnostic Laboratory, Fargo, ND for a full 17-component toxin screen. Samples were analyzed using a variety of mass spectrometry, ELISA, and high-pressure liquid chromatography methods with a practical quantitation limit of 0.5 mg/kg.

[2] Positive control diet formulated to contain < 0.5 mg/kg DON and all remaining diets formulated to contain 3 mg/kg DON.

[3] High-deoxynivalenol (DON) DDGS were analyzed with both an ELISA test kit (8.9 mg/kg) and at NDSU (14.4 mg/kg). Levels were averaged due to variability.

[4] Sodium metabisulfite (Samirian Chemical, Campbell, CA).

[5] Total DON reported as a combination of DON and 15-ADON, as both DON metabolites have similar toxicity (Pestka, 1987).

[6] Mineral analyses were conducted at MVTL Labs (New Ulm, MN).

Table 2-4. Composition of experimental diets, Exp. 3 (as-fed basis)

Item	Positive control	Negative control	NC + 0.25% SMB[1]	NC + 0.50% SMB[1]
Ingredient, %				
Corn	45.33	45.33	44.84	44.33
DDGS, 26.3% CP	25.00	---	---	---
Contaminated DDGS, 26.0% CP	---	25.00	25.00	25.00
Soybean meal, 46.5% CP	24.90	24.90	24.95	25.00
Choice white grease	1.30	1.30	1.50	1.70
Limestone	1.10	1.10	1.10	1.10
Salt	0.45	0.45	0.45	0.45
Monocalcium phosphate, 21% P	0.55	0.55	0.55	0.55
Trace mineral premix[2]	0.08	0.08	0.08	0.08
Copper sulfate	0.07	0.07	0.07	0.07
Selenium	0.05	0.05	0.05	0.05
Vitamin premix[3]	0.03	0.03	0.03	0.03
L-Lys HCl	0.46	0.46	0.46	0.46
Methionine hydroxy analog	0.12	0.11	0.11	0.11
L-Thr	0.07	0.07	0.07	0.07
Medication[4]	0.40	0.40	0.40	0.40
Mold inhibitor[5]	0.10	0.10	0.10	0.10
Phytase[6]	0.04	0.04	0.04	0.04
Sodium metabisulfite	---	---	0.25	0.50
TOTAL	100	100	100	100
Calculated analysis				
SID[7] amino acids, %				
Lys	1.20	1.20	1.20	1.20
Ile:Lys	61	61	61	61
Leu:Lys	145	144	143	143
Met:Lys	34	34	34	34
Met & Cys:Lys	58	58	58	58
Thr:Lys	60	60	60	60
Trp:Lys	17.5	17.5	17.5	17.5
Val:Lys	72	72	72	72
Total Lys, %	1.39	1.39	1.39	1.39
ME, kcal/kg	3,307	3,307	3,307	3,307
SID Lys:ME, g/Mcal	3.63	3.63	3.63	3.63
CP, %	21.80	21.80	21.79	21.78

Ca, %	0.66	0.66	0.66	0.66
P, %	0.58	0.58	0.58	0.58
Available P, %	0.30	0.31	0.31	0.31
Na, %	0.25	0.25	0.31	0.37
Cl, %	0.43	0.43	0.43	0.43
Added S, %[8]	---	---	0.08	0.16

[1] Sodium metabisulfite (Samirian Chemicals, Campbell, CA).

[2] Trace mineral premix provided per kg of premix: 13.3 mg of Cu, 1.40 mg of I, 134 mg of Fe, 53.3 mg of Mn, and 160 mg of Zn.

[3] Vitamin premix provided per kg of premix: 22,046,000 IU of vitamin A, 5,291,000 IU of vitamin D_3, 97,002 IU of vitamin E, 10,288 mg of vitamin K, 88.2 mg of vitamin B_{12}, 79,366 mg of niacin, 61.7 mg of pantothenic acid, and 13,228 mg of riboflavin.

[4] To provide chlortetracycline at 441g/t.

[5] Ammo Curb (Kemin Industries, Des Moines, IA).

[6] Phyzyme 2500 (Danisco Animal Nutrition, St. Louis, MO).

[7] Standardized ileal digestible.

[8] Originating from sodium metabisulfite ($Na_2S_2O_5$) which is 33% sulfur.

Table 2-5. Effects of pelleting and sodium metabisulfite (SMB) on growth performance of nursery pigs fed deoxynivalenol (DON)-contaminated diets, Exp. 3[1]

		Negative control diets (NC; 3 mg/kg DON)[2]							Probability, *P* <				
	Positive Control	NC		NC + 0.25% SMB[3]		NC + 0.50% SMB[3]			Pellet ×		Pellet vs.	SMB effect	
Diet form:	Meal	Meal	Pellet	Meal	Pellet	Meal	Pellet	SEM	SMB[4]	DON	meal	Linear	Quad
d 0 to 27													
ADG, g	652	596	663	607	675	615	681	10.0	1.00	0.001	0.001	0.03	0.76
ADFI, g	1,078	988	1,006	1,013	1,017	1,020	1,025	18.6	0.87	0.001	0.43	0.08	0.68
G:F	0.605	0.604	0.659	0.600	0.664	0.603	0.665	0.007	0.74	0.89	0.001	0.67	0.86
Pig BW, kg													
d 0	13.07	13.04	13.08	13.03	12.97	13.02	13.04	0.212	0.59	0.68	0.97	0.61	0.33
d 7	16.62	15.85	16.44	15.98	16.38	15.91	16.51	0.241	0.62	0.001	0.001	0.55	0.99
d 14	21.28	20.06	20.98	20.32	21.04	20.42	21.09	0.292	0.72	0.001	0.001	0.15	0.76
d 21	26.07	24.85	26.04	25.21	26.16	24.90	26.34	0.327	0.44	0.001	0.001	0.35	0.35
d 27	30.67	29.26	31.17	29.53	31.19	29.63	31.55	0.386	0.79	0.001	0.001	0.10	0.83

[1] A total of 987 mixed sex pigs (initially 13.0 ± 0.2 kg BW) were used in a 27 d experiment with 5 replicate pens per treatment and 28 pigs per pen.
[2] Analyzed mycotoxin levels in negative control diets averaged: 3.3 mg/kg DON, 0.7 mg/kg 15-ADON, and 0.5 mg/kg zearalenone.
[3] Sodium metabisulfite (Samirian Chemicals, Campbell, CA).
[4] Each contrast compared the following treatments: 1) "Pellet × SMB" evaluated the 2-way interaction between pelleting diets and adding SMB in the 6 NC treatments; 2) "DON" compared positive control to negative control (NC), both meal and pellet form; 3) "Pellet vs. Meal" compared final diet form in treatments 2 to 7; and 4) "SMB effect" compared the linear and quadratic effects of adding increasing levels of SMB in treatments 2 to 7.

Table 2-6. Mycotoxin and mineral analysis of diets, Exp. 4 (as-fed basis)

	DDGS source[1]		Experimental diets[1,2]						
			Positive control		Negative control		NC + crumbled DDGS[3]		NC + crumbled DDGS w/ SMB[4]
Item	Control	High-DON	Meal	Pellet	Meal	Pellet	Meal	Pellet	Meal
Mycotoxin, mg/kg									
DON	< 0.5	16.0	< 0.5	< 0.5	3.5	3.3	3.4	3.5	1.6
15-ADON	< 0.5	2.2	< 0.5	< 0.5	0.6	0.6	0.6	0.6	0.6
Total DON	< 0.5	18.2	< 0.5	< 0.5	4.1	3.9	4.0	4.1	2.2
Zearalenone	< 0.5	1.20	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Mineral, %									
Na	---	---	0.28	0.34	0.29	0.29	0.28	0.31	0.23
S	---	---	0.39	0.46	0.43	0.43	0.43	0.46	0.57

[1] DDGS and diet samples were sent to the NDSU Veterinary Diagnostic Laboratory, Fargo, ND for a full 17-component toxin screen. Samples were analyzed using a variety of mass spectrometry, ELISA, and high-pressure liquid chromatography methods with a practical quantitation limit of 0.5 mg/kg.

[2] Positive control diet formulated to contain < 0.5 mg/kg DON and all remaining diets formulated to contain 5 mg/kg DON.

[3] DDGS was pelleted, then crumbled before being added back to final diet to prevent segregation.

[4] Sodium metabisulfite (Samirian Chemicals, Campbell, CA) was added to DDGS at 2.5% prior to pelleting and crumbling into final diet. Final diet contained 0.77 % SMB.

Table 2-7. Composition of experimental diets, Exp. 4 (as-fed basis)

Item	Positive control	Negative control	NC crumbled[1]	NC crumbled w/SMB[2]
Ingredient, %				
Corn	41.36	41.36	41.36	40.44
DDGS, 26.3% CP	30.00	---	---	---
Contaminated DDGS, 26.0% CP	---	30.00	30.00	31.00
Soybean meal, 46.5% CP	24.15	23.95	23.95	24.00
Choice white grease	1.30	1.30	1.30	1.60
Limestone	1.10	1.10	1.10	1.10
Salt	0.43	0.43	0.43	---
Monocalcium phosphate, 21% P	0.45	0.45	0.45	0.45
Trace mineral premix[3]	0.08	0.08	0.08	0.08
Copper sulfate	0.07	0.07	0.07	0.07
Selenium	0.05	0.05	0.05	0.05
Vitamin premix[4]	0.03	0.03	0.03	0.03
L-Lys HCl	0.46	0.46	0.46	0.46
Methionine hydroxy analog	0.12	0.11	0.11	0.11
L-Thr	0.07	0.07	0.07	0.07
Medication[5]	0.40	0.40	0.40	0.40
Mold inhibitor[6]	0.10	0.10	0.10	0.10
Phytase[7]	0.04	0.04	0.04	0.04
TOTAL	100	100	100	100
Calculated analysis				
SID[8] amino acids, %				
Lys	1.20	1.20	1.20	1.20
Ile:Lys	61	61	61	61
Leu:Lys	147	148	148	148
Met:Lys	34	34	34	34
Met & Cys:Lys	58	58	58	58
Thr:Lys	60	60	60	60
Trp:Lys	17.5	17.5	17.5	17.5
Val:Lys	73	73	73	73
Total Lys, %	1.40	1.40	1.40	1.40
ME, kcal/kg	3,307	3,307	3,307	3,307
SID Lys:ME, g/Mcal	3.63	3.63	3.63	3.63
CP, %	22.3	22.4	22.4	22.4
Ca, %	0.66	0.66	0.66	0.66
P, %	0.57	0.58	0.58	0.58

Available P, %	0.30	0.31	0.31	0.31
Na, %	0.25	0.25	0.25	0.30
Cl, %	0.43	0.43	0.43	0.17
Added S, %[9]	---	---	---	0.25

[1] DDGS (dried distillers grains with solubles) were pelleted, then crumbled and added back to final diet to prevent segregation.

[2] Sodium metabisulfite (Samirian Chemicals, Campbell, CA); added to contaminated DDGS at 2.5% prior to pelleting and crumbling. SMB level of 0.77% in final diet.

[3] Trace mineral premix provided per kg of premix: 13.3 mg of Cu, 1.40 mg of I, 134 mg of Fe, 53.3 mg of Mn, and 160 mg of Zn.

[4] Vitamin premix provided per kg of premix: 22,046,000 IU of vitamin A, 5,291,000 IU of vitamin D_3, 97,002 IU of vitamin E, 10,288 mg of vitamin K, 88.2 mg of vitamin B_{12}, 79,366 mg of niacin, 61.7 mg of pantothenic acid, and 13,228 mg of riboflavin.

[5] To provide chlortetracycline at 441g/t.

[6] Ammo Curb (Kemin Industries, Des Moines, IA).

[7] Phyzyme 2500 (Danisco Animal Nutrition, St. Louis, MO).

[8] Standardized ileal digestible.

[9] Originating from sodium metabisulfite ($Na_2S_2O_5$) which is 33% sulfur.

Table 2-8. Effects of pelleting, dried distillers grains with solubles (DDGS) source, and sodium metabisulfite (SMB) on growth performance of nursery pigs fed deoxynivalenol (DON)-containing diets, Exp. 4[1]

	Positive control		Negative control[2]		NC + crumbled DDGS[3]		NC + crumbled DDGS w/ SMB[4]		Probability, $P <$				
Diet form:	Meal	Pellet	Meal	Pellet	Meal	Pellet	Meal	SEM	Pellet × DDGS	DON	Pellet vs. meal	Pelleting DDGS	SMB
d 0 to 21													
ADG, g	584	628	520	582	543	581	577	10.5	0.15	0.001	0.001	0.21	0.01
ADFI, g	881	875	791	801	799	807	848	18.0	0.94	0.001	0.68	0.55	0.01
G:F	0.664	0.718	0.657	0.729	0.680	0.720	0.681	0.020	0.04	0.45	0.001	0.33	0.95
Pig BW kg													
d 0	11.21	11.22	11.14	11.19	11.12	11.15	11.24	0.317	0.97	0.65	0.84	0.86	0.60
d 7	14.50	14.68	13.74	14.37	13.73	14.20	14.15	0.267	0.70	0.002	0.01	0.67	0.15
d 14	17.98	18.45	16.84	17.92	16.92	17.62	17.66	0.358	0.41	0.001	0.001	0.63	0.03
d 21	22.63	23.51	21.27	22.54	21.62	22.50	22.59	0.455	0.47	0.001	0.001	0.58	0.01

[1] A total of 1,180 mixed sex pigs (initially 11.2 ± 0.3 kg BW) were used in a 21-d study conducted concurrently at Kansas State University Swine Teaching and Research Center (Manhattan, KS) and New Fashion Pork Research Nursery (Buffalo Center, IA). At each location, there were 5 replicate pens per treatment with 7 and 28 pigs per pen, respectively.

[2] Analyzed mycotoxin levels in negative control diets averaged: 3.4 mg/kg DON and 0.6 mg/kg 15-ADON.

[3] DDGS was pelleted, then crumbled and added back to final diet to prevent segregation.

[4] Sodium metabisulfite (Samirian Chemicals, Campbell, CA) was added to DDGS at 2.5% prior to pelleting and crumbling into final diet. Final diet contained 0.77 % SMB.

[5] Each contrast compared the following treatments: 1) "Pellet × DDGS" evaluated the 2-way interaction between pelleting DDGS and pelleting final diets in the 4 NC treatments; 2) "DON" compared positive control to negative control (NC) without crumbling, both meal and pellet form; 3) "Pellet vs. Meal" compared final diet form in the first 6 treatments; 4) "Pelleting DDGS" compared the effect of pelleting DDGS and crumbling before final diet manufacturing in the 4 NC treatments; 5) "SMB" compared treatment 5 to treatment 7, where NC DDGS were pelleted, crumbled, and fed in meal form, isolating the effect of adding SMB.

Chapter 3 - Effects of pre-slaughter feed-withdrawal time on finishing-pig carcass characteristics and economic return in a commercial environment

Abstract

The effects of feed-withdrawal time before slaughter on finishing-pig carcass composition and net returns were evaluated in 2 studies. In Exp. 1, 728 pigs (BW = 128.9 ± 1.2 kg) were used in a completely randomized design with 12 replicates per treatment. The 4 treatments were feed withdrawal times of 8, 24, 36, or 48 h. Pigs were fed a common corn-soybean meal diet containing dried distillers grains with solubles (DDGS), bakery co-products, and 5.0 mg/kg ractopamine HCl. Feed withdrawal time decreased (linear; $P < 0.02$) feed intake per pig, live weight, HCW, and backfat while increasing percentage yield (quadratic; $P < 0.01$), fat-free-lean-index (FFLI; linear; $P < 0.001$), and overall carcass price (linear; $P < 0.001$). These results were due in part to a tendency for increased (linear; $P < 0.07$) premiums and decreased (linear; $P < 0.01$) weight discounts. Withholding feed decreased (linear; $P < 0.001$) feed intake. In Exp. 2, 843 pigs (BW = 125.4 ± 1.6 kg) were used to determine the impact of feed withdrawal on growth, carcass, blood lactate, and meat quality. There were 4 treatments: withholding feed for 8, 12, 24, or 36 h with 10 replicates per treatment. Pigs were fed a common corn-soybean meal-based diet containing 20% DDGS and 5.0 mg/kg ractopamine HCl. Withholding feed decreased (linear; $P < 0.001$) live weight, ultimately resulting in decreased ($P < 0.01$) HCW. There were no differences in FFLI or backfat, but percentage yield (linear; $P < 0.001$) increased with longer withdrawal times. Carcass contaminations by leaking gastrointestinal (leaking ingesta) or fecal (runny bung) contents were also measured. Although withholding feed did not affect runny bung, it did increase (linear; $P < 0.001$) the incidence of leaking ingesta; whereas blood lactate, visual color score, and purge loss were not affected. However, withholding feed increased 45 min pH (quadratic; $P > 0.02$), ultimate pH (linear; $P < 0.01$), and increased (quadratic; $P < 0.03$) visual marbling score. Withholding feed before slaughter increased (quadratic; $P < 0.05$) carcass price and while premiums were similar, sort weight discounts decreased (quadratic; $P < 0.05$). Gross and net revenue received were similar, but withholding

feed decreased (linear; $P < 0.001$) feed intake, resulting in feed savings of up to 3 kg/pig. Overall, 24 to 36 h of feed withdrawal can be used to avoid weight discounts for overweight pigs without negatively impacting carcass composition and maintaining overall revenue.

Keywords: carcass, economics, fasting**,** feed withdrawal, swine

Introduction

Finishing pigs typically experience a period of feed deprivation during transport and lairage. Feed withdrawal prior to transportation for slaughter inherently reduces feed intake and thereby increases feed savings (Kephart and Mills, 2005). Furthermore, pigs with a full stomach are more difficult to handle (Eikelenboom et al., 1991) and are more likely to experience transport sickness (Bradshaw et al., 1996). Fasting also reduces gut fill which decreases the likelihood of carcass contamination by inadvertently lacerating the gastrointestinal tract during evisceration (Eikelenboom et al. 1991, Miller et al., 1997) and ultimately reduces waste at the abattoir (Eikelenboom et al., 1991). Furthermore, withholding feed before slaughter has been shown to impact pork quality by reducing muscle glycogen levels at the time of exsanguination, leading to a higher ultimate pH (Warriss and Brown, 1983), lower drip loss (Eikelenboom et al., 1991), and consequently lower incidence of pale, soft and exudative (PSE) pork (Murray and Jones, 1994).

However, extended periods (> 24 h) of feed restriction can increase pig aggression (Kelley et al., 1980) and skin and carcass damage (Brown et al., 1999). Extending feed restriction beyond 18 h may also reduce carcass weight (Saffle and Cole, 1960; Warriss and Brown, 1983) and increase the incidence of dark, firm and dry (DFD) pork (Guardia et al., 2009). Due to the potentially deleterious effects of long withdrawal, recommended times prior to slaughter currently range from 8 to 24 h (Eikelenboom et al., 1991; Warriss, 1994). However, little work has evaluated the economic implications of increasing feed withdrawal prior to slaughter, particularly pigs that may exceed the desired weight for processors. Therefore, the primary objectives of this study were to examine the effect of feed withdrawal on finishing pig carcass composition, feed savings, blood lactate, runny bung, leaking digesta, loin quality, and overall economic returns.

Materials and Methods

General

All practices and procedures used in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. Both trials were conducted at commercial research finishing facilities in southwestern Minnesota. These facilities were double curtain-sided with completely slatted flooring and deep pits for manure storage. The research barn contained 48 pens (3.05 × 5.49 m) equipped with a 5-hole conventional dry feeder (STACO, Inc., Schaefferstown, PA) and a cup waterer which afforded ad libitum consumption of feed and water. In both experiments, an automated feeding system (FEEDPro; Feedlogic Corp., Willmar, MN) was used to deliver and record feeding amounts on an individual pen basis. All complete diets, ground corn, and supplements were manufactured at the New Horizons Feed Mill (Pipestone, MN) and were formulated to meet or exceed all requirement estimates (NRC, 1998).

In both experiments, pigs were transported (approximately 95 km) for slaughter to a commercial abattoir (JBS Swift and Company; Worthington, MN). The transit time was approximately 2 h and this time period was included in the respective treatment durations in both experiments. Pigs were individually tattooed according to pen number to allow for data retrieval by pen and carcass data collection at the abattoir. The abattoir had an average line speed of 1,090 animals per h. All animals were rendered irreversibly unconscious using 90% CO_2 exposure in a dip-lift system for a minimum of 3 min per animal. Hot carcass weights (HCW) were measured immediately after evisceration and each carcass was evaluated for percentage yield, backfat and loin depth. Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the abattoir. Fat depth and loin depth were measured with an optical probe (SFK; Herlev, Denmark) inserted between the 3rd and 4th ribs located anterior to the last rib at a distance approximately 7.1 cm from the dorsal midline. Fat-free lean index (FFLI) was calculated using NPPC (2000) guidelines for carcasses measured with the Fat-O-Meater such that FFLI = ((15.31 + (0.51 × HCW, lb) – (31.277 × last rib fat thickness, in.) + (3.813 × loin muscle depth, in.))/HCW, lb. Grade premiums and sort loss discounts were also calculated to accurately determine the net revenue generated per pig.

The economic implications of feed withdrawal time were determined using $1.99/kg as the carcass price. Gross revenue was influenced by sort loss discounts and grade premiums

assigned on a per pig basis by the abattoir based on a pricing matrix calculated using HCW and lean meat yield. Feed intake was also recorded during the 48 h period prior to slaughter. Feed costs per treatment were then calculated using a diet cost of $0.33/kg. Net revenue per pig was derived by subtracting feed cost from gross revenue. All monetary values used are expressed in USD.

Experiment 1

A total of 728 mixed-sex pigs (337 × 1050; PIC, Hendersonville, TN; and initially 128.9 ± 1.2 kg BW) were used with 10 to 19 pigs per pen and 12 replicate pens per treatment in a completely randomized design. Pens were ranked by mean pig BW and then treatments allotted to each of 48 pens, with pigs per pen and location within the barn balanced across treatment. Pens were mixed gender and had ad libitum access to water throughout the experiment.

Experimental treatments were designed to reflect the amount of time that pigs had feed removed prior to exsanguination. The four treatments were: 1) feed access up until point of loading on the day of slaughter (8 h); 2) 24-h feed withdrawal; 3) 36-h feed withdrawal, and 4) 48-h feed withdrawal. A common complete diet containing 5 mg/kg ractopamine HCl (RAC; Paylean, Elanco Animal Health, Greenfield, IN) was fed throughout the experiment. The diet was corn-soybean meal-based, containing dried distillers grains with solubles (DDGS) and bakery co-products (Table 3-1). Before allotment, the heaviest pigs and underweight or cull pigs were removed from each pen according to the farm's normal marketing procedure. Pigs were initially weighed by pen at 52 h before exsanguination to allow time for allotment before the application of the 48-h treatment (Table 3-2). At this time, feed amounts in each feeder were recorded. The FEEDPro system recorded any additional feed delivered to each pen during the experiment. When treatments were applied, feeders were shut off, cleaned, and remaining feed recorded for calculation of feed intake during the test period. Pigs were also weighed by pen immediately before loading for transport to the abattoir.

To eliminate transportation effects, the 3 trucks were loaded so that a balanced number of pens per treatment were included on each truck. Duration from the beginning of load-out, which started at 0900, until the first pig was exsanguinated was approximately 8 h. This included approximately 4 h for load-out and transit and approximately 4 h of lairage. Upon arrival at the

slaughter plant, pigs were again weighed by pen. During lairage, pigs had ad libitum access to water but not feed.

Experiment 2

A total of 843 mixed-sex pigs (1050; PIC, Hendersonville, TN; initially 125.4 ± 1.6 kg BW) were used with 16 to 26 pigs per pen and 10 replicate pens per treatment in a randomized complete block design. Pens were ranked by mean pig BW and pigs were allotted to each of 40 pens with pigs per pen balanced across treatment. Four experimental treatments were used: 1) feed access until the point of loading on the day of slaughter (8 h), 2) 12-h feed withdrawal, 3) 24-h feed withdrawal, and 4) 36-h feed withdrawal. Pigs were initially weighed by pen 42 h before exsanguination to allow time for allotment before the application of the 36-h treatment (Table 3-4). At this time, feed amounts in each feeder were recorded. The FEEDPro system recorded any additional feed delivered to each pen during the experiment. Treatments were applied and pigs were weighed and loaded as in Exp. 1.

Before allotment, the heaviest pigs and underweight or cull pigs (determined visually) were removed from each pen according to the farm's normal marketing procedure. A common corn-soybean meal-based diet contained 20% DDGS diet containing 5 mg/kg RAC was fed throughout the experiment. Ad libitum access to feed and water was provided.

To eliminate any transportation effects, pigs were loaded onto four commercial swine transport trailers so that a balanced number of pens per treatment were included on each truck. Load-out began at 0300 and concluded at approximately 0500, with all trucks arriving at the plant before 0800. Actual time when the first pig was exsanguinated was 1205. Mean time between load-out and slaughter was 8 h across treatments. Upon arrival at the abattoir, pigs were again weighed by pen. During lairage, pigs had access to water but not feed.

Although 843 pigs and 10 replicate pens per treatment were initially allotted to this experiment, data were recovered from only 25 pens (543 pigs, initially 125.2 ± 1.5 kg BW) as a result of pig misidentification at the abattoir.

Intestinal Evaluation

Runny bung and leaking ingesta were also evaluated in Exp. 2 due to concerns of a relationship with feed withdrawal. Runny bung was defined as visible contamination of the

exterior of the carcass from feces and leaking ingesta defined as stomach contents escaping from the oral cavity after being suspended by the calcaneal tendon after exsanguination. Both measurements were determined visually at the inspection station by trained plant personnel on a per-pig basis (yes or no), collected and recorded as overall percentage prevalence per pen (Table 3-4).

Lactate and Meat Quality Analyses

In Exp. 2, a subsample of two barrows per pen (n=96) were selected to represent the approximate median BW per pen and were individually identified with a unique tattoo and ear tag in order to collect blood lactate (LAC) measurements and meat quality characteristics (Table 3-5). These animals were sampled for blood lactate levels at two different time points during the marketing process: 1) post-loading and 2) exsanguination.

During loading, pigs were moved between 15 and 77 m down a 0.9 m wide alleyway, depending on pen location, by farm personnel and researchers. The portable loading ramp used was 0.95 m wide and the ramp was at a 16° incline. Electric prods were used when necessary while pigs were entering and moving up the loading chute. These pigs were loaded into two separate compartments on the first truck in order to collect LAC and prevent mixing with the remainder of the trial pigs. Once the subsample of 96 barrows were loaded onto the first truck and prior to the remaining compartments being loaded, researchers entered the trailer in order to collect the post-loading blood sample for LAC analysis. Sorting boards were used to segregate pigs for blood collection, but no physical restraint methods were used. Blood lactate collection was conducted according to Edwards et al. (2010). The animal's distal ear vein was pricked using a retractable 20 gauge needle. Afterward, a sample strip was inserted into a hand-held lactate analyzer (Lactate Scout, EKF Diagnostic GmbH, Magdeburg, Germany) and a drop of blood from the animal's ear was immediately administered to the sample strip. The analyzer provided LAC in approximately 15 s and the results were recorded. Upon arrival at the abattoir, the trucker and plant personnel unloaded all animals and the 96 barrows for meat quality analysis were housed in a single lairage pen independently from other pigs.

The second blood sample was collected within 10 s of exsanguination where blood was collected in potassium oxalate sodium fluoride tubes which were then sealed and placed on ice until all 96 barrows were slaughtered. Immediately after collection, samples were analyzed with the hand-held lactate analyzer used for the post-loading LAC sample. Prior to data collection at

both time points, hand-held lactate analyzers were tested using a standard solution to ensure accuracy (CV 6.0%).

For meat quality analyses, the left side of the carcass was used throughout the trial. All pH measurements were recorded using a pH meter (Model 9025, Hanna Instruments, Smithfield, RI) with a glass tip probe. The pH measurements were taken at three time points to evaluate the pH decline post-slaughter: 45 min, 3 h, and 21 h. At each time point the probe was inserted into the *longissimus thoracis* (LT) between the 10^{th} and 11^{th} rib. Approximately 24 h postmortem, carcasses were fabricated for sample collection and additional analysis. A 40 cm section of the LT was removed from the posterior end of the loin, individually labeled, and allowed to bloom for 30 minutes. After blooming, subjective color and marbling score were determined by a trained evaluator using the 1 to 6 scoring system for color and 1 to 10 scoring system for marbling (NPPC, 2000). The LT was subsequently vacuum-packaged and transported on ice to the Kansas State University Meats Laboratory for subsequent analysis. Samples were stored at 4° C and aged for 10 d post-slaughter. At that time, ultimate pH was recorded by placing the probe into the LT at a central position across the sirloin face. Purge loss was measured by initially weighing the packaged LT, then removing the packaging and pat drying both the packaging and the LT sample. After weighing the dried package and LT sample, purge loss was calculated as a percentage of the original LT weight. After pH and color analyses, LT samples were repackaged and frozen at -80°C.

Statistical Analysis

In both experiments, pen was used as the experimental unit for growth, carcass and economic analyses. In Exp. 1, data were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Inst., Inc., Cary, NC). Experiment 2 was arranged in a randomized complete block design (RCBD) with previous treatment as the blocking factor. The statistical model included the fixed effect of withdrawal treatment with block as the random component. In Exp. 2, the misidentification of several pens at the abattoir resulted in variation in initial pig BW. To eliminate this potential treatment bias at the onset of the trial, initial pig BW was used as a covariate for growth and HCW. In both experiments, HCW was used as a covariate for fat depth, loin depth, and FFLI. For the subsample of barrows in Exp. 2, treatments were also arranged in an RCBD, as in the overall experiment. The PROC MIXED procedure was

used to analyze meat quality parameters and both block and pen were evaluated as random effects. For both experiments, means were evaluated using linear and quadratic CONTRAST statements in SAS. The coefficients for the unequally spaced linear and quadratic contrasts were derived using the PROC IML procedure in SAS. Least square means were calculated for each independent variable. Results were considered to be significant if *P*-values were ≤ 0.05 and considered tendencies if *P*-values were ≤ 0.10.

Results

Experiment 1

Pigs that experienced increased periods of pre-slaughter feed withdrawal had decreased live weight at load-out (linear; $P < 0.001$) and at the abattoir (linear; $P < 0.001$), resulting in a greater amount of weight change (quadratic; $P < 0.001$) most drastically seen after 24 h of feed withdrawal. For carcass characteristics, pigs fasted for increasing lengths of time had lighter (linear; $P < 0.02$) HCW than control pigs subjected to normal transit and lairage times (8 h) from this location. Increased withdrawal time also increased (quadratic; $P < 0.001$) percentage yield. Extending feed withdrawal times also increased FFLI (linear; $P < 0.001$) and decreased (linear; $P < 0.01$) backfat depth, but had no effect ($P > 0.35$) on loin depth.

Regarding economics (Table 3-3), extending feed restriction beyond 8 h resulted in higher (linear; $P < 0.001$) overall carcass price. Pigs withheld from feed also tended to receive more premiums (linear; $P < 0.08$) per pig and had as much as $2.20 per pig less sort loss discounts (linear; $P < 0.01$). However, there was no effect ($P > 0.32$) on gross revenue received per pig because of the reduction in live and HCW in pigs fasted longer than 24 h. Withholding feed decreased (quadratic; $P < 0.001$) feed intake per pig marketed, resulting in increased (quadratic; $P < 0.001$) feed savings of over 5 kg per pig from 8 to 48 h. Although these feed savings did not translate into an effect ($P > 0.70$) on net revenue received per pig, withholding feed for 24 h did result in a numeric increase in net revenue of $1.51 more per pig than those with feed access until loading.

Experiment 2

Although 843 pigs and 10 replicate pens per treatment were initially allotted to this experiment, data were recovered from only 25 pens (543 pigs, initially 276.0 ± 3.3 lb BW) as a

result of pig misidentification at the packing plant. Of the original 10 replicates per treatment, there was complete data on 7 pens from the 8-h control group, 7 pens from the 12-h treatment, 6 pens from the 24-h group, and 5 pens from the 36-h treatment. Therefore, the on-farm live BW and feed intake data also reflect only the 25 pens where carcass data was obtained.

There were no differences ($P > 0.25$) in d 0 BW across treatment for the remaining pens at allotment. As in Exp. 1, increased duration of feed withdrawal decreased (linear; $P < 0.001$) live weights at load-out and upon arrival at the abattoir, and overall live BW change was thereby reduced (linear; $P < 0.001$) by increased feed withdrawal time. Furthermore, the reduction in live BW by increased feed withdrawal ultimately resulted in decreased (linear; $P < 0.01$) HCW and increased (linear; $P < 0.001$) percentage yield. Additionally, in contrast to results seen in Exp. 1, there were no differences ($P > 0.42$) in FFLI, or backfat depth. As in Exp. 1, there were also no differences ($P > 0.53$) in loin depth.

The prevalence of runny bung within each pen was similar ($P > 0.50$) across all treatments. However, the prevalence of leaking ingesta within each pen greatly increased (linear; $P < 0.001$) with longer periods of feed withdrawal. This was most evident in the 36-h treatment, where 19.6% of pigs within each pen exhibited leaking ingesta. This rate is concerning as visible leaking ingesta is a major criterion for head condemnation and results in a loss of approximately 2.5% of the carcass value.

For meat quality analyses, LAC measurements were similar ($P > 0.45$) across treatments after loading as well as at exsanguination. Longer feed withdrawal periods increased (quadratic; $P < 0.02$) 45 min pH, but at 3 h postmortem there were no differences ($P > 0.18$) in LT pH. Even so, at 21 h postmortem, longer feed withdrawal periods tended to increase (linear; $P < 0.08$) LT pH, agreeing with ultimate pH values which were higher (linear; $P < 0.01$) in pigs subjected to extended feed withdrawal. Although feed withdrawal time did not significantly affect ($P > 0.30$) visual pork color, pigs that experienced longer feed withdrawal periods had higher (quadratic; $P < 0.03$) visual marbling scores, which appeared to peak at the 36 h time point. Purge loss did not differ ($P > 0.16$) between withdrawal treatments.

For economics (Table 3-6), increasing the length of feed withdrawal increased (quadratic; $P < 0.06$) overall carcass price as in Exp. 1. But in contrast to Exp. 1, the amount of premiums received per pig remained similar ($P > 0.32$) across treatments. This may be attributed to the fact that the pigs in Exp. 2 originated from a maternal line genotype and received less premiums per

pig ($2.10 vs. $8.50) than pigs in Exp. 1. Sort loss discounts tended to decrease (quadratic; $P < 0.06$) with longer fasting periods, but there were no differences ($P > 0.68$) in gross revenue with increasing withdrawal time. As expected, feed intake per pig marketed decreased (linear; $P < 0.001$) as feed withdrawal time increased, resulting in feed savings of up to 3 kg/pig. Overall, this reduction in feed cost did not result in differences ($P > 0.68$) in net revenue received per pig.

Discussion

It is well-documented that pre-slaughter feed withdrawal reduces live BW, primarily due to the emptying of the gastrointestinal tract. Results from Warriss and Brown (1983), Kephart and Mills (2005), and Panella-Riera et al. (2012) suggest that at somewhere between 12 and 18 h of feed restriction prior to slaughter, there is also a reduction in HCW. Warriss and Brown (1983) estimated that fasting pigs for between 18 and 48 h resulted in a loss in carcass weight of 0.11% per hour. In the current study, the rate of loss in HCW between 24 and 48 h pre-slaughter was 0.11% per h in Exp. 1, while in Exp. 2 the loss rate was more conservative, losing only 0.05% per hour between 12 and 36 h of feed withdrawal. Reasons for the differences seen between the present experiments are unclear, but may be associated with the large number of misidentified carcasses during Exp. 2.

Feed withdrawal time also increased carcass yield by 2.0% at 48 h in Exp. 1 and by 1.8% at 36 h in Exp. 2. This increase is related to a decrease in overall viscera weight (Kephart and Mills 2005), particularly gut fill (Jones et al., 1985) and liver weight, which Warriss and Brown (1983) described as occurring rapidly over the first 24 h then stabilizing at about 80% of initial, unfasted weight. The decrease in liver weight is primarily attributed to a loss of water and glycogen. Decreases in muscle glycogen and water content are also linked to the reduction in HCW that begins to occur within 12 to 18 h of feed withdrawal (Jones et al., 1985).

In Exp. 1, extended feed withdrawal time increased calculated FFLI through a decrease in backfat. However, this response was not present in Exp. 2. Although previous research has shown numeric decreases in backfat depth (Beattie et al., 2002; Leheska et al., 2002), there is little evidence of fasting for short periods prior to slaughter affecting overall backfat or FFLI.

From the standpoint of food safety, an important finding of the present study was the increased prevalence of leaking ingesta with longer periods of feed withdrawal. This was most evident in the 36 h treatment, where 19.6% of pigs in each pen exhibited leaking ingesta

compared to only 3.2% in the control group. Leaking ingesta is a major criterion for head contamination, which can result in losses of approximately 2.5% of overall carcass value. This inherently suggests that during fasting pigs may increase water intake and thereby alter stomach content to a more fluid state which can escape up the esophagus when shackled. Based on the results of the present study, it appears that the occurrence of leaking ingesta begins to increase between 12 and 24 h, but the greatest increases occur beyond 24 h of feed restriction. Morrow et al. (2002) reported that feed withdrawal did not impact the percentage of pigs with *Salmonella* organisms in their cecal contents, although they were present in 62% of pigs at slaughter. Despite concerns of contaminating the exterior of the carcass with cecal contents, feed withdrawal had no effect on the prevalence of runny bung, which was only observed in 4.3% of pigs per pen across treatment.

In Exp. 2, LAC measurements were taken to evaluate stress levels of fasted pigs after loading and again at exsanguination. Edwards et al. (2010) showed that LAC at exsanguination can be used to monitor the adequacy of animal handling systems prior to slaughter as well as to monitor the rate of early post-mortem metabolism and muscle drip loss. In the present study, increasing feed withdrawal time did not affect LAC after loading or after exsanguination. These results agree with results of Fernadez et al. (1995) and Bertol et al. (2005), who both reported no affect of feed withdrawal on LAC concentration in rested or stressed pigs. Similarly, Hambrecht et al. (2005) saw no difference in exsanguination LAC concentration when pigs were subjected to a 2 × 2 factorial with short or long time periods during both transport and lairage.

The increase in 45 min and ultimate LT pH with increasing feed withdrawal time seen in the current study agrees with prior research by Panella-Riera et al. (2012), but also shows that ultimate pH continues to increase in the LT from 12 to 36 h of feed withdrawal, coinciding with responses seen in the *M. semimembranosus* and the *M. adductor* in Warriss and Brown (1983). This consistent increase in ultimate pH has been correlated with darker color scores in previous research (Leheska et. al., 2002), but in the present study no differences were observed in visual color score, agreeing with Kephart and Mills (2005) who saw no differences in color between 6 and 24 h of feed withdrawal. These results are also supported by Faucitano et al. (2006) and Panella-Riera (2012), neither of which saw differences in muscle lightness (L*) values when feed withdrawal was applied prior to slaughter. In the current study, visual marbling levels increased up to 24 h of feed withdrawal. Earlier feed withdrawal research had attributed an

increase in marbling to greater color contrast between fat and lean caused by the darker colored lean in fasted pigs (Wulf et al., 2002). However, in this study color scores were not significant and the reason for increased marbling scores remains unclear. Moreover, in this study purge loss was not influenced by feed withdrawal, although a linear decrease in drip loss has been typically associated with feed restriction (Jones et al., 1985).

From an economic perspective, in Exp. 1, longer feed withdrawal times increased carcass price in a linear fashion, a considerable part of which was due to a concomitant 54% reduction in sort loss discounts and a 14% increase in premiums when feed withdrawal was implemented up to 48 h prior to slaughter. However, after the recovered data were analyzed in Exp. 2, there were greater differences in initial BW than desired. Given that the control group had a lighter initial BW, they most likely avoided a portion of the sort loss discounts that the control group had received in Exp. 1, artificially inflating their overall carcass price This would explain the quadratic response seen in carcass price and sort loss discounts where there had been a strong linear response in both variables in Exp. 1. Regardless, gross revenue received was not influenced by feed withdrawal in either experiment, although in Exp. 1 gross revenue numerically decreased beyond 24 h of feed withdrawal. As expected, increased feed withdrawal time resulted in a linear reduction in feed costs by an average of 77% at 36 h of feed withdrawal, and in Exp. 1 when feed withdrawal was extended to 48 h an additional 11% of feed savings were realized on a per pig basis. In both experiments, despite the consistent reduction in feed intake per pig marketed, pre-slaughter feed withdrawal had no effect on overall net revenue. It is also important to note that carcass price increases driven by reductions in sort loss are only seen when pigs are above the optimal weight for the processor, which was the case in the present study.

Although overall net revenue was not influenced by feed withdrawal in the current study, the economic model used fails to take certain factors into account. Currently, some abattoirs discount loads of pigs upon arrival when average live BW exceeds predetermined limits. Feed withdrawal prior to slaughter can add value by reducing live BW upon delivery without sacrificing carcass value while simultaneously reducing overall feed costs. The results of this study show that to minimize losses in HCW, pre-slaughter feed withdrawal times should not exceed 24 h. In practice, it is also important to consider feeding patterns (Hyun et al. 1997) as

intake is typically lowest during night hours and loading pigs early in the morning may elicit some of the benefits of <12 h of feed withdrawal without additional labor.

There are also advantages for the abattoir, including reduced gastrointestinal lacerations, less waste and improvements in pork quality. However, the increase in leaking ingesta seen with feed withdrawal times longer than 12 h is concerning, and the true impact on head condemnations and losses in carcass value needs to be studied further.

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Figures and Tables

Table 3-1. Composition of diets, Exp. 1 and 2 (as-fed basis)

Item	Experiment 1	Experiment 2
Ingredient, %		
Corn	29.86	61.45
Soybean meal, 46.5% CP	13.05	16.56
Bakery by-product	29.88	---
Dried distillers grains with solubles	25.00	20.00
Limestone	1.20	1.03
Salt	0.09	0.35
Vitamin and trace mineral premix[1]	0.08	0.09
Lys sulfate, 50.7%	0.70	0.45
L-Thr	0.12	0.02
Phytase[2]	0.012	---
Ractopamine HCl[3]	0.050	0.050
Total	100	100
Calculated analysis		
SID[4] amino acids, %		
Lys	0.96	0.90
Ile:Lys	64	69
Met:Lys	31	32
Met & Cys:Lys	58	65
Thr:Lys	70	65
Trp:Lys	16	18
Val:Lys	77	83
Total Lys, %	1.10	1.04
ME, kcal/kg	3,457	3,364
SID Lys:ME, g/Mcal	2.76	2.67
CP, %	19.25	18.71
Ca, %	0.56	0.47
P, %	0.43	0.43
Available P, %[5]	0.28	0.21

[1] Provided per kg of premix: 4,509,409 IU vitamin A; 701,463 IU vitamin D_3; 24,050 IU vitamin E; 1,403 mg vitamin K; 3,006 mg riboflavin; 12,025 mg pantothenic acid; 18,038 mg niacin; and 15.0 mg vitamin B_{12}. Also provided per kg of premix: 40.1 g Mn from manganese oxide and manganese sulfate; 90.2 g Fe from iron sulfate; 100.2 g Zn from zinc oxide; 10.0 g Cu from copper sulfate; 501 mg I from ethylenediamine dihydroiodide; and 301 mg Se from sodium selenite.

[2] Optiphos 2000 (Enzyvia LLC, Sheridan, IN).

[3] Paylean (Elanco Animal Health, Greenfield, IN), fed at 5 mg/kg in the final diet.

[4] Standardized ileal digestible.

[5] Phytase provided 0.09% available P in Exp. 2.

Table 3-2. Effects of pre-slaughter feed withdrawal on finishing pig performance and carcass traits in a commercial environment, Exp. 1[1]

	Feed withdrawal, h[2]					Probability, *P* <	
Item	8	24	36	48	SED	Linear	Quadratic
Pig BW, kg							
d 0 (48 hr before marketing)	129.9	129.6	130.1	129.8	1.75	0.93	0.90
d 2 (Wt on farm)	131.0	128.6	125.4	124.4	1.59	0.001	0.17
d 2 (Wt at plant)	128.8	125.5	122.8	121.9	1.57	0.001	0.10
Weight change, kg	1.1	-1.0	-4.7	-5.4	0.33	0.001	0.001
HCW, kg	95.8	95.5	93.8	93.1	1.26	0.02	0.67
Yield, %	74.43	76.09	76.35	76.40	0.327	0.001	0.001
Fat depth, mm[3]	17.0	16.5	16.2	16.0	0.32	0.01	0.26
Loin depth, mm[3]	63.2	63.8	63.7	64.2	0.81	0.35	0.97
FFLI, %[3,4]	52.81	53.14	53.41	53.58	0.221	0.001	0.31

[1] A total of 728 pigs (initially 129.9 ± 1.24 kg BW) were used with 12 replicate pens per treatment and an average of 15 pigs per pen.

[2] Actual time feed was withheld before slaughter. The 8 h treatment served as control.

[3] Adjusted with HCW as a covariate.

[4] Fat-free lean index (FFLI) was calculated using NPPC (2000) guidelines for carcasses measured with the Fat-O-Meater such that FFLI = ((15.31 + (0.51 × HCW, lb) – (31.277 × last rib fat thickness, in.) + (3.813 × loin muscle depth, in.))/HCW, lb.

Table 3-3. Effects of pre-slaughter feed withdrawal on economic returns, Exp. 1[1]

	Feed withdrawal, h[2]					Probability, *P* <	
Item	8	24	36	48	SED	Linear	Quadratic
Carcass price, $/kg[3]	2.03	2.05	2.07	2.07	0.012	0.001	0.17
Premiums, $/pig	7.74	8.49	8.80	8.95	0.628	0.08	0.41
Sort loss, $/pig	-4.11	-3.57	-1.97	-1.91	0.841	0.01	0.24
Gross revenue, $/pig	194.73	195.39	193.79	192.71	2.643	0.32	0.87
Feed intake/pig marketed, kg	6.25	3.68	1.88	1.22	0.276	0.001	0.001
Feed cost, $/pig	2.07	1.22	0.62	0.40	0.090	0.001	0.001
Net revenue, $/pig[4]	192.66	194.17	193.17	192.31	2.659	0.70	0.69

[1] A total of 728 pigs (initially 129.9 ± 1.24 kg BW) were used with 12 replicate pens per treatment and an average of 15 pigs per pen.
[2] Actual time feed was withheld before slaughter. The 8 h treatment served as control.
[3] HCW price of $1.99/kg was used and reflects lean premiums and sort loss discounts.
[4] Net revenue = (HCW x HCW price) - (Feed intake/pig marketed x $0.33/kg).

Table 3-4. Effects of pre-slaughter feed withdrawal time on finishing pig performance and carcass traits in a commercial environment, Exp. 2[1]

	Feed withdrawal, h[2]					Probability, *P* <	
Item	8	12	24	36	SED	Linear	Quadratic
Pig BW, kg							
d 0 (42 hr before marketing)	123.3	124.3	125.8	125.6	2.01	0.25	0.48
d 2 (Wt on farm)[3]	125.6	125.4	123.5	121.5	0.26	0.001	0.24
d 2 (Wt at plant)[3]	122.8	122.5	120.4	118.8	0.46	0.001	0.94
Weight change, kg[3]	0.1	-0.1	-2.0	-4.0	0.26	0.001	0.27
HCW, kg[3]	92.6	92.5	91.6	91.4	0.47	0.01	0.48
Yield, %	75.15	75.30	76.05	77.02	0.435	0.001	0.64
Fat depth, mm[4]	20.3	19.9	20.5	19.6	0.586	0.47	0.43
Loin depth, mm[4]	56.3	56.8	56.2	57.7	1.73	0.53	0.60
FFLI, %[4,5]	50.41	50.74	50.33	50.90	0.395	0.42	0.45
Runny bung, %[6]	4.02	2.38	6.59	4.80	3.30	0.50	0.57
Leaking ingesta, %[6]	3.17	4.34	9.39	19.60	4.165	0.001	0.39

[1] Of 40 pens (843 pigs) initially allotted to this experiment, only 25 pens (543 pigs; 125.2 ± 1.5 kg initial BW) were utilized as a result of data lost at the plant. Number of observations: 8 h (7 pens); 12 h (7 pens); 24 h (6 pens); 36 h (5 pens).

[2] Actual time feed was withheld before slaughter. The 8 h treatment served as control.

[3] Adjusted with d 0 pig BW as a covariate.

[4] Adjusted with actual HCW as a covariate.

[5] Fat-free lean index (FFLI) was calculated using NPPC (2000) guidelines for carcasses measured with the Fat-O-Meater such that FFLI = ((15.31 + (0.51 × HCW, lb) – (31.277 × last rib fat thickness, in.) + (3.813 × loin muscle depth, in.))/HCW, lb.

[6] Prevalence per pen.

Table 3-5. Effects of pre-slaughter feed withdrawal time on blood lactate and meat quality measurements in finishing pigs, Exp. 2[1]

	Feed withdrawal, h[2]					Probability, *P* <	
Item	8	12	24	36	SED	Linear	Quadratic
Blood lactate, mM[3]							
Post-loading[3]	4.85	4.11	4.72	5.09	0.795	0.45	0.58
Exsanguination	6.44	7.50	6.87	7.83	0.675	0.14	0.76
Longissimus thoracis pH							
45 min	6.57	6.65	6.71	6.59	0.060	0.78	0.02
3 h	6.50	6.52	6.56	6.50	0.054	0.85	0.18
21 h	5.85	5.90	5.89	5.93	0.039	0.08	0.87
Ultimate	5.84	5.92	5.89	5.99	0.051	0.01	0.68
Visual color score[4]	3.63	3.71	3.80	3.56	0.239	0.80	0.30
Visual marbling score[4]	1.77	1.99	2.26	1.90	0.216	0.51	0.03
10-d purge loss, %	1.53	1.58	1.51	1.29	0.195	0.16	0.48

[1] Two median weight barrows per pen (n=80) were selected for lactate and meat quality analyses. Data shown are from 79 carcasses.
[2] Actual time feed was withheld before slaughter. The 8 h treatment served as control.
[3] Collected using a hand-held lactate analyzer (Lactate Scout, EKF Diagnostic GmbH, Magdeburg, Germany).
[4] National Pork Producer's Council standards (2000).

Table 3-6. Effects of pre-slaughter feed withdrawal time on economic returns, Exp. 2[1]

	Feed withdrawal, h[2]					Probability, $P <$	
Item	8	12	24	36	SED	Linear	Quadratic
Carcass price, $/kg[3]	2.00	1.98	1.99	2.01	0.010	0.11	0.06
Premiums, $/pig	2.02	1.92	1.62	2.80	0.943	0.44	0.32
Sort loss, $/pig	-1.76	-3.14	-2.49	-1.11	0.760	0.13	0.06
Gross revenue, $/pig[4]	183.43	183.11	182.65	183.73	2.655	0.92	0.68
Feed intake/pig marketed, kg	3.54	3.14	1.78	0.58	0.174	0.001	0.72
Feed cost, $/pig	1.17	1.04	0.59	0.19	0.057	0.001	0.71
Net revenue, $/pig[5]	182.25	182.07	182.06	183.54	2.656	0.62	0.68

[1] Of 40 pens (843 pigs) initially allotted to this experiment, only 25 pens (543 pigs; 125.2 ± 1.5 kg initial BW) were utilized as a result of data lost at the plant. Number of observations: 8 h (7 pens); 12 h (7 pens); 24 h (6 pens); 36 h (5 pens).

[2] Actual time feed was withheld before slaughter. The 8 h treatment served as control.

[3] Carcass price used was $1.99/kg and reflects lean premiums and sort loss discounts.

[4] Gross revenue= adjusted HCW (d 0 weight used as a covariate) × carcass price.

[5] Net revenue = (HCW × HCW price) - (Feed intake/pig marketed × $0.33/kg).

Chapter 4 - Effects of diet blending and feed budgeting on finishing pig growth performance, carcass characteristics and economic return

Abstract

Three experiments were conducted to compare the effects of different phase-feeding regimens for finishing pigs on growth performance, carcass characteristics and economic return. In all experiments, the FEEDPro system (Feedlogic Corp., Willmar, MN) was used to administer treatments. In Exp. 1, 283 pigs (PIC TR4 × 1050; initially 35.0 kg BW) were used in a 97-d study with 12 replicate pens per treatment and 8 pigs per pen. Treatments were: 1) phase-feeding 4 diets (standard), 2) blending a high- and low-Lys complete diet to a set Lys curve (curve), and 3) blending ground corn and a complete supplement (corn-supplement) within each phase to match diet composition of treatment 1. Pigs fed corn-supplement had poorer ($P < 0.01$) G:F than curve pigs along with greater ($P < 0.03$) percentage lean and lower ($P < 0.04$) fat depth than standard or curve pigs. In Exp. 2, 808 pigs (PIC 337 ×1050; initially 35.5 kg BW) were used in a 110-d study with 10 replicate pens per treatment and approximately 27 pigs per pen. Treatment design was similar to that of Exp. 1. Treatment diets were fed in 4 phases (36 to 108 kg) and a common diet containing 5.0 mg/kg ractopamine HCl was fed during Phase 5 (108 to 128 kg). Overall, pigs fed the standard diets had greater ($P < 0.05$) ADG and ADFI than pigs fed curve or corn-supplement diets, while corn-supplement pigs had poorer ($P < 0.04$) G:F than curve pigs. Aside from standard pigs having heavier ($P < 0.03$) HCW than corn-supplement pigs, all other carcass characteristics were similar across treatments. Even though curve pigs had lower ($P < 0.01$) feed cost than standard pigs, there were no differences in revenue or IOFC among treatments. In Exp. 3, 252 pigs (PIC 327 × 1050, initially 36.2 kg BW) were used in a 95-d study with 9 replicate pens per treatment with 7 pigs per pen. Treatments were: 1) phase-feeding a series of 4 diets (standard), 2) blending a high- and low-Lys complete diet to a set Lys curve (curve), over-budgeting (over) treatment 1 diets by 20% in each phase, and 4) under-budgeting (under) treatment 1 diets by 20% in each phase. Overall, growth and carcass characteristics were similar. Feed costs for curve pigs were lower ($P < 0.03$) compared to all other treatments. These studies show that feeding a corn-supplement blend resulted in poorer performance, feeding to a

Lys curve resulted in lower feed costs and over- and under-feed budgeting by 20% did not influence overall growth rate or economic returns.

Keywords: feed blending, feed budgeting, finishing pig, growth, phase-feeding

Introduction

The swine industry has evolved from feeding as little as a single diet during the finishing period to more extensive programs utilizing up to seven diets. However, optimal nutrient concentrations vary with changes in lean growth and live weight, therefore there are frequently periods when the diet being fed is supplying excess nutrients (Moore and Mullan, 2005). In growing and finishing pigs, the rate of protein accretion in relation to live weight is curvilinear, increasing to a maximum and then decreasing over time (Thompson et al., 1996). As a result, amino acid concentrations are generally reduced in the diet as the pig becomes heavier. By more accurately matching the change in pigs' nutrient requirements with age and physiological state, N and P excretion can be reduced without reductions in performance (Jongbloed and Lenis, 1992; Honeyman, 1996; Paik et al., 1996). Increasing the number of feeding phases was previously demonstrated to have economic and environmental benefits (Van der Peet Schwering et al., 1999; Pomar et al., 2007, Pomar et al. 2009); however, in traditional systems these benefits have been shown to have a diminishing rate of returns due to simultaneous increases in management and feed storage costs (Boland et al., 1999).

Blend feeding, which involves mixing and delivering two diets in proportionate ratios, may provide feed cost savings. A general trend for increasing average slaughter weights may also augment the cost benefits of phase-feeding as Fowler (1984), Bikker et al. (1996) and Gill (1999) have shown that there is greater scope for reducing protein supply with increasing body weight. The primary objective of this research was to determine the effects of daily blending complete diets to a predetermined Lys curve compared to conventional phase-feeding strategies in finishing pigs. A secondary objective was to determine growth and economics of over- or under-budgeting a standard phase feeding program.

Materials and Methods

General

All practices and procedures used in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. Experiments 1 and 3 were conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. The research barn had 2 identical rooms each containing 40 pens (2.4 × 3.1 m) with adjustable gates facing the alleyway, allowing for continuous provision of 0.93 m^2 per pig. Each pen was equipped with a cup waterer and a single-sided, dry self-feeder with two eating spaces (Farmweld, Teutopolis, IL) located in the fence line. Pens were located over a completely slatted concrete floor with a 1.2 m pit underneath for manure storage. Experiment 2 was conducted at a commercial research finishing facility in southwestern Minnesota. The facility was a double curtain-sided with completely slatted flooring. The barn contained 48 pens (3.05 × 5.49 m) equipped with a 5-hole conventional dry feeder (STACO, Inc., Schaefferstown, PA) and a cup waterer to allow ad libitum consumption of feed and water. In both research facilities, an automated FEEDPro feeding system was used to deliver and record feeding amounts on an individual pen basis.

In all three trials, feed cost was calculated as the sum of individual diet cost plus grinding, mixing, and delivery (GMD) costs. The individual components of the GMD charges used were 1) grinding = $5.50/t; 2) mixing = $3.30/t; and 3) delivery = $7.70/t. In Exp. 1 & 2, the complete diets used in the standard and curve treatments received all three GMD charges (grinding, mixing, and delivery). For the corn-supplement treatment, grinding was charged to the ground corn, mixing was charged to the supplement, and delivery was charged to both components. For Exp. 3, all treatments were charged with all GMD charges. Feed cost per pig and per kg of gain was calculated for each phase and the overall period of the experiment. Total revenue and income over feed cost (IOFC) were also determined within each experiment using a carcass price of $1.99/kg and current ingredient costs. Total revenue was influenced by sort loss discounts and grade premiums assigned on a per pig basis by the abattoir based on a pricing matrix calculated using HCW and lean meat yield. The average feed cost was subtracted from the derived pig revenue to attain the IOFC per pen. All monetary values used in this paper are expressed as USD.

Experiment 1

A total of 283 mixed sex pigs (TR4 × 1050; PIC, Hendersonville, TN; initial 35.0 ± 0.6 kg BW) were used in a 97-d trial to compare phase-feeding regimens. Pens were allotted to 1 of 3 experimental treatments using a completely randomized design. Each treatment had 12 replicate pens and 8 pigs per pen (4 barrows and 4 gilts). The three experimental treatments were: 1) a standard 4-phase complete feeding program (standard), 2) blending a high and low Lys complete diet over the entire experiment (curve), and 3) blending ground corn and a complete supplement within each phase (corn-supplement). For the standard 4-phase feeding program, four finishing diets (Table 4-1) were formulated to provide 2.72, 2.30, 2.00 and 1.81 g SID Lys/Mcal ME and were fed from 35 to 55 (d 0 to 21), 55 to 80 (d 21 to 42), 80 to 100 (d 42 to 71), and 100 to 126 kg BW (d 71 to 97) for phases 1 to 4, respectively. For the curve treatment, a complete high Lys and low Lys diet was formulated to provide 3.15 and 1.63 g SID Lys/Mcal ME, respectively. The two diets were blended in varying ratios on a daily basis (Figure 4-1) to meet a SID Lys requirement curve which was set using previously documented feed intake data in this facility. For the corn-supplement treatment, four complete supplements were formulated (Table 4-2) and were stored separately from ground corn in feed storage bins. The FEEDPro system blended ground corn and the complete supplement in calculated ratios to be identical in dietary nutrient composition to those fed the Standard phase feeding program for each growing phase. The SID Lys:ME ratios (g/Mcal) provided by the three feeding regimens to pigs throughout the finishing period is shown in Figure 4-2. The figure illustrates the stair-step reduction of SID Lys:ME ratios used for the standard and corn-supplement treatments and the more gradual reduction in SID Lys:ME ratio for the curve treatment. The gradual reduction in SID Lys:ME ratio was achieved by changing the blending ratio on a daily basis. All complete diets, ground corn, and supplements were manufactured at the KSU Animal Science Feed Mill and were formulated to meet or exceed all nutrient requirement estimates (NRC, 1998).

Pigs were weighed and feed disappearance was determined at the end of each phase to calculate ADG, ADFI and G:F (Table 4-3). At the end of the trial, pigs were weighed and transported (approximately 204 km) to an abattoir (Triumph Foods, Inc., St. Joseph, MO). Pigs had been individually tattooed according to pen number to allow for data retrieval by pen and carcass data collection at the abattoir. Hot carcass weights were measured immediately after evisceration and each carcass was evaluated for percentage yield, backfat and loin depth (Table

4-4). Percentage yield was calculated by dividing HCW by live BW obtained at the farm before transport to the abattoir. Fat depth and loin depth were measured with an optical probe (SFK, Herlev, Denmark) inserted between the third and fourth ribs located anterior to the last rib at a distance approximately 7.1 cm from the dorsal midline. Percentage lean was calculated according to National Pork Producers Council (1991) equations for lean containing 5% fat where Lean (5% fat), lb = 2.83 + (0.469 × HCW, lb) – (18.47 × last rib fat thickness, in.) + (9.824 × loin muscle depth, in.). Grade premiums and sort loss discounts were also utilized to accurately determine the net revenue generated per pig (Table 4-5).

Experiment 2

A total of 808 mixed sex pigs (337 × 1050, PIC; Hendersonville, TN; initially 35.5 ± 0.7 kg BW) were used in a 110-d trial to compare phase-feeding to blending two complete finishing diets on a Lys curve in a commercial environment. Pens were randomly assigned to 1 of 3 treatments according to average BW within pen in a completely randomized design. There were 26 to 27 pigs per pen (mixed sex) with 10 replicate pens per treatment. The 3 experimental treatments were: 1) a standard 4-phase complete feed program (standard), 2) blending a high- and low-Lys complete diet (curve), and 3) blending ground corn and a complete-supplement within each phase (corn-supplement). For the Standard 4-phase feeding program, 4 finishing diets (Table 4-6) were formulated to provide 2.83, 2.59, 2.32, and 2.05 g SID Lys/Mcal ME and were fed from 35 to 52 (Phase 1), 52 to 71 (Phase 2), 71 to 86 (Phase 3), and 86 to 108 kg (Phase 4), respectively.

For the curve treatment, a complete high- and low-Lys diet was formulated to provide 2.98 and 1.93 g SID Lys/Mcal ME, respectively. These two diets were blended in different ratios daily (Figure 4-3) to meet a SID Lys requirement curve that was configured using previously determined SID Lys requirements in this facility with the same genetics. For the corn-supplement treatment, complete supplements were manufactured (Table 4-7) by phase and the FEEDPro system blended ground corn and the complete supplement in calculated ratios to be identical in dietary nutrient composition to the standard phase-feeding program for each growing phase. Figure 4-4 illustrates the stair-step reduction of SID Lys:ME ratios used for the standard and corn-supplement treatments and the more gradual reduction in SID Lys:ME ratio for the

curve treatment. The gradual reduction in SID Lys:ME ratio was achieved by changing the ratio of the two diets provided on a daily basis.

A common complete diet containing 5.0 mg/kg ractopamine HCl (RAC; Paylean, Elanco Animal Health, Greenfield, IN) was fed to all three treatments for 22 days from 108 to 127 kg BW immediately prior to marketing. This diet was formulated to contain 2.67 g SID Lys/Mcal ME.

All complete diets, ground corn, and supplements were manufactured at the New Horizons Feed Mill (Pipestone, MN) and were formulated to meet all requirement estimates (NRC, 1998). Feed samples of each treatment were collected from several feeders at a single time point within each dietary phase. These samples were homogenized and analyzed for Lys content (AOAC 982.30 Ea,b, chp. 45.3.05, 2006) at the University of Missouri Agricultural Experiment Station Chemical Laboratories (Table 4-8).

Pigs from each pen were weighed as a group, and feed disappearance was determined approximately every 21 days to determine ADG, ADFI, and G:F (Table 4-9). On d 88 of the experiment, the 4 heaviest pigs from each pen (determined visually) were weighed and removed in accordance with the farm's normal marketing procedure. On d 110, pigs were transported (approximately 95 km) to a commercial abattoir (JBS Swift and Company; Worthington, MN) for processing. Pigs had been individually tattooed according to pen number to allow for data retrieval by pen and carcass data collection at the abattoir. Hot carcass weights were measured immediately after evisceration and each carcass was evaluated for percentage yield, backfat and loin depth (Table 4-10). Percentage yield was calculated by dividing HCW by live BW obtained at the farm before transport to the abattoir. Fat depth and loin depth were measured with an optical probe (SFK, Herlev, Denmark) inserted between the third and fourth ribs located anterior to the last rib at a distance approximately 7.1 cm from the dorsal midline. Fat-free lean index (FFLI) was calculated using NPPC (2000) guidelines for carcasses measured with the Fat-O-Meater such that FFLI = ((15.31 + (0.51 × HCW, lb) – (31.277 × last rib fat thickness, in.) + (3.813 × loin muscle depth, in.))/HCW, lb. Grade premiums and sort loss discounts were included to accurately determine the net revenue generated per pig (Table 4-11). As a result of misidentification of pigs by abattoir personnel, of the original 10 replicates per treatment, authors were able to obtain carcass data for 6 pens from the standard treatment, 10 pens from the curve group, and 7 pens from the corn-supplement treatment.

Experiment 3

A total of 252 mixed-sex pigs (327 × 1050, PIC; Hendersonville, TN; initial BW = 36.2 ± 0.4 kg BW) were used in a 95-d trial to compare feed-budgeting strategies and blending two complete finishing diets on a Lys curve on growth performance, carcass characteristics and economics. Pens were allotted to 1 of 4 experimental treatments using a randomized complete block design. Each treatment had 9 replicate pens and 7 pigs per pen (4 gilts and 3 barrows per pen). The four experimental treatments were: 1) a standard 4-phase complete feed program (standard), 2) blending a high and low Lys complete diet over the entire experiment (curve), 3) Treatment 1 diets with 20% greater feed budget for phases 1, 2, and 3 (over), and 4) Treatment 1 diets with 20% lower feed budget for phases 1, 2, and 3 (under). All the diets were dispensed using the FEEDPro system and provided ad libitum access to feed. For the standard 4-phase feeding program as well as the over and under treatments, four finishing diets (Table 4-12) were formulated to provide 2.72, 2.30, 2.00 and 1.81 g SID Lys/Mcal ME.

The FEEDPro system was programmed to deliver a predetermined amount of feed from each diet to each pen and to automatically update allotted budgets when pigs were removed due to death or illness. Pigs fed the standard treatment were programmed to receive a set feed budget of 53.1, 62.6, 72.7 and 79.4 kg for Diets 1 to 4, respectively. Pigs fed the over and under treatments were assigned feed budgets 20% higher and 20% lower than their standard counterparts for phases 1, 2 and 3 with phase 4 fed for the remainder of the trial once the phase 3 diet was consumed. When budgeted allotment of each phase was exhausted for the over and under treatments, the FEEDPro system automatically switched phases on an individual pen basis.

Pigs from all treatments were weighed and feed disappearance was recorded on the date of phase changes for the standard treatment in order to establish equal periods for data comparison. Measurements of ADG, ADFI, and G:F were calculated at each of these phase changes (Table 4-14). Based on the feed budgeted for the standard treatment, the data periods were d 0 to 23 (Phase 1), d 23 to 49 (Phase 2), d 49 to 72 (Phase 3), and d 72 to 95 (Phase 4).

For the curve treatment, a complete high Lys and low Lys diet was formulated to provide 2.97 and 1.75 g SID Lys/Mcal ME, respectively. The two diets were blended in varying ratios on a daily basis (Figure 4-5) to meet a SID Lys requirement curve which was set using previously documented feed intake data in this facility. The SID Lys:ME ratios (g/Mcal) provided by the four feeding programs to pigs throughout the finishing period is shown in Figure 4-6. The figure

illustrates the stair-step reduction of SID Lys:ME ratios used for the different phase feeding treatments and the more gradual reduction in SID Lys:ME ratio for the diet blending treatment. The gradual reduction in SID Lys:ME ratio was achieved by changing the ratio of the two diets provided on a daily basis. All complete diets, ground corn, and supplements were manufactured at the KSU Animal Science Feed Mill. Feed samples were collected after diet manufacturing, homogenized and analyzed for Lys content (AOAC 982.30 Ea,b, chp. 45.3.05, 2006) at the University of Missouri Agricultural Experiment Station Chemical Laboratories (Table 4-13).

On d 84, pigs were weighed and transported (approximately 204 km) to an abattoir (Triumph Foods, Inc., St. Joseph, MO). Pigs had been individually tattooed according to pen number to allow for data retrieval by pen and carcass data collection at the abattoir. Standard carcass criteria of percentage carcass yield, HCW, backfat depth, loin depth and percentage lean were measured (Table 4-15). Hot carcass weights were measured immediately after evisceration, and percentage yield was calculated by dividing HCW by live BW obtained at the farm before transport to the abattoir. Carcass trait measurements were calculated as in Exp. 1 and grade premiums and sort loss discounts were included to accurately determine the net revenue generated per pig (Table 4-16).

Statistical Analysis

In Exp. 1, data were analyzed as a completely randomized design (CRD) using the GLM procedure of SAS (SAS Inst., Inc., Cary, NC). Experiments 2 and 3 used PROC MIXED in SAS for data analysis. Experiment 2 was analyzed as a CRD and Exp. 3 was analyzed as a randomized complete block design, with location in the barn as the blocking factor. In all three experiments, HCW was used as a covariate for fat depth, loin depth, lean percentage and FFLI. When treatment effect was a significant source of variation, means were separated using the PDIFF option of SAS in Exp. 1 and 2 and by pre-planned CONTRAST statements in Exp. 3. Least square means were calculated for each independent variable. Statistical significance was set at $P \leq 0.05$ and trends at $P < 0.10$ for all statistical tests.

Results

Diet Analysis

Diet samples collected for Exp. 1 were not available for analysis. The analyzed Lys levels for standard and curve regimens in Exp. 2 confirm the decreasing Lys content over the growing period and are within permitted analytical variation limits according to AAFCO (2005). However, the analyzed Lys levels for the corn-supplement blend were more variable; suggesting that there either may have been sampling error or the FEEDPro system could have been inaccurately blended the corn and supplement. Analyzed Lys levels in diets from Exp. 3 are in general agreement with formulated Lys content.

Experiment 1

Average daily gain and pig BW were similar ($P > 0.12$) across treatments in each of the four phases. In phases 1 to 3, ADFI was also similar ($P > 0.14$); but in phase 4 pigs fed using curve diets had lower ($P < 0.03$) ADFI than pigs fed using standard phase feeding of complete diets or the corn-supplement blend. For feed efficiency, phase 1 (35 to 55 kg) pigs fed the corn-supplement blend had greater ($P < 0.03$) G:F than pigs fed standard or curve diets. However, G:F was poorer ($P < 0.05$) in pigs fed the corn-supplement blend in phase 3 (80 to 100 kg) than pigs fed standard or curve diets. In phase 4 (100 to 126 kg), pigs fed to a curve had poorer ($P < 0.04$) G:F than pigs fed using standard phase feeding of either complete diets or the ground corn-supplement blend. Overall (35 to 126 kg), ADG, ADFI, and final BW were similar ($P > 0.14$) across treatments. However, pigs fed the corn-supplement blend had poorer ($P < 0.01$) G:F than pigs fed curve diets and tended to have poorer ($P < 0.09$) G:F than pigs fed using the standard program.

For carcass characteristics, there were no differences ($P > 0.18$) in HCW, percentage yield, and loin depth across treatments. Pigs fed using the corn-supplement blend had greater ($P < 0.03$) percentage lean and lower ($P < 0.04$) fat depth than pigs fed using standard phase-fed diets or curve diets blended using the FEEDPro system.

Feeding curve diets tended ($P < 0.07$) to result in feed savings ($2.59/pig) versus the standard phase feeding program. The majority of the difference for curve and standard diets was due to lower ADFI and better G:F observed in phase 4, which resulted in $1.44 reduction ($P <$

0.01) in feed cost per pig. For the ground corn-supplement blend, cost of mixing ($3.30/t) was not assessed for ground corn, which contributed to lower GMD cost and numerically lower feed costs per pig. Feed cost per kg gain was lower ($P < 0.01$) for pigs fed the corn-supplement blend in phase 1 and lower ($P < 0.03$) for the curve diet in phases 3 and 4, but overall, no differences ($P \geq 0.11$) were observed across the treatments. There were no ($P \geq 0.41$) differences in total revenue or IOFC across all treatments.

Experiment 2

In phase 1 (35 to 52 kg) and phase 2 (52 to 71 kg), growth performance and pig BW were similar ($P > 0.13$) across all treatments. For Phase 3 (71 to 86 kg), ADG, G:F and pig BW were not influenced ($P \geq 0.18$) by blending treatments. However, pigs fed diets blended on a Lys curve had lower ($P < 0.01$) ADFI than pigs fed either standard phase diets or those fed a corn-supplement blend. In phase 4 (86 to 108 kg), pigs fed the corn-supplement blend had poorer ($P < 0.04$) ADG than pigs fed using either standard phase feeding or blended diets on a Lys curve. Additionally, pigs fed standard diets had improved ($P < 0.02$) ADFI as compared to pigs fed curve diets or a corn-supplement blend. However, pigs fed curve diets had increased ($P < 0.03$) G:F compared to pigs fed the corn-supplement blend, with standard pigs being intermediate. For BW in phase 4, pigs fed standard diets were heavier ($P < 0.02$) than pigs fed curve diets and tended to be heavier ($P < 0.02$) than those fed the corn-supplement blend. Within the overall trial period (35 to 108 kg), pigs fed standard diets had higher ($P < 0.02$) ADG compared to both blending treatments and had higher ADFI ($P < 0.01$) than pigs fed a curve diet, with those fed a corn-supplement blend being intermediate. However, pigs fed curve diets had improved ($P < 0.04$) G:F over other treatments. During phase 5 (108 to 127 kg) where all pigs were fed a common diet containing ractopamine HCl, pigs previously fed the corn-supplement blended diets had higher ($P < 0.02$) ADFI than those previously fed curve diets. Additionally, pigs formerly fed standard phase diets tended to be heavier ($P < 0.10$) than pigs formerly fed a ground corn-supplement blend.

Over the entire finishing period (35 to 127 kg), pigs fed standard diets had higher ($P < 0.04$) ADG than pigs fed either curve diets or a corn-supplement blend. Additionally, pigs fed standard diets or a corn-supplement blend had higher ($P < 0.05$) ADFI than curve pigs.

However, pigs fed curve diets had improved ($P < 0.04$) G:F over pigs fed a corn-supplement blend.

For carcass characteristics, there were no differences ($P \geq 0.22$) in percentage yield, FFLI, backfat depth or loin depth across all treatments. However, pigs fed standard diets had heavier ($P < 0.03$) HCW than pigs a corn-supplement blend and tended to have heavier ($P < 0.07$) HCW than those fed curve diets.

Higher ADG and ADFI for pigs fed standard diets led to greater ($P < 0.01$) feed cost per pig compared to curve pigs and a trend ($P < 0.08$) for higher feed costs compared to pigs fed the corn-supplement blend. However, because standard pigs experienced greater gain, feed cost/kg gain was similar ($P > 0.10$) across all treatments overall and for most individual phases. Furthermore, there were no differences ($P \geq 0.15$) in total revenue per pig. While there were no differences ($P \geq 0.15$) in IOFC across treatments, pigs fed diets blended to a Lys curve had a $1.80 and $3.11 advantage in IOFC over standard and corn-supplement treatments, respectively.

Experiment 3

While pen weights and feed disappearance were recorded on d 23, 49, 72 and 95 according to average phase changes in the standard treatment, phase changes in the over and under treatments took place when allotted feed budgets were exhausted on a per pen basis. In the over treatment, the average date of diet change were d 29, 56 and 83 for phases 2 through 4, respectively. In the under treatment, the average date of diet changes were d 18, 42, and 61 for phases 2 through 4, respectively.

In phase 1 (d 0 to 23), ADG was lower ($P < 0.04$) in pigs fed the curve treatment compared to each of the three phase-fed programs. Although no differences ($P > 0.47$) in ADFI were seen across treatments, pigs fed the curve diet had poorer ($P < 0.04$) G:F than pigs fed over- and under-budgeted phase feeding programs. While ADG was similar ($P > 0.16$) across all treatments during phase 2 (d 23 to 49), under-budgeted pigs had higher ADFI ($P < 0.05$) than curve pigs and poorer ($P < 0.05$) G:F than pigs fed standard or curve diets. In phase 3 (d 49 to 72) pigs in the phase and under treatments had greater ($P < 0.05$) ADG than pigs fed the over treatment, with curve fed pigs being intermediate. Average daily feed intake was similar ($P > 0.18$) across treatments in phase 3, but pigs fed the under treatment had improved ($P < 0.05$) G:F when compared to pigs that were over-budgeted for each phase. In phase 4 (d 72 to 95), no

differences ($P > 0.13$) were seen in ADG, ADFI or G:F across treatments. Overall (d 0 to 95), there were no differences ($P > 0.11$) in ADG, ADFI, G:F or final BW across treatments.

For carcass characteristics, there was a trend ($P = 0.09$) for pigs fed the standard phase feeding program to have higher yielding carcasses than pigs over-budgeted or fed to a Lys curve. This was driven by a trend ($P = 0.10$) for heavier HCW in pigs fed the standard compared to curve treatments. Across treatments, there were no differences ($P > 0.14$) in percentage lean, fat depth or loin depth.

Feeding diets blended to a Lys curve resulted in the lowest ($P < 0.03$) feed costs in Phases 2, 3 and overall, resulting in average feed savings/pig of $4.09 compared to the three phase-feeding strategies. For feed cost per kg gain, feeding curve diets resulted in higher ($P < 0.03$) costs compared to pigs fed over-budgeted diets during phase 1, with standard and under treatments being intermediate. Conversely, in phase 2, curve diets resulted in the most economical weight gain ($P < 0.001$) and in phase 3, pigs fed curve and under diets had lower ($P < 0.04$) feed cost per kg gain than those over-budgeted. Overall, delivering diets to a Lys curve resulted in lower ($P < 0.01$) cost per kg gain than over-budgeting and tended ($P < 0.06$) to be lower than standard and under treatments. Total revenue received per pig tended ($P < 0.10$) to be higher ($5.37/pig) for pigs fed standard diets over curve or under treatments. This advantage was mainly due to the advantage in ADG in standard pigs, which resulted in heavier HCW. Pigs phase-fed a correctly estimated feed budget (standard) tended ($P < 0.09$) to have higher IOFC than curve ($4.61/pig) or over ($4.55/pig) treatments; whereas pigs fed under-budgeted diets performed similarly ($P > 0.49$) to their standard phase-fed counterparts, sacrificing just $1.81 per pig.

Discussion

With the advent of on-site computer programming and feed delivery systems that can blend and deliver diets daily, the capability of modern feeding technology has radically evolved in recent years. These advances now allow producers to exploit nutritional science that has been known for years, such as the decrease in Lys:ME requirements as the pig grows during the growing period (Gill 1999). Blending base diets daily according to known requirements offer potential benefits including lower feed costs and the minimization of nutrient excretion while still maintaining optimal growth performance. Although these perceived benefits are essential to

the development of sustainable swine production systems (Honeyman 1996), comprehensive evaluations of this practice using current technology on commercial farms are limited.

While Pomar et al. (2007) reported faster growth rates for pigs fed using a daily Lys curve via an automated feed delivery system compared to pigs fed a three-phase diet, the results of the present study generally disagree, with consistent reductions in growth rate across all three experiments. The observed differences may be attributed to the fact that in Pomar et al. (2007), curve-fed pigs had greater total Lys intake than phase-fed pigs; whereas in the present study all pigs across treatments had similar Lys intake, as phase-fed diets were formulated to provide SID Lys:ME ratios (Figure 4-2;Figure 4-4;Figure 4-6) that, within each phase, provided both an excess and shortage of nutrients based on expected requirements.

Overall feed efficiency was improved in pigs fed diets blended to a Lys curve over those that were phase-fed a series of 4 diets, particularly in Exp. 1 & 2. Increasing the number of feeding phases in finishing has shown consistent improvements in feed efficiency, (Lee et al., 1999; Moore and Mullan, 2009; Pomar et al, 2007) which corresponds with reductions in N and P excretion (Lenis and Jongbloed, 1999; van der Peet-Schwering 1996). The feed efficiency improvement for pigs fed blended diets resulted in net feed savings of $2.59, $4.07, and $4.56 per pig for Exp. 1 to 3, an average approximate reduction of 4% in overall feed costs over phase-fed pigs. These feed savings resulted in numerical advantages in IOFC in Exp. 2 but due to reduced HCW in curve-fed pigs, did not result in greater IOFC in Exp. 1 or 3. As noted by Moore and Mullan (2009), it is also important to consider that while diet blending using the FEEDPro system can reduce feed costs, the reported feed costs do not account for the cost of purchasing and installing the equipment required to implement feed blending.

Mixing ground corn and a complete supplement to provide diets equivalent to standard phase-feeding regimens is an additional avenue to utilize the feed blending capabilities of the FEEDPro system. In Exp. 1 & 2, corn-supplement blending resulted in poorer feed efficiency compared to blending diets to a Lys curve, and reduced ADG compared to standard phase-feeding. Feed cost per kilogram of gain for pigs fed the corn-supplement blend were nearly as high as standard pigs in both experiments, but net revenue suffered due to the numerically lighter HCW in the corn-supplement treatment. High feed costs combined with the lowest returns resulted in pigs fed the corn-supplement blend having the poorest IOFC in Exp. 1 & 2. While diet samples could not be analyzed in Exp. 1, in Exp. 2 the variation in analyzed Lys content for

the corn-supplement blend was concerning. This variation may explain the poorer growth performance, particularly during the later stages of the growing-finishing period. As the corn-supplement blend should theoretically have provided an equivalent diet to the standard program, the reason for this variation in Lys content remains unclear. Reasons that could explain this variation include: sampling error, incorrect supplement nutrient levels, or the inaccuracy of the FEEDPro blending capabilities when handling diets differing in form and density. While the accuracy of feed blending was determined using diets of similar texture upon installation of the FEEDPRO system at each facility, it would be prudent for future research evaluating similar blending strategies to verify the blending capability of the system with ingredients of different bulk densities. Recent increases in feed ingredient costs within the U.S. livestock industry may reduce the practicality of two-ingredient mixing strategies such as corn-supplement blending, as modern diets are incorporating a larger number of starch and protein sources than traditional corn-soy rations (Plain 2007).

When evaluating diet budgeting strategies in Exp. 3, it appears that over-budgeted diets may have restricted growth in the mid- and late-finishing period due to an oversupply of protein. Lenis (1989), Lee et al. (2000) and Garry et al. (2007) have shown that excess amino acids that cannot be used for body protein deposition have to be deaminated and excreted, resulting in a deterioration in growth and feed efficiency. Conversely, under-budgeted diets supplied a SID Lys:ME ratio slightly below biological requirements throughout the duration of the experiment. Growth performance for under-budgeted pigs was slightly poorer during phases 1 and 2 (36 to 81 kg), but similar to Standard pigs in late finishing (81 to 132 kg). Based on well-documented compensatory growth responses seen when feeding adequate protein in later growth periods (Wahlstrom and Libal, 1983), Main et al. (2008) suggested that as long as Lys requirements are met in late-finishing, feeding slightly less than the Lys requirement in early-finishing may offer feed cost savings without forfeiting growth performance. Likewise, under-budgeting by 20% appears to result in similar growth performance responses and potential feed cost reductions. As additional efforts are made to minimize feed costs in the finishing phase, formulating early-finishing diets slightly lower than the pigs' physiological needs may offer an opportunity to lower overall feed costs.

In conclusion, feeding diets blended to a Lys curve can effectively reduce overall feed costs but may also lead to reductions in growth performance. The reason why growth

performance in curve-fed pigs was consistently poorer than phase-fed pigs is unclear, and additional research may elucidate the underlying reasons. While these experiments have shown the effectiveness of blending two base diets on finishing-pig growth performance, it would be beneficial to also evaluate the nutrient excretion of finishing pigs fed curve diets compared to phase-feeding. Finally, over- and under-feed budgeting did not significantly influence overall growth rate or economic return.

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Figures and Tables

Table 4-1. Diet composition of the standard and curve regimens, Exp. 1 (as-fed basis)

	Standard[1]				Curve[2]	
Item	Phase 1	Phase 2	Phase 3	Phase 4	High Lys	Low Lys
Ingredient, %						
Corn	78.42	83.11	86.54	88.45	73.75	90.53
Soybean meal, 46.5% CP	18.95	14.61	11.40	9.63	23.30	7.70
Monocalcium phosphate, 21% P	0.50	0.30	0.23	0.15	0.70	0.05
Limestone	0.95	0.95	0.90	0.90	0.96	0.89
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.15	0.13	0.10	0.08	0.16	0.07
Trace mineral premix[4]	0.15	0.13	0.10	0.08	0.16	0.07
L-Lys HCl	0.30	0.26	0.24	0.22	0.34	0.20
DL-Met	0.03	---	---	---	0.05	---
L-Thr	0.07	0.04	0.03	0.03	0.10	0.03
Phytase[5]	0.13	0.13	0.13	0.13	0.13	0.13
Total	100	100	100	100	100	100
Calculated analysis						
SID[6] amino acids, %						
Lys	0.91	0.77	0.67	0.61	1.05	0.55
Ile:Lys	61	63	64	66	60	67
Met:Lys	29	28	30	32	29	34
Met & Cys:Lys	56	58	62	66	55	70
Thr:Lys	62	62	63	65	62	66
Trp:Lys	16.5	16.5	16.5	16.5	16.5	16.5
Val:Lys	71	74	78	81	68	84
Total Lys, %	1.01	0.86	0.75	0.69	1.16	0.63
ME, kcal/kg	3,340	3,349	3,355	3,362	3,331	3,366
SID Lys:ME, g/Mcal	2.72	2.30	2.00	1.81	3.15	1.63
CP, %	15.83	14.14	12.90	12.22	17.53	11.48
Ca, %	0.54	0.49	0.45	0.43	0.60	0.40
P, %	0.46	0.40	0.37	0.35	0.51	0.32
Available P, %[7]	0.28	0.23	0.21	0.19	0.33	0.17
Diet cost/t, US $[8]	299.47	289.17	283.25	279.58	309.42	275.58

[1] Standard 4 phase complete diet feeding program where diets were fed from 35 to 55 kg, 55 to 80, 80 to 100, and 100 to 126 kg BW for phases 1 to 4, respectively.

[2] Feed delivery based on a Lys estimate curve where a complete high and low Lys diet was blended throughout the duration of the experiment.

[3] Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[4] Provided per kg of premix: 26.5 g Mn from manganese oxide; 110 g Fe from iron sulfate; 110 g Zn

from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

[5] Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided 600,533 phytase units phytase/kg.

[6] Standardized ileal digestible.

[7]Phytase provided 0.10% available P to the diet.

[8] Diet costs were calculated with $233.58/t corn and $391.88/t soybean meal, along with a $16.50/t manufacturing and delivery charge.

Table 4-2. Composition of the complete supplements (as-fed basis) and the proportion of ground corn and supplement by phase, Exp. 1[1,2]

	Complete supplement			
Ingredient, %	Phase 1	Phase 2	Phase 3	Phase 4
Soybean meal, 46.5% CP	87.85	86.51	84.66	83.37
Monocalcium P, 21% P	2.32	1.78	1.67	1.30
Limestone	4.40	5.63	6.69	7.80
Salt	1.62	2.07	2.60	3.03
Vitamin premix[3]	0.70	0.74	0.74	0.65
Trace mineral premix[4]	0.70	0.74	0.74	0.65
L-Lys HCl	1.39	1.54	1.75	1.86
DL-Met	0.12	---	---	---
L-Thr	0.34	0.25	0.22	0.26
Phytase[5]	0.58	0.74	0.93	1.08
Total	100	100	100	100
Blend:				
Ground corn, %[6]	78	83	87	88
Complete supplement, %	22	17	13	12
Supplement cost/t, US $[7]	452.13	445.22	449.00	449.01

[1] Diets were blended and feed budgeted to be identical in composition and nutrient analyses for each phase to those fed the standard 4-phase feeding program (Table 4-1).
[2] Diets were fed from 35 to 55 kg, 55 to 80, 80 to 100, and 100 to 126 kg BW for phases 1 to 4, respectively.
[3]Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.
[4] Provided per kg of premix: 26.5 g Mn from manganese oxide; 110 g Fe from iron sulfate; 110 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.
[5] Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided 600,533 phytase units phytase/kg.
[6] Ground corn was priced at $233.58/t and was charged a $13.20/t feed grinding and delivery charge.
[7] Supplement costs were calculated with $399.88/t soybean meal and an $11.00/t feed mixing and delivery charge.

Table 4-3. Effects of diet blending using the FEEDPro system on finishing pig growth performance, Exp. 1[1]

	Treatment[2]			
Item	Standard	Curve	Corn-supplement	SEM
Pig weights, kg				
Initial	35.0	35.0	35.0	0.61
d 21	54.5	54.5	54.7	0.73
d 47	80.0	78.7	79.7	1.01
d 71	101.2	100.2	99.7	1.18
d 97	127.2	125.9	125.9	1.38
Phase 1 (35 to 55 kg)				
ADG, kg	0.93	0.93	0.94	0.011
ADFI, kg	2.12	2.14	2.08	0.028
G:F	0.438[a]	0.435[a]	0.450[b]	0.004
Phase 2 (55 to 80 kg)				
ADG, kg	0.98	0.93	0.96	0.189
ADFI, kg	2.64	2.58	2.67	0.040
G:F	0.371[y]	0.360[xy]	0.358[x]	0.005
Phase 3 (80 to 100 kg)				
ADG, kg	0.89	0.90	0.83	0.023
ADFI, kg	2.77	2.69	2.73	0.050
G:F	0.321[ab]	0.334[a]	0.305[b]	0.007
Phase 4 (100 to 126 kg)				
ADG, kg	1.00	0.99	1.01	0.018
ADFI, kg	3.50[a]	3.35[b]	3.53[a]	0.046
G:F	0.286[a]	0.296[b]	0.286[a]	0.003
Overall (35 to 126 kg)				
ADG, kg	0.95	0.94	0.94	0.010
ADFI, kg	2.79	2.72	2.79	0.033
G:F	0.342[ab]	0.346[a]	0.336[b]	0.002

[1] A total of 283 pigs(TR4 × 1050, PIC Hendersonville, TN) were used in a 97-d trial with 8 pigs per pen and 12 replicate pens per treatment.

[2] Standard = complete diets in each phase; Curve = blending of high and low Lys diet fed to a set Lys curve; Corn-supplement = blending of ground corn and complete supplement.

[a,b x,y] Within a row, means without a common superscript differ ($P < 0.05$) for statistical significance and ($P < 0.10$) for tendencies, respectively.

Table 4-4. Effects of diet blending using the FEEDPro system on carcass characteristics of finishing pigs , Exp. 1[1]

	Treatment[2]			
Item	Standard	Curve	Corn-supplement	SEM
HCW, kg	94.0	93.7	92.6	1.20
Yield, %[3]	73.93	74.43	73.59	0.439
Lean, %[4,5]	52.15[a]	52.26[a]	52.87[b]	0.189
Fat depth, mm[4]	21.1[a]	20.6[a]	19.3[b]	0.42
Loin depth, mm[4]	60.5	60.6	60.9	0.63

[1] A total of 288 pigs (TR4 × 1050, PIC Hendersonville, TN) were used in a 97-d trial with 8 pigs per pen and 12 replicate pens per treatment.
[2] Standard = complete diets in each phase; Curve = blending of high and low Lys diet fed to a set Lys curve; Corn-supplement = blending of ground corn and complete supplement.
[3] Percentage yield was calculated by dividing HCW by live weight obtained before transport to the abattoir.
[4] Data analyzed by using HCW as a covariate.
[5] Calculated using NPPC (1991) guidelines for lean containing 5% fat. Lean % = (2.83 + (0.469 × (0.4536 × HCW)) – (18.47 × (0.0394 × Fat depth)) + (9.824 × (0.0394 × Loin depth))/(0.4536 × HCW).
[a,b] Within a row, means without a common superscript differ ($P < 0.05$).

Table 4-5. Economics of diet blending using the FEEDPro system, Exp. 1[1]

	Treatment[2]			
Item	Standard	Curve	Corn-supplement	SEM
Feed cost/pig, $				
Phase 1	14.09[ab]	14.33[b]	13.70[b]	0.204
Phase 2	21.13	20.51	21.01	0.317
Phase 3	20.07	19.31	19.37	0.372
Phase 4	27.14[b]	25.70[a]	26.91[ab]	0.378
Total	82.44[y]	79.85[x]	80.99[xy]	0.992
Feed cost/kg gain, $[3]				
Phase 1	0.722[b]	0.725[b]	0.695[a]	0.006
Phase 2	0.824[x]	0.854[y]	0.845[xy]	0.013
Phase 3	0.937[ab]	0.905[a]	0.969[b]	0.017
Phase 4	1.038[b,y]	1.000[a,x]	1.030[ab,y]	0.012
Overall	0.881	0.870	0.884	0.006
Total revenue, $/pig[4,5]	186.45	184.71	184.63	2.376
IOFC, $/pig[6]	104.01	104.85	103.63	1.811

[1] 288 pigs (TR4 × 1050, PIC Hendersonville, TN) were used in a 97-d trial with 8 pigs per pen and 12 replicate pens per treatment.
[2] Standard = complete diets in each phase; Curve = blending of high and low Lys diet fed to a set Lys curve; Corn-supplement = blending of ground corn and complete supplement.
[3] Feed cost/kg gain = (Direct feed cost + GMD cost/pig) ÷ total live gain; Assumed grinding = $5.50/t; mixing = $3.30/t; delivery and handling = $7.70/t.
[4] Scenario 1: carcass base price = $1.99/kg.
[5] Total revenue = carcass price (including premiums/discounts for lean and yield) × HCW.
[6] IOFC, income over feed cost = total revenue/pig - feed cost/pig during trial period.
[a,b x,y] Within a row, means without a common superscript differ ($P < 0.05$) for statistical significance and ($P < 0.10$) for tendencies, respectively.

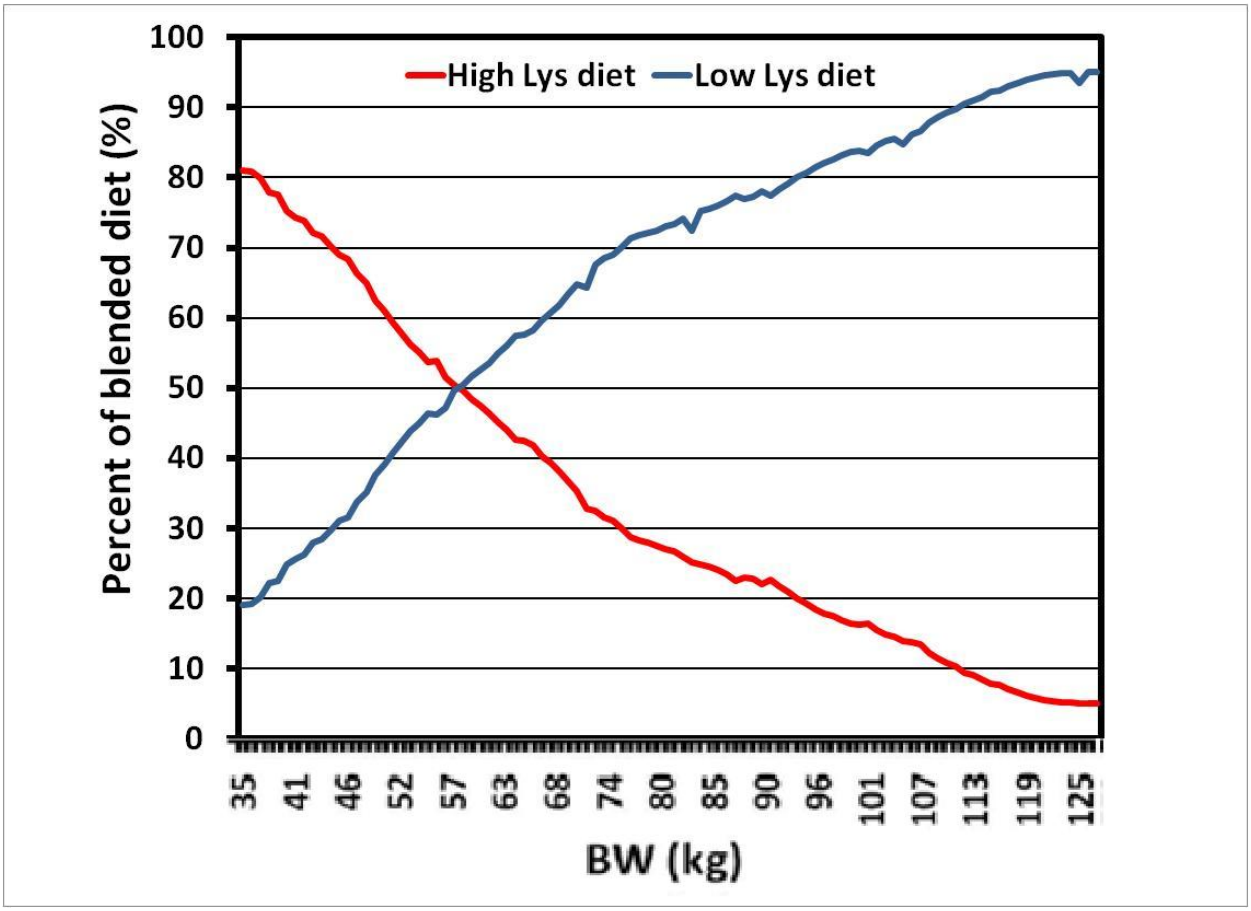

Figure 4-1. Percentage of the high and low Lys diets blended to a set Lys curve using the FEEDPro system (Exp. 1).

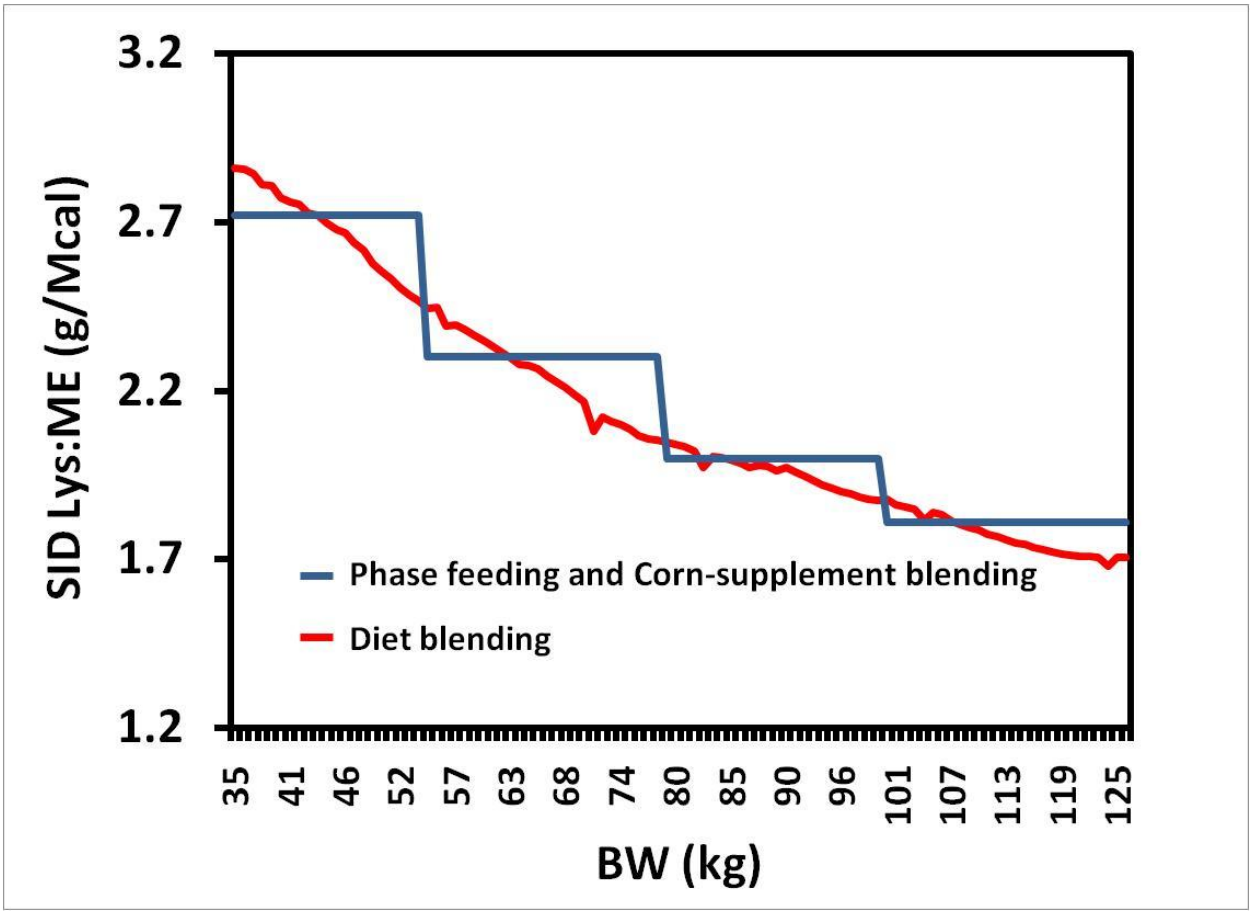

Figure 4-2. SID Lys:ME ratio (g/Mcal) provided to pigs according to a 4-phase feeding program using complete finishing diets, a blend of ground corn-supplement, or a blend of complete high and low Lys diets fed to a set Lys curve using the FEEDPro system (Exp. 1).

Table 4-6. Diet composition for the standard and curve regimens, Exp. 2 (as-fed basis)

	Standard[1]					Curve[2]	
Item	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	High Lys	Low Lys
Ingredient, %							
Corn	52.32	54.98	57.92	60.83	61.45	50.74	61.56
Soybean meal, 46.5% CP	15.43	12.84	10.06	7.18	16.56	17.01	6.50
Dried distillers grains with solubles	30.00	30.00	30.00	30.00	20.00	30.00	30.00
Limestone	1.25	1.20	1.10	1.10	1.03	1.23	1.10
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin and trace mineral premix[3]	0.10	0.10	0.09	0.09	0.09	0.10	0.09
Biolys	0.55	0.52	0.48	0.45	0.45	0.57	0.40
L-thr	---	---	---	---	0.02	---	---
Phytase[4]	0.01	0.01	---	---	---	0.01	---
Ractopamine HCl[5]	---	---	---	---	0.05	---	---
Total	100	100	100	100	100	100	100
Calculated analysis							
SID[6] amino acids, %							
Lys	0.95	0.87	0.78	0.69	0.90	1.00	0.65
Ile:Lys	69	70	72	75	69	68	78
Met:Lys	33	34	37	40	32	32	41
Met & Cys:Lys	67	70	75	81	65	65	85
Thr:Lys	63	65	67	71	65	62	73
Trp:Lys	17	17	17	17	18	17	17
Val:Lys	83	86	90	95	83	82	99
Total Lys, %	1.11	1.03	0.93	0.83	1.04	1.17	0.79
ME, kcal/kg	3,360	3,362	3,366	3,368	3,364	3,360	3,368
SID Lys:ME, g/Mcal	2.83	2.59	2.32	2.05	2.67	2.98	1.93
CP, %	20.19	19.20	18.12	17.00	18.71	20.81	16.71
Ca, %	0.55	0.53	0.48	0.47	0.47	0.55	0.47
P, %	0.47	0.46	0.45	0.43	0.43	0.47	0.43
Available P, %[7]	0.30	0.27	0.24	0.22	0.21	0.30	0.22
Diet cost/t, US $[8]	289.33	285.59	281.36	277.05	329.21	291.77	275.54

[1] Phases 1 to 5 were fed from approximately 35 to 52, 52 to 71, 71 to 86, 86 to 108, and 108 to 127 kg BW, respectively.

[2] Feed delivery based on a Lys requirement curve where a complete high- and low-Lys diet was blended for the duration of the experiment.

[3]Provided per kg of premix: 4,509,409 IU vitamin A; 701,463 IU vitamin D_3; 24,050 IU vitamin E; 1,403 mg vitamin K; 3,006 mg riboflavin; 12,025 mg pantothenic acid; 18,038 mg niacin; and 15.0 mg vitamin B_{12}.Also provided per kg of premix: 40.1 g Mn from manganese oxide and manganese sulfate; 90.2 g Fe from iron sulfate; 100.2 g Zn from zinc oxide; 10.0 g Cu from copper sulfate; 501 mg I from Ethylenediamine dihydroiodide; and 301 mg Se from sodium selenite.

[4] Optiphos 2000 (Enzyvia LLC, Sheridan, IN)

[5] Paylean (Elanco Animal Health, Greenfield, IN). Provides 5 mg/kg ractopamine HCl when added at 0.05% of the diet.
[6] Standardized ileal digestible.
[7] Phytase provided 0.10% available P in diets 1, 2 and the high Lys blending diet.
[8] Diet costs were calculated with $233.58/t corn and $391.88/t soybean meal, along with a $16.50/t manufacturing and delivery charge.

Table 4-7. Composition of the complete supplements (as-fed basis) and the proportion of ground corn and supplement by phase, Exp. 2[1,2]

	Complete supplement			
Ingredient, %	1	2	3	4
Soybean meal (46.5%)	32.35	28.53	23.90	18.34
Dried distillers grains with solubles (DDGS)	62.92	66.64	71.29	76.59
Limestone	2.62	2.67	2.61	2.81
Salt	0.73	0.78	0.83	0.89
Vitamin and trace mineral premix[3]	0.21	0.22	0.21	0.23
L-Lys HCl	1.15	1.16	1.14	1.14
Phytase[4]	0.02	0.01	0.01	---
Total	100	100	100	100
Blend:				
Ground corn, %[5]	52	55	58	61
Complete supplement, %	48	45	42	39
Supplement cost/t, US $[5]	306.15	299.74	291.48	281.78

[1] Diets were blended and feed budgeted to be identical in composition and nutrient analyses for each phase to those fed the standard 4-phase feeding program (Table 4-6).
[2] Phases 1, 2, 3, 4, and 5 were fed from approximately 35 to 52, 52 to 71, 71 to 86, 86 to 108, and 108 to 127 kg BW, respectively.
[3] Provided per kg of premix: 4,509,409 IU vitamin A; 701,463 IU vitamin D_3; 24,050 IU vitamin E; 1,403 mg vitamin K; 3,006 mg riboflavin; 12,025 mg pantothenic acid; 18,038 mg niacin; and 15.0 mg vitamin B_{12}.Also provided per kg of premix: 40.1 g Mn from manganese oxide and manganese sulfate; 90.2 g Fe from iron sulfate; 100.2 g Zn from zinc oxide; 10.0 g Cu from copper sulfate; 501 mg I from Ethylenediamine dihydroiodide; and 301 mg Se from sodium selenite.
[4] Optiphos 2000 (Enzyvia LLC, Sheridan, IN)
[5] Ground corn was priced at $233.58/t and was charged a $13.20/t feed grinding and delivery charge.
[6] Supplement costs were calculated with $399.88/t soybean meal and $220.46/t DDGS, along with an $11.00/t mixing and delivery charge.

Table 4-8. Analyzed dietary Lys content, Exp. 2 (as-fed basis)[1,2]

	Treatment[3]		
Sample	Standard	Curve	Corn-supplement
Phase 1 (35 to 52 kg)	1.06	1.06	0.85
Phase 2 (52 to 71 kg)	0.85	0.88	1.10
Phase 3 (71 to 86 kg)	0.88	0.80	0.72
Phase 4 (86 to 108 kg)	0.82	0.76	0.68

[1] Diets were blended and feed budgeted to be identical in composition and nutrient analyses for each phase to those fed the standard 4-phase feeding program.
[2] Diet samples collected at each time point from several pens per treatment after delivery by the FEEDPro system. Samples were analyzed for total Lys level at the University of Missouri Experiment Station Chemical Laboratories in Columbia, MO.
[3] Standard = complete diets in each phase; Curve = blending of high and low Lys diet fed to a set Lys curve; Corn-supplement = blending of ground corn and complete supplement.

Table 4-9. Effects of diet blending using the FEEDPro system on finishing-pig growth performance, Exp. 2[1]

	Treatment[2]			
Item	Standard	Curve	Corn-supplement	SEM
Pig weights, kg				
Initial	35.9	35.6	35.0	0.69
d 21	53.0	52.1	51.7	0.89
d 42	72.1	70.6	70.2	1.18
d 63	88.0	85.9	85.6	1.10
d 88	110.6^{b}	107.9^{ab}	106.6^{a}	1.04
d 110	129.1^{y}	127.1^{xy}	126.2^{x}	0.98
Phase 1 (35 to 52 kg)				
ADG, kg	0.81^{y}	0.78^{x}	0.80^{xy}	0.015
ADFI, kg	1.80^{y}	1.72^{x}	1.76^{xy}	0.030
G:F	0.453	0.452	0.448	0.006
Phase 2 (52 to 71 kg)				
ADG, kg	0.91	0.88	0.88	0.018
ADFI, kg	2.36	2.27	2.32	0.045
G:F	0.385	0.391	0.379	0.008
Phase 3 (71 to 86 kg)				
ADG, kg	0.75	0.72	0.74	0.021
ADFI, kg	2.71^{b}	2.46^{a}	2.65^{b}	0.042
G:F	0.278	0.294	0.278	0.009
Phase 4 (86 to 108 kg)				
ADG, kg	0.90^{b}	0.88^{b}	0.84^{a}	0.012
ADFI, kg	2.80^{b}	2.62^{a}	2.65^{a}	0.038
G:F	$0.321^{ab,x}$	$0.334^{b,y}$	$0.316^{a,xy}$	0.005
Phase 1 to 4 (35 to 108 kg)				
ADG, kg	0.85^{b}	0.82^{a}	0.81^{a}	0.008
ADFI, kg	2.43^{b}	2.28^{a}	2.36^{ab}	0.030
G:F	0.348^{a}	0.359^{b}	0.345^{a}	0.004
Phase 5 (108 to 127 kg)				
ADG, kg	0.94^{y}	0.88^{x}	0.94^{y}	0.023
ADFI, kg	2.86^{b}	2.79^{a}	2.91^{b}	0.037
G:F	0.329	0.316	0.323	0.008
Overall (35 to 127 kg)				
ADG, kg	0.86^{b}	0.83^{a}	0.84^{a}	0.008
ADFI, kg	2.51^{b}	2.37^{a}	2.45^{b}	0.027
G:F	0.344^{ab}	0.350^{b}	0.340^{a}	0.003

[1] A total of 808 pigs (337 × 1050, PIC, Hendersonville, TN) were used in a 110-d trial with 27 pigs per pen and 10 replicate pens per treatment.

[2] Standard = complete diets in each phase; Curve = blending of high and low Lys diet fed to a set Lys curve; Corn-supplement = blending of ground corn and complete supplement.

[a,b x,y] Within a row, means without a common superscript differ ($P < 0.05$) for statistical significance and ($P < 0.10$) for tendencies, respectively.

Table 4-10. Effects of diet blending using the FEEDPro system on carcass characteristics of finishing pigs, Exp. 2[1]

	Treatment[2]			
Item	Standard	Curve	Corn-supplement	SEM
HCW, kg	95.4[b,y]	93.3[ab,x]	92.5[a,xy]	0.78
Yield, %	75.9	75.9	76.2	0.38
Fat depth, mm[3]	20.2	20.5	19.9	0.43
Loin depth, mm[3]	56.6	56.9	59.4	1.25
FFLI, %[3,4]	50.47	50.71	50.28	0.244

[1] Carcass data from 483 pigs. Standard (6 pens); Curve (10 pens); Corn-supplement (7 pens).
[2] Standard = complete diets in each phase; Curve = blending of high and low Lys diet fed to a set Lys curve; Corn-Supplement = blending of ground corn and complete supplement.
[3] Adjusted with HCW as covariate.
[4] Fat-free lean index (FFLI) was calculated using NPPC (2000) guidelines for carcasses measured with the Fat-O-Meater such that FFLI = ((15.31 + (0.51 × HCW, lb) – (31.277 × last rib fat thickness, in.) + (3.813 × loin muscle depth, in.))/HCW, lb.
[a,b x,y] Within a row, means without a common superscript differ ($P < 0.05$) for statistical significance and ($P < 0.10$) for tendencies, respectively.

Table 4-11 Economics of diet blending using the FEEDPro system, Exp. 2[1]

	Treatment[2]			
Item	Standard	Curve	Corn-supplement	SEM
Feed cost/pig, $				
Phase 1	10.92^{y}	10.50^{x}	10.57^{xy}	0.180
Phase 2	14.17	13.64	13.72	0.268
Phase 3	16.05^{b,y}	14.62^{a,xy}	15.39^{b,x}	0.233
Phase 4	19.37^{b}	18.21^{a}	18.10^{a}	0.261
Phase 5[3]	20.75^{ab}	20.22^{a}	21.09^{b}	0.258
Total	81.25^{b,y}	77.18^{a,xy}	78.86^{ab,x}	0.864
Feed cost/kg gain, $[4]				
Phase 1	0.639	0.641	0.631	0.009
Phase 2	0.745	0.735	0.745	0.015
Phase 3	1.017	0.963	0.996	0.029
Phase 4	1.028	0.991	1.029	0.16
Phase 5	1.049^{x}	1.102^{y}	1.069^{x}	0.029
Total	0.902	0.892	0.901	0.009
Total revenue, $/pig[5,6]	188.11	185.84	184.42	1.671
IOFC, $/pig[7]	106.86	108.66	105.55	1.521

[1] Data collected from 808 pigs (approximately 270 pigs per treatment).
[2] Standard = complete diets in each phase; Curve = blending of high- and low-Lys diet fed to a set Lys curve; Corn-supplement = blending of ground corn and complete supplement.
[3]Paylean diet delivered in same form across all treatments. Differences are due to variation in performance.
[4] Feed cost/kg gain = (direct feed cost + GMD cost/pig) ÷ total live gain; assumed grinding = $5.50/t; mixing = $3.30/t; delivery and handling = $7.70/t.
[5] Carcass base bid = $1.99/kg.
[6] Total revenue = carcass price (including premiums/discounts for lean and yield) × HCW.
[7] IOFC, income over feed cost = total revenue/pig - feed cost/pig.
[a,b x,y] Within a row, means without a common superscript differ ($P < 0.05$) for statistical significance and ($P < 0.10$) for tendencies, respectively.

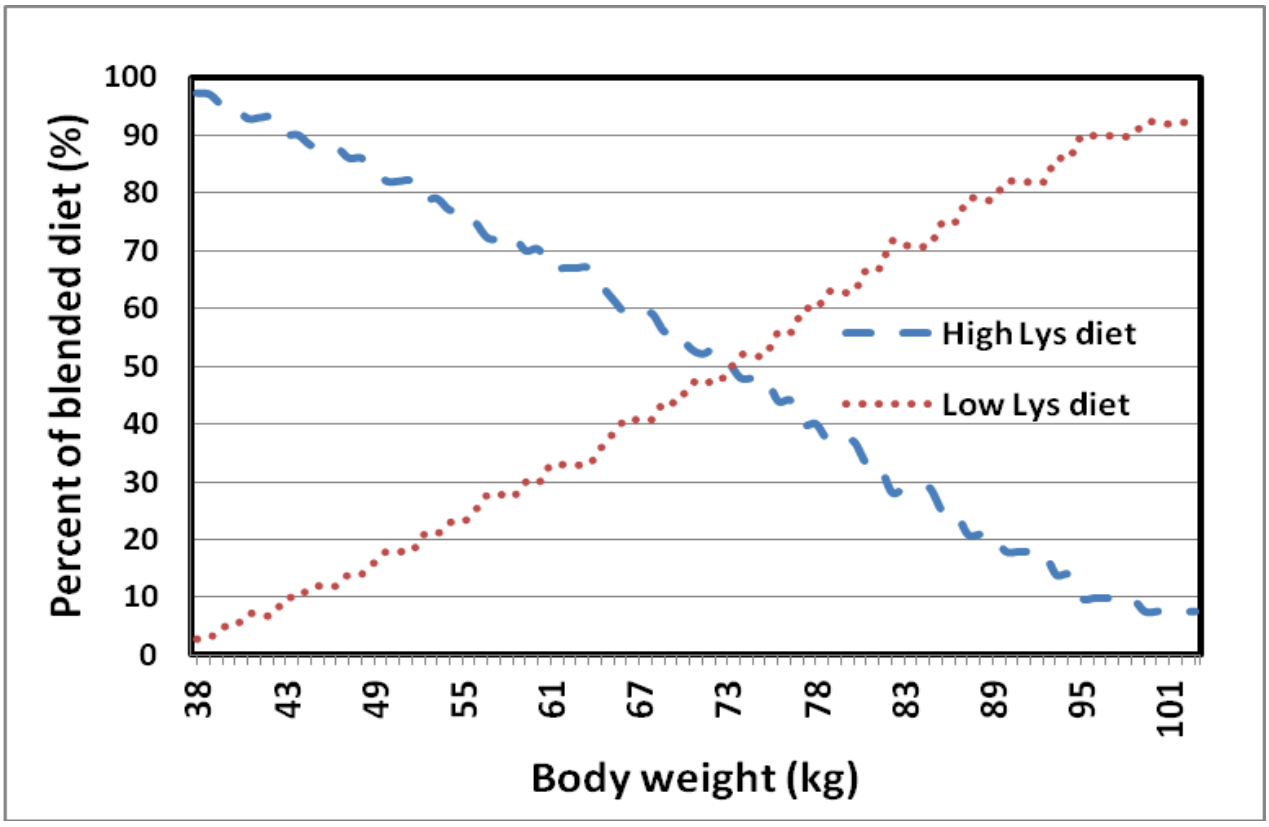

Figure 4-3. Percentage of the high and low Lys diets blended to a Lys requirement curve using the FEEDPro system (Exp. 2).

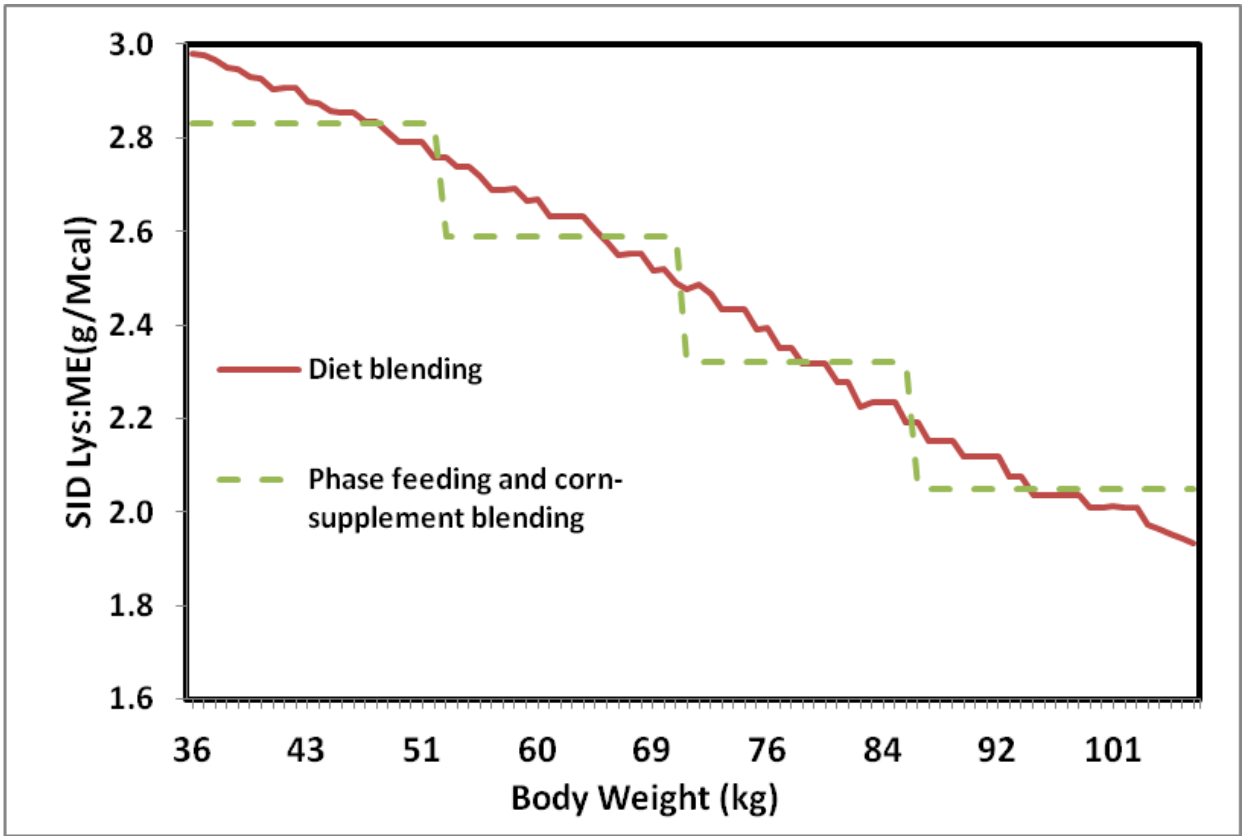

Figure 4-4. SID Lys:ME ratio (g/Mcal) provided to pigs according to a 4-phase feeding program using complete finishing diets, a blend of ground corn-supplement, or a blend of complete high and low Lys diets fed to a set Lys curve using the FEEDPro system (Exp. 2).

Table 4-12. Diet composition for the standard and curve regimens, Exp. 3 (as-fed basis)

	Standard[1]				Curve[2]	
Item	Phase 1	Phase 2	Phase 3	Phase 4	High Lys	Low Lys
Ingredient, %						
Corn	78.42	83.10	86.46	88.45	75.80	89.11
Soybean meal, 46.5% CP	18.95	14.60	11.48	9.63	21.44	8.99
Monocalcium phosphate, 21% P	0.50	0.30	0.23	0.15	0.55	0.13
Limestone	0.95	0.95	0.90	0.90	0.96	0.93
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.15	0.13	0.10	0.08	0.16	0.07
Trace mineral premix[4]	0.15	0.13	0.10	0.08	0.16	0.07
L-Lys HCL	0.30	0.26	0.23	0.22	0.32	0.21
DL-Met	0.03	---	---	---	0.04	---
L-Thr	0.07	0.04	0.03	0.04	0.09	0.04
Phytase[5]	0.13	0.13	0.13	0.13	0.13	0.13
Total	100	100	100	100	100	100
Calculated analysis						
SID[6] amino acids, %						
Lys	0.91	0.77	0.67	0.61	0.99	0.59
Ile:Lys	61	63	64	66	60	66
Met:Lys	29	28	30	32	29	32
Met & Cys:Lys	56	58	62	66	55	67
Thr:Lys	62	62	63	66	62	66
Trp:Lys	16.5	16.5	16.5	16.5	16.5	16.5
Val:Lys	71	74	78	81	69	82
Total Lys, %	1.01	0.86	0.75	0.69	1.10	0.67
ME, kcal/kg	3,340	3,349	3,355	3,362	3,336	3,362
SID Lys:ME, g/Mcal	2.72	2.30	2.00	1.81	2.97	1.75
CP, %	15.80	14.10	12.90	12.20	16.80	12.00
Ca, %	0.54	0.49	0.45	0.43	0.56	0.43
P, %	0.46	0.40	0.37	0.35	0.48	0.34
Available P, %[7]	0.28	0.23	0.21	0.19	0.29	0.19
Diet cost/t, US $[8]	284.97	275.54	270.13	266.78	290.08	265.53

[1] Phases 1, 2, 3, and 4 were fed to Standard phase feeding treatment from d 0 to 23, 23 to 49, 49 to 72, and 72 to 95, respectively. Over and Under treatments underwent phase changes automatically when allotted budget was consumed.

[2] Feed delivery based on a Lys requirement curve where a complete high- and low-Lys diet was blended for the duration of the experiment.

[3] Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and

15.4 mg vitamin B_{12}.
[4] Provided per kg of premix: 26.5 g Mn from manganese oxide; 110 g Fe from iron sulfate; 110 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.
[5] Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided 600,533 phytase units phytase/kg.
[6] Standardized ileal digestible.
[7]Phytase provided 0.10% available P to the diet.
[8] Diet costs were calculated with $233.58/t corn and $391.88/t soybean meal along with a $16.50/t manufacturing and delivery charge.

Table 4-13. Analyzed **dietary Lys content, Exp. 3 (as-fed basis)**[1]

Diet	Total Lys, %
Phase feeding[2]	
Phase 1	0.98
Phase 2	0.84
Phase 3	0.72
Phase 4	0.69
Feed blending[3]	
High-Lys	1.03
Low-Lys	0.64

[1] Diet samples collected after diet manufacturing. Samples were analyzed for total Lys level at the University of Missouri Experiment Station Chemical Laboratories in Columbia, MO.

[2] Phase 1, 2, 3, and 4 were fed to the Standard phase feeding treatment from d 0 to 23 (53.1 kg), 23 to 49 (62.6 kg), 49 to 72 (72.7 kg), and 72 to 95 (79.4 kg), respectively. Over and under treatments underwent phase changes automatically when allotted budget was consumed.

[3] Feed delivery based on a Lys requirement curve where a complete high- and low-Lys diet was blended for the duration of the experiment.

Table 4-14. Effects of diet blending using the FEEDPro system and over- or under-budgeting in phase-feeding programs on finishing pig growth performance, Exp. 3[1]

	Treatment				
Item	Standard	Curve	Over	Under	SEM
Pig weights, kg					
Initial	36.2	36.2	36.2	36.2	0.39
d 23	59.0^{xy}	58.2^{x}	59.1^{y}	59.0^{xy}	0.56
d 49	81.3	80.2	80.7	80.7	0.80
d 72	109.6	107.8	108.8	108.7	1.11
d 95	132.8	131.1	131.8	132.0	1.31
Phase 1 (d 0 to 23)					
ADG, kg	1.00^{b}	0.96^{a}	1.00^{b}	0.99^{b}	0.012
ADFI, kg	2.12	2.09	2.10	2.10	0.028
G:F	0.469^{ab}	0.457^{a}	0.474^{b}	0.472^{b}	0.005
Phase 2 (d 23 to 49)					
ADG, kg	0.99	0.95	0.96	0.97	0.018
ADFI, kg	2.55^{ab}	2.42^{a}	2.48^{ab}	2.57^{b}	0.051
G:F	0.387^{b,xy}	0.392^{b,xy}	0.385^{ab,y}	0.376^{a,x}	0.004
Phase 3 (d 49 to 72)					
ADG, kg	1.08^{b}	1.05^{ab}	1.01^{a}	1.07^{b}	0.021
ADFI, kg	2.98	2.94	2.91	2.89	0.045
G:F	0.365	0.359	0.348^{a}	0.371^{b}	0.008
Phase 4 (d 72 to 95)					
ADG, kg	1.01	1.01	1.00	1.01	0.020
ADFI, kg	3.27	3.35	3.23	3.27	0.055
G:F	0.309	0.302	0.310	0.309	0.005
Overall (d 0 to 95)					
ADG, kg	1.02	0.99	0.99	1.01	0.012
ADFI, kg	2.72	2.69	2.67	2.71	0.037
G:F	0.374	0.369	0.371	0.373	0.004

[1] A total of 252 pigs (337 × 1050, PIC; Hendersonville, TN) were used in a 95-d trial with 9 replicate pens per treatment and 7 pigs per pen.
[2] Standard = complete diets in each phase; Curve = blending of high- and low-Lys diet fed to a set Lys curve; Over = phase feeding diets with 20% greater feed budget per phase; Under = phase feeding with 20% lower feed budget per phase.
[a,b x,y] Within a row, means without a common superscript differ ($P < 0.05$) for statistical significance and ($P < 0.10$) for tendencies, respectively.

Table 4-15. Effects of diet blending using the FEEDPro system and over- or under-budgeting in phase-feeding programs on carcass characteristics of finishing pigs, Exp. 3[1]

	Treatment[2]				
Item	Standard	Curve	Over	Under	SEM
HCW, kg	99.7^{y}	97.6^{x}	97.9^{xy}	98.5^{xy}	0.97
Yield, %	75.1^{y}	74.5^{x}	74.4^{xy}	74.6^{xy}	0.24
Lean, %[3,4]	50.1	50.2	50.5	50.1	0.30
Fat depth, mm[3]	25.8	24.9	24.6	25.4	0.52
Loin depth, mm[3]	58.6	57.6	58.9	58.1	1.04

[1] A total of 252 pigs (337 × 1050, PIC; Hendersonville, TN) were used in a 95-d trial with 9 replicate pens per treatment and 7 pigs per pen.
[2] Standard = complete diets in each phase; Curve = blending of high- and low-Lys diet fed to a set Lys curve; Over = phase feeding diets with 20% greater feed budget per phase; Under = phase feeding with 20% lower feed budget per phase.
[3] Adjusted with HCW as covariate.
[4] Calculated using NPPC (1991) guidelines for lean containing 5% fat. Lean % = (2.83 + (0.469 × (0.4536 × HCW)) – (18.47 × (0.0394 × Fat depth)) + (9.824 × (0.0394 × Loin depth))/ (0.4536 × HCW).
[a,b x,y] Within a row, means without a common superscript differ ($P < 0.05$) for statistical significance and ($P < 0.10$) for tendencies, respectively.

Table 4-16. Economics of diet blending using the FEEDPro system and over- or under budgeting in phase-feeding programs on finishing pig performance, Exp. 3[1]

	Treatment[2]				
Item	Standard	Curve	Over	Under	SEM
Feed cost/pig, $					
Phase 1	15.90	15.57	15.76	15.81	0.189
Phase 2	20.79^{b}	18.46^{a}	20.32^{b}	20.54^{b}	0.405
Phase 3	24.27^{b}	22.91^{a}	24.15^{b}	23.80^{ab}	0.386
Phase 4	24.62	24.09	24.73	24.67	0.355
Total	85.59^{b}	81.03^{a}	84.95^{b}	84.82^{b}	0.949
Feed cost/kg gain, $[4]					
Phase 1	0.695^{ab}	0.709^{b}	0.687^{a}	0.694^{ab}	0.007
Phase 2	0.810^{b}	0.748^{a}	0.817^{b}	0.818^{b}	0.009
Phase 3	0.974^{ab,x}	0.948^{a,x}	1.047^{b,y}	0.965^{a,x}	0.027
Phase 4	1.064	1.037	1.078	1.060	0.019
Total	0.885^{ab,y}	0.861^{a,x}	0.902^{b,y}	0.885^{ab,y}	0.008
Total revenue, $/pig[5,6]	192.87^{y}	187.25^{x}	187.75^{x}	190.32^{xy}	2.161
IOFC, $/pig[7]	111.98^{y}	107.37^{x}	107.43^{x}	110.17^{xy}	1.953

[1] A total of 252 pigs (337 × 1050, PIC; Hendersonville, TN) were used in a 95-d trial with 9 replicate pens per treatment and 7 pigs per pen.
[2] Standard = complete diets in each phase; Curve = blending of high- and low-Lys diet fed to a set Lys curve; Over = phase feeding diets with 20% greater feed budget per phase; Under = phase feeding with 20% lower feed budget per phase.
[3] Feed cost/kg gain = (Direct feed cost + GMD cost/pig) ÷ total live gain; Assumed grinding = $5.50/t; mixing = $3.30/t; delivery and handling = $7.70/t.
[4] Total revenue = carcass base price ($1.99/kg; includes premiums/discounts for lean and yield) × HCW.
[5] IOFC, income over feed cost = total revenue/pig - feed cost/pig.
[a,b x,y] Within a row, means without a common superscript differ ($P < 0.05$) for statistical significance and ($P < 0.10$) for tendencies, respectively.

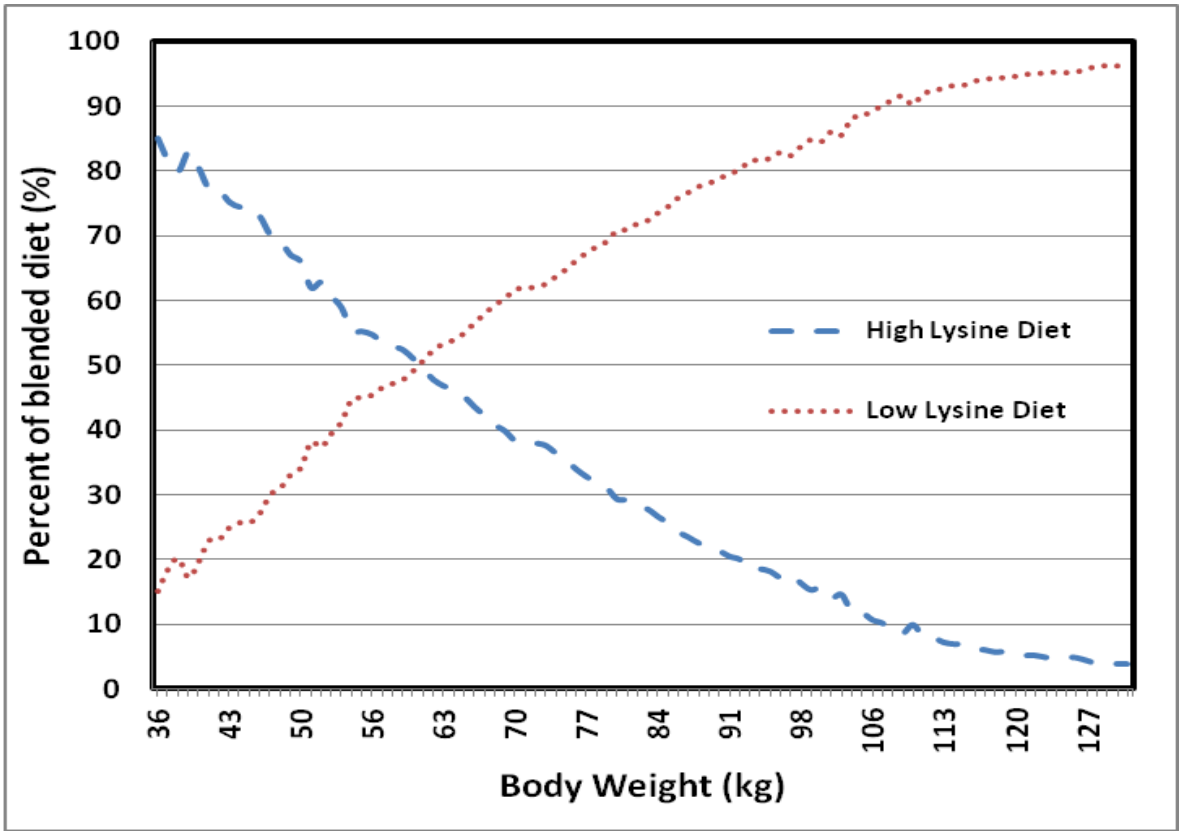

Figure 4-5. Percentage of high- and low-Lys diets blended to a set Lys curve using the FEEDPro system.

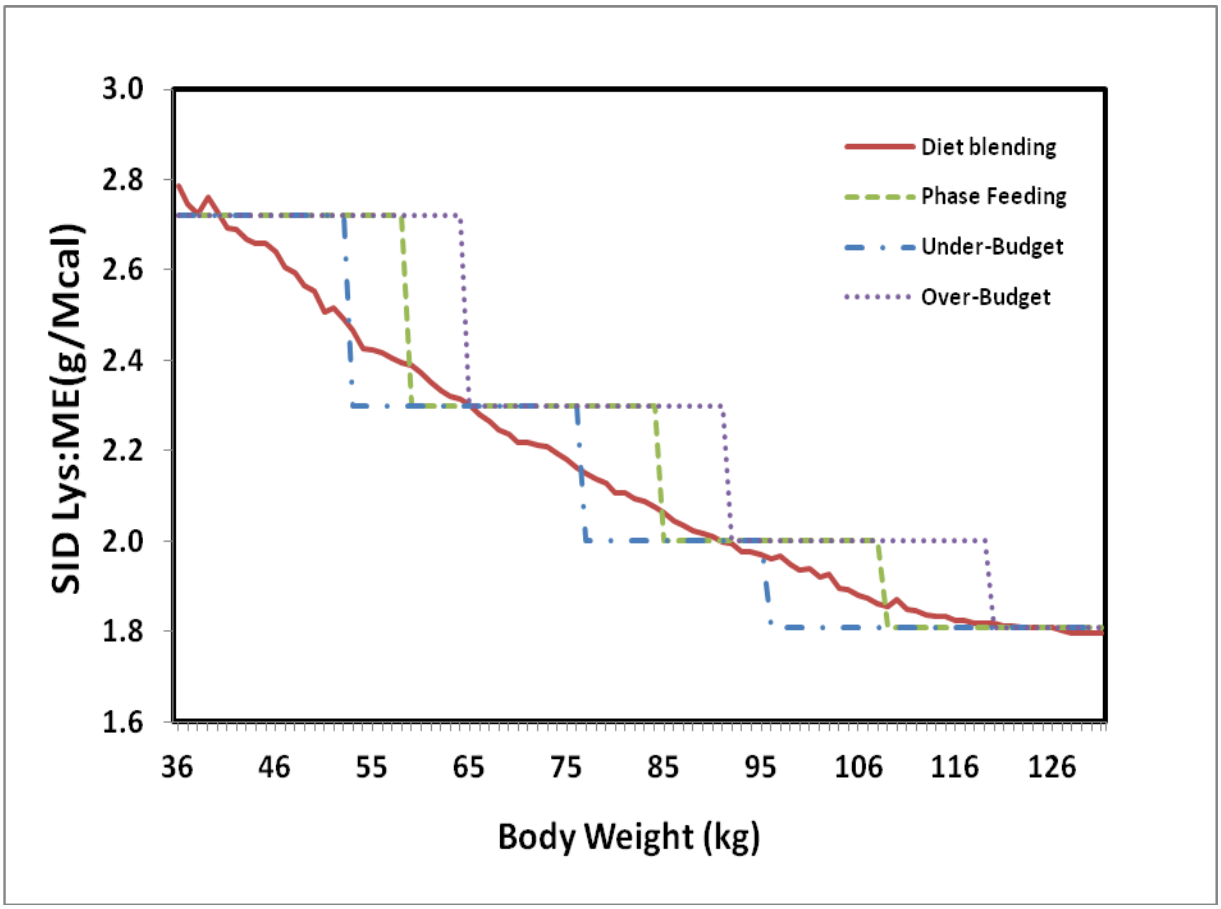

Figure 4-6. SID Lys:ME ratio (g/Mcal) delivered to pigs (36 to 132 kg BW) based on a 4-phase feeding program with 3 different feed budgeting strategies compared to blending of high- and low-Lys diets based on a predetermined Lys curve using the FEEDPro system.