THE EFFECTS OF DIETARY FAT SOURCE AND FEEDING DURATION ON PIG GROWTH PERFORMANCE AND FAT QUALITY

by

ETHAN WADE STEPHENSON

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College of Agriculture

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Approved by:

Major Professor
Michael Tokach

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Abstract

In 3 experiments, 4,720 pigs were used to determine the effects of: 1) dietary fat and feeding duration on growth performance and fat quality in finishing pigs; or 2) a novel protease or 3) increasing levels of Zn amino acid complex (ZnAA) or ZnO on finishing pig performance. Experiment 1 tested the effects of feeding tallow, soybean oil, or a blend of the two for various feeding durations (d 0 to 42, 42 to 84, or 0 to 84). Overall, pigs fed added fat for the entire 84 d had improved G:F compared to those fed a control diet. Additionally, pigs fed additional fat for the entire study had improved ADG and G:F as well as increased d 84 BW compared to pigs fed additional fat for 42 d. Increasing the feeding duration of soybean oil lowered monounsaturated fatty acids and increased polyunsaturated fatty acid concentrations while these values remained relatively unchanged by the addition of tallow. There were feeding period by fat source interactions for fatty acid composition and iodine value for belly and backfat, but not jowl fat, indicating a longer turnover rate for jowl fat compared to belly or backfat. In Exp. 2, adding a protease to a nutrient deficient diet increased ADFI and tended to increase ADG compared to pigs fed a negative control diet. There were no differences observed in ADG, ADFI, or G:F between pigs fed a positive control diet, formulated to 90% of the pigs SID lysine requirement, and those fed a negative control diet plus the protease, which would suggest the release values attributed to the enzyme were accurate. In Exp. 3, supplementing additional Zn from either ZnAA or ZnO at 25, 50, or 75 ppm in finishing diets for commercial finishing pigs was evaluated. Overall, no differences were observed in ADFI, but a Zn source by level interaction was observed for ADG and G:F, as pigs fed increasing ZnO were observed to have similar performance, while pigs fed added levels of 25 and 50 ppm Zn from ZnAA had decreased performance compared to those fed the highest level of ZnAA.

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Chapter 1 - Influence of dietary fat source and feeding duration on finishing pig growth performance, carcass composition, and fat quality

ABSTRACT

A total of 160 finishing pigs (PIC 327 × 1050; initially 45.6 kg) were used in an 84-d experiment to evaluate the effects of dietary fat source and feeding duration on growth performance, carcass characteristics, and carcass fat quality. There were 2 pigs per pen with 8 pens per treatment. The 10 dietary treatments were a corn-soybean meal control diet with no added fat and a 3 × 3 factorial with main effects of fat source (4% tallow, 4% soybean oil, or a blend of 2% tallow and 2% soybean oil) and feeding duration (d 0 to 42, 42 to 84, or 0 to 84). The control corn-soybean meal diet was fed in place of added fat diets when needed for duration treatment purposes. On d 0, 1 pig was identified in each pen and fat biopsy samples of the back, belly, and jowl were collected on d 0, 41, and 81 for fatty acid analysis. At the conclusion of the study, all pigs were harvested, carcass characteristics were determined, and back, belly, and jowl fat samples were collected for analysis. Overall (d 0 to 84), there were no differences among pigs fed the different fat sources for growth and carcass characteristics; however, pigs fed diets with added fat for the entire study had improved (P=0.036) G:F compared to pigs fed the control diet without added fat. Pigs fed supplemental fat throughout the entire study also had improved (P<0.05) ADG and G:F as well as heavier d 84 BW (P=0.006) compared to pigs fed additional fat during only one period. Adding fat for the entire study increased (P=0.032) backfat and tended to reduce (P=0.079) fat free lean index compared to pigs fed the control diet without added fat. Added fat also increased (P<0.05) iodine value (IV) when compared to pigs fed the control diet. Increasing the feeding duration of soybean oil lowered monounsaturated fatty acids

(MUFA) and increased polyunsaturated fatty acid (PUFA) concentrations for all fat depots, while these values remained relatively unchanged by the addition of tallow (duration × fat source interactions, $P<0.05$). Our study failed to show any feeding period × fat source interactions ($P<0.05$) in fatty acid composition or IV for jowl fat, whereas this interaction occurred for belly and backfat, which would indicate a longer turnover rate for jowl fat. In conclusion, feeding additional fat improved ADG and G:F; however, feeding soybean oil for an increased duration, either alone or in combination with tallow, negatively affected the fatty acid composition and IV of different fat depots.

INTRODUCTION

The addition of fats and oils in swine diets has been shown to decrease feed intake, increase ADG, and improve feed efficiency in grow-finish pigs (De la Llata et al., 2001). However, carcass quality in pork can be negatively affected by dietary ingredients and fat sources, as the fatty acid profile of the pork fat is related to those in the diet (Wood et al., 2003). Iodine Value (**IV**) is commonly used by pork processors to evaluate pork fat quality as an indication of the proportion of unsaturated fatty acids present. Processors that are measuring IV target a value of 73 to 75g/100 g, with high values being less ideal (Benz et al., 2010). High IV values create challenges for processors as the "soft fat" can create problems in belly slicing and reduce shelf life due to oxidative rancidity (NRC, 2012).

Fat source (Apple et al., 2009a), withdrawal periods (Xu et al., 2009), and duration of feeding unsaturated feeds (Browne et al., 2013a) has been shown to affect IV. It has been suggested that removing unsaturated fat sources in late finishing diets could alleviate some of the negative effects of these fat sources on carcass and fat quality (Benz et al., 2011a). Limiting the

duration of feeding unsaturated fats and substituting a saturated fat, such as beef tallow, in late finishing has shown promise for positively affecting IV (Browne et al., 2013a; Kellner et al., 2014).

Paulk et al. (2015) performed a meta-analysis to generate predictive IV equations for various fat depots in swine. This study was used to validate those equations. A portion of the data from this study was reported by Paulk et al. (2015) with the remainder being reported herein. This study was conducted to determine the effects of feeding soybean oil, beef tallow, or a blend of the two, as well as feeding duration, on finishing pig growth performance, carcass characteristics, and IV of belly, jowl and backfat. Change in fatty acid profile throughout the duration of the study was also evaluated.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. A total of 160 finishing pigs (PIC 327 × 1050) with an average initial BW of 45.6 $\pm$ 0.25 kg were housed at the Kansas State University Swine Teaching and Research Center finishing barn. The finishing barn was an environmentally controlled facility with 2.32 m^2 slatted-floor pens. Each pen was equipped with a dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Upon placement in the barn, pigs were fed a common corn-soybean meal based diet without added fat prior to the start of the experiment.

Animals and Diets

Pens of pigs were blocked by sex and BW and allotted to 1 of 10 dietary treatments, with 2 barrows or 2 gilts housed in each pen with a total of 8 pens per treatment. Dietary treatments consisted of a corn-soybean meal control diet with no added fat or a 3 × 3 factorial arrangement of treatments with main effects of fat source (4% tallow, 4% soybean oil, or a blend of 2% tallow and 2% soybean oil) and feeding duration (d 0 to 42, 42 to 84, or 0 to 84). The control corn-soybean meal diet was fed in place of added fat diets when needed for duration treatment purposes. Diets were formulated to be fed in 3 phases (d 0 to 28, d 28 to 56, and d 56 to 84) (Table 1). Soybean oil, tallow, and a blend of the two were added to provide diets high in unsaturated fatty acids, high in saturated fatty acids, or a blend of the two, respectively. A constant standardized ileal digestible Lys:NE ratio was maintained within each phase by increasing soybean meal in the diets with added fat. Diets were formulated by using NRC (2012) composition values for ingredients. Dietary treatments were prepared at the Kansas State University O.H. Kruse Feed Technology Innovation Center.

Sample Collection

Samples of each diet were collected from feeders for each phase and treatment. Samples were then subsampled and analyzed for DM (method 934.01; AOAC, 2006), CP (method 990.03; AOAC, 2006), CF (method 978.10; AOAC, 2006), crude fat (method 920.39; AOAC, 2006), ash (method 942.05; AOAC, 2006), ADF and NDF (Van Soest, 1963; Ward Laboratories Inc., Kearney, NE; Table 2).

Pigs and feeders were weighed approximately every 2 wk to calculate ADG, ADFI, and G:F. Prior to marketing, pigs were individually tattooed so that carcass measurements could be collected on an individual pig basis. On d 84, final pig weights were taken and pigs were

transported approximately 530 km to a commercial packing facility for harvest (Sioux-Preme Packing Co., Sioux Center, IA). Fat samples (jowl, 10th rib, and belly) were collected at the commercial packing facility as close to the d 81 biopsy site as possible (see procedure below). Carcass measurements taken at the plant included HCW, 10th rib loin eye area, and backfat depth.

One pig from every pen was identified and fat biopsy samples were collected and analyzed for fatty acid and IV on d 0, 41, and 81. For sample collection, pigs were restrained using a snare, the hair was clipped in each location (jowl, belly, and loin), and 1 mL of Lidocaine was administered to the sample location. The location of the first backfat biopsy location was approximately at the first lumbar vertebra. The location was determined by following the curvature of the last rib of the animal to where it met the vertebral column, moving 1.27 cm towards the posterior of the animal and 1.27 cm lateral from midline. For subsequent collections, the location moved in a straight line 2.54 cm towards the posterior of the animal from the previous biopsy site. The landmark for the first jowl biopsy site was approximately at the angle of the mandible. The location was moved in a straight line 2.54 cm towards the posterior of the animal from the previous biopsy site for subsequent biopsies. The location of the first belly biopsy was directly ventral relative to the backfat biopsy. The location was determined by following the curvature of the last rib towards where it terminates on the underbelly, moving 1.27 cm towards the posterior of the animal and 1.27 cm lateral from midline. For subsequent collections on d 41 and 81, locations were moved in a straight line 2.54 cm towards the posterior of the animal from the previous biopsy site. After adequate time was given for the biopsy site to be desensitized, an 8 gauge needle was used to pierce the skin and a 10 gauge biopsy needle was

used to collect approximately 250 mg of tissue per biopsy site. Fat tissue samples were snap frozen in liquid N and then stored in a -80˚C freezer until analysis.

Fat Quality Analysis

Both feed and fat depot samples were analysed according to Palmquist and Jenkins (2003) with revisions. Samples were analysed by mixing 0.025 g of dry sample with 2 mL of benzene containing methyl tridecanoate as internal standard (2 mg/mL of benzene, Fluka 91558) and 3 mL methanolic-HCl before being flushed with nitrogen. Tubes were then capped, vortexed, heated for 2 h at 70°C, and vortexed every 30 min during heating. Tubes were cooled to room temperature, mixed with 5 mL 6% K_2CO_3 and 2 mL benzene, vortexed, and then centrifuged at 500 × *g* for 5 min. The organic solvent layer was then analysed by gas chromatography. An Agilent gas chromatograph (model 7890A, Santa Clara, CA) equipped with a HP-88 J&W Agilent GC capillary column (30 m × 0.25 mm × 0.20 μm film) was used for the analysis. The injection temperature was 250°C, the split ratio was 1:100, the flame-ionization detector was set at 280°C and used hydrogen (35 mL/min), air (400 mL/min), makeup helium (25 mL/min), and helium carrier gas at constant flow (0.91 mL/min). The oven temperature program was set as follows: initial temperature of 80°C, hold 1 min, increase 14°C/min to 240°C, and hold 3 min. Supelco 37 Component FAME Mix (47885-U Supelco, Sigma-Aldrich) was used as a standard. Calculation of IV from the fatty acid profile was done according to the following equation: (IV) = (% C16:1) × 0.9502 + (% C18:1) × 0.8598 + (% C18:2) × 1.7315 + (% C18:3) × 2.6152 + (% C20:1) × 0.7852 + (% C20:4) × 3.2008 + (% C20:5) × 4.0265 + (% C22:1) × 0.7225 + (% C22:5) × 3.6974 + (C22:6) × 4.4632 (NRC, 2012).

Statistical Analysis

All growth performance and carcass data was analyzed as a randomized complete block design using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC) with pen as the experimental unit. Pens were blocked by BW within sex. Block was included as a random effect. Sex, fat source, feeding duration, and all their possible interactions served as fixed effects. Feeding duration refers to the length of time fat was added into the diet (42 or 84 d); while feeding period refers to when fat was added into the diet (period 1 was d 0 to 42 while d 42 to 84 was period 2). Hot carcass weight was used as a covariate to analyze backfat, loin depth and percentage lean. Contrast statements for both periods 1 and 2 consisted of: 1) no added fat vs added fat, 2) tallow vs blend, 3) blend vs soy oil, and 4) tallow vs soy oil. Contrast statements for the overall growth performance and carcass characteristics were: 1) no added fat vs. added fat both periods, 2) added fat both periods vs. added fat only during a single period, 3) added fat only during period 1 vs. added fat only during period 2, 4) tallow vs. blend, 5) blend vs. soy oil, and 6) tallow vs. soy oil. The statistical structure was the same for fatty acid composition except day of sample collection and all possible interactions were included as fixed effects. Day was included as the repeated variable with pig as the subject. The covariance structure modified first-order autoregressive model was used. For fatty acid composition, contrast statements evaluating the interactions of feeding duration, feeding period and fat source were used, while also comparing the main effect of fat source. Statistical significance was determined at $P < 0.05$ and P-values falling within $P > 0.05$ and $P < 0.10$ were defined as a trend or tendency.

RESULTS

Diet Analysis

Diet analyses revealed that nutrients were similar to calculated values considering normal analytical variation. Chemical analyses of tallow and soybean oil used in this study were similar to expectations and indicated large differences in total saturated fatty acids (**SFA**); specifically, 45.7 and 15.1% for tallow and soybean oil, respectively (Table 3). Conversely, total PUFA concentrations were 6.7 and 58.9% for tallow and soybean oil, respectively. As a result, IV for soybean oil, 129.9 g/100 g, was more than double that of tallow, 49.9 g/100 g. Diet analysis for each of the 3 phases were consistent amongst one another, as diets with 4% tallow maintained greater total SFA concentrations relative to 4% soybean oil diets, with diets having a blend of the two sources being intermediate. In contrast, 4% soybean oil diets had greater concentrations of total PUFA in comparison to 4% tallow diets, with the blend of the two being intermediate.

Growth and Carcass Characteristics

From d 0 to 42, pigs fed diets with added fat had increased ($P = 0.005$) ADG and improved ($P = 0.001$) G:F compared to pigs fed diets not containing added fat (Table 4). Pigs fed diets with added tallow or soybean oil had improved ($P < 0.05$) G:F compared with pigs fed a diet containing a blend of soybean oil and tallow. During period 2 (d 42 to 84), pigs tended ($P = 0.052$) to have increased ADG and had improved ($P = 0.001$) G:F when fed added fat. No differences were found among fat sources during period 2.

Overall (d 0 to 84), pigs fed added fat in both periods had increased ($P = 0.018$) ADG and improved ($P = 0.042$) G:F as well as greater final BW ($P = 0.006$) compared to pigs fed additional fat only during a single period (d 0 to 42 or 42 to 84). In addition, pigs fed fat in both periods had improved ($P = 0.036$) G:F compared to pigs fed diets not containing added fat. Pigs

fed diets with soybean oil tended to have improved ($P = 0.092$) G:F vs. those fed a diet containing a blend of soybean oil and tallow.

For carcass characteristics, adding fat from d 0 to 84 increased ($P = 0.032$) backfat and tended to reduce ($P = 0.079$) fat free lean index compared to pigs fed diets with no added fat. There were no differences ($P > 0.10$) in HCW, percentage yield, or loin eye area among treatments.

Fatty Acid Composition and Iodine Value

Backfat

The main effect of adding 4% fat increased ($P < 0.05$) C18:2, C18:3, PUFA, and IV while decreasing ($P < 0.05$) C16:1, C18:1, C20:1, SFA, and MUFA compared to pigs fed a control diet over both periods (Table 5). A feeding duration × fat source interaction ($P < 0.05$) was observed for C18:1, C18:2, C18:3, SFA, MUFA, PUFA, and IV for pigs fed tallow vs. soybean oil and for C18:2, C18:3, C20:1, MUFA, PUFA, and IV for the blend of soybean oil and tallow vs. soybean oil. In both of these interactions, MUFA was decreased while PUFA was increased by the addition of soybean oil whereas the values were relatively unchanged by the addition of tallow or a blend of the two. A feeding duration × fat source (tallow vs. the blend of soybean oil and tallow) interaction ($P < 0.05$) was also observed for C18:2, C18:3, PUFA, and IV as those were increased to a greater extent by the blend of soybean oil and tallow vs. tallow alone. The duration of feeding tallow did not impact IV (Figure 1 Panel A), while the increased duration of feeding the blend diet (Figure 1 Panel B) increased backfat IV 7.2 g/100g compared to those fed tallow. Feeding soybean oil (Figure 1 Panel C) for the increased duration of 84 d also increased backfat IV by 15.4 g/100g when compared to pigs fed tallow.

Feeding period × fat source interactions ($P < 0.05$) were observed for C18:2, C18:3, MUFA, PUFA, and IV for pigs fed the blend of soybean oil and tallow vs. soybean oil and tallow vs. soybean oil. For tallow vs. soybean oil, the interaction ($P < 0.05$) also occurred for C18:1 and C20:1. These interactions were a result of pigs fed soybean oil from d 42 to 84 having a greater increase in PUFA and reduction in MUFA on d 84 which increased IV by 6 g/100g when compared to pigs fed soybean oil from d 0 to 42; whereas feeding tallow or the blend of soybean oil and tallow had relatively similar values for d 84 MUFA, PUFA, and IV regardless of period fed. For pigs fed the control diet from d 0 to 42 and then added fat from d 42 to 84, tallow or the blend of soybean oil and tallow reduced backfat IV by 8.9 and 3.9 g/100g, respectively, compared to those fed soybean oil.

No interactions were observed for C16:1 concentration's in backfat biopsies, however, feeding tallow did increase ($P < 0.05$) the fatty acid's concentration level in the fat depot for d 42 and 84 compared to pigs fed the blend of soybean oil and tallow as well as those fed soybean oil. Also for d 84, pigs fed the blend of soybean oil and tallow had increased ($P < 0.05$) concentrations of C16:1 in comparison to pigs fed soybean oil. C22:5n3 concentrations were increased ($P < 0.05$) on d 84 for pigs fed soybean oil compared to pigs fed tallow.

Belly Fat

Adding 4% fat increased ($P < 0.05$) C18:2, C18:3, PUFA, and IV and decreased ($P < 0.05$) C16:1, C18:1, SFA, and MUFA for both period 1 and 2 compared to control pigs (Table 6). In addition, C20:1 was decreased ($P < 0.05$) on d 84 when 4% fat was added compared to pigs fed the control diet which contained no added fat. Feeding duration × fat source interactions ($P < 0.05$) were observed for pigs fed soybean oil vs. tallow for C18:1, C18:2, C18:3, SFA, MUFA, PUFA, and IV. A feeding duration × fat source interaction ($P < 0.05$) was also observed for

C18:2, C18:3, PUFA, and IV for pigs fed soybean oil vs. the blend of soybean oil and tallow. Furthermore, feeding duration × fat source interactions ($P < 0.05$) for tallow vs. the blend of soybean oil and tallow for C18:2, C18:3, and PUFA were observed, while also finding a tendency ($P = 0.081$) for IV. These interactions were a result of feeding duration not affecting IV for pigs fed tallow (Figure 2 Panel A) while the increased duration from 42 to 84 d increased IV by 2.54 g/100g for pigs fed the blend of tallow and soybean oil (Figure 2 Panel B) and 6.15 g/100g for those fed soybean oil (Figure 2 Panel C). Furthermore, interactions were a result of elevated levels of PUFA and reduced levels of SFA and MUFA with increasing feeding duration of soybean oil relative to other fat sources.

A feeding period × fat source (tallow vs. soybean oil) interaction ($P < 0.05$) was observed for C18:1, C18:2, C18:3, C20:1, MUFA, PUFA, and IV. These were driven by the decrease of MUFA levels and the increased PUFA levels in pigs fed soybean oil relative to pigs fed tallow. There was a feeding period × fat source (soybean oil vs. the blend of soybean oil and tallow) interaction ($P < 0.05$) observed for C18:2, C18:3, PUFA, and IV which again was found by the increased concentrations in pigs fed soybean oil. Pigs fed the blend of soybean oil and tallow had a greater increase in C18:3 than those fed tallow (feeding period × fat source, $P < 0.05$). These interactions are better illustrated for IV as pigs fed either tallow or a blend of soybean oil and tallow for only a single period (either 1 or 2) were observed to have very similar belly fat IV on d 84. However, those fed soybean oil from d 42 to 84 had a 3.62 g/100g greater belly fat IV than those fed soybean oil from d 0 to 42. Therefore, the turnover observed in pigs fed a highly unsaturated fat source compared to pigs fed a more saturated fat source not having any differences amongst period drove the interaction.

While no interactions were observed, feeding tallow during either period increased ($P <$

0.05) C16:1 concentration's in belly fat compared to pigs fed soybean oil or the blend of soybean oil and tallow. Additionally, C22:5n3 concentration was increased ($P < 0.05$) for both period 1 and 2 when pigs were fed soybean oil compared to tallow. Similarly, pigs fed the blend of soybean oil and tallow during period 1 had increased ($P < 0.05$) C22:5n3 concentrations when compared to those fed tallow.

Jowl Fat

Adding 4% fat increased ($P < 0.05$) C18:2, C18:3, C22:5n3, PUFA, and IV and decreased ($P < 0.05$) C16:1, SFA, and MUFA on both d 42 and 84 and decreased ($P < 0.05$) total C18:1 on d 42 compared to pigs fed the control diet (Table 7). There was a feeding duration × fat source interaction ($P < 0.05$) among pigs fed tallow vs. soybean oil for C18:2, C18:3, C22:5n3, SFA, MUFA, PUFA, and IV. A feeding duration × fat source interaction ($P < 0.05$) was also observed for the blend of soybean oil and tallow vs. soybean oil for C18:2, C18:3, C20:1, PUFA, and IV. These interactions were driven by the elevated levels of PUFA and reduced levels of MUFA and SFA with increasing feeding duration for soybean oil relative to other fat sources. A feeding duration × fat source (tallow vs. blend) interaction ($P = 0.001$) was observed for C18:3 as well as a tendency ($P < 0.10$) for C18:2, PUFA, and IV. The IV interactions were a result of the duration of feeding tallow (Figure 3 Panel A) not impacting IV, while the increased duration of feeding soybean oil and tallow (Figure 3 Panel B) or soybean oil (Figure 3 Panel C) increased jowl fat IV by 4.7 and 10.8 g/100g, respectively, compared to those fed tallow.

For C18:3, feeding period × fat source interactions ($P < 0.05$) for the blend of soybean oil and tallow vs. soybean oil alone and tallow vs. soybean oil were observed, as well as a tendency ($P < 0.10$) for an interaction for tallow vs. the blend of soybean oil and tallow. This was caused by the greater increase in C18:3 concentration in pigs fed soybean oil relative to tallow or the

blend of soybean oil and tallow. Pigs fed tallow had a greater increase in C20:1 than pigs fed soybean oil, (feeding period × fat source, $P < 0.05$). No feeding period × fat source interactions ($P < 0.05$) were observed for IV. This is due to the similar IV's reported on d 84 within each fat source for pigs fed added fat for a single period, which is unlike the other fat depots evaluated in this study.

No interactions were observed for the fatty acids C16:1 and C18:1; however, concentrations for each of these fatty acids were increased ($P < 0.05$) in pigs fed tallow compared to soybean oil for both periods 1 and 2. Additionally, C18:1 concentration was increased ($P < 0.05$) in pigs fed tallow compared to those fed either soybean oil or the blend of soybean oil and tallow in both periods.

DISCUSSION

Numerous studies have shown that adding fat to swine diets in some or all of the finishing phase improves feed efficiency when compared to pigs fed a diet without fat (Weber et al., 2006; Benz et al., 2011a; Kellner et al., 2014). The increase in ADG from d 0 to 42 for pigs fed added fat in the current study agrees with results from Campbell and Taverner (1988) and De la Llata et al. (2001), indicating pigs were in an energy dependent state for this period of growth as described by Pettigrew and Esnaola (2001). By adding dietary fat, more energy was provided in the feed which allowed pigs to increase protein accretion when compared to pigs that were not fed an additional fat source in this early stage of growth. Data from De la Llata et al. (2001) would suggest that in the late finishing stage, adding fat will generally elicit an improvement in ADG when pigs are housed in a commercial facility (> 20 pigs per pen) vs those housed in small pens in typical university research settings. Despite the current study being performed in a university research setting, a tendency for improved ADG was also observed for pigs fed added

fat in the final 42 d. There was no difference in ADG when adding fat throughout the entire finishing period, which agrees with data from Weber et al. (2006) and Apple et al. (2009a). The lack of response in overall growth to adding fat was partly due to the fact that there were fewer treatments in the overall fat response comparison (3 treatments) than in either period 1 or 2 (6 treatments).

Results from Apple et al. (2009a), Lee et al. (2013), and Kellner et al. (2014) show no ADFI response when comparing added fat diets to those without additional fat, which would agree with results from the current research. However, some have observed reductions in ADFI when feeding additional fat compared to feeding a diet without added fat (De la Llata et al., 2001 and Eggert et al., 2007).

Added dietary fat has been shown to improve HCW and carcass yield (Smith et al., 1999; Jackson et al., 2009); while others have shown no affect, which would agree with findings from the present study (Bee et al., 2002; Apple et al., 2009a; Coble et al., 2015). However, added fat did increase backfat depth. Similarly, Apple et al. (2009a) and Benz et al. (2011b) reported that carcasses from pigs fed added dietary fat, regardless of source, had greater average backfat depths than carcasses from pigs fed a diet without added fat. This would be expected as the pig is consuming a high energy diet and once the pig has reached the break point of protein accretion they will fatten rapidly (Pettigrew and Esnaola, 2001).

Several feeding duration × fat source interactions were observed in the study herein. The feeding duration × fat source interactions for tallow vs. soybean oil and soybean oil vs. the blend of soybean oil and tallow were a result of elevated levels of PUFA and reduced MFA and SFA due to feeding soybean oil which has a higher unsaturated fatty acid content compared to tallow. When comparing soybean oil vs. the blend of soybean oil and tallow, they both behaved

similarly; however, interactions of feeding duration × fat source and feeding period × fat source were caused by the greater magnitude of change in the fatty acid profile caused by feeding only soybean oil. Feeding period × fat source interactions for tallow vs. soybean oil or the blend of soybean oil and tallow were observed due to the relatively consistent response throughout feeding by pigs fed tallow for a single period and the inverse responses observed by pigs fed soybean oil or the blend of soybean oil and tallow for a single period that are then fed a control diet. This would be consistent with results from Apple et al. (2009a), as the authors observed that feeding beef tallow increased MUFA levels in the LM compared to feeding soybean oil. They also observed that feeding soybean oil increased PUFA levels compared to feeding a control diet or diets with added poultry fat or beef tallow.

Browne et al. (2013a) observed changes in 18:2*n*-6, total 18:1, MUFA, PUFA, SFA, and IV in backfat among pigs fed either beef tallow or yellow grease over a 103 d period. They found that linoleic acid and PUFA values were increased by 3.69 and 4.03 percentage units, respectively, while IV was increased 4.78 g/100 g in pigs fed yellow grease vs. beef tallow. Similarly, Kellner et al. (2014) observed that feeding a highly unsaturated fat source (corn oil) at either 3 or 6% of the diet significantly increased IV when compared to diets with either choice white grease or beef tallow.

Recently, Paulk et al. (2015) performed a literature review to create predictive equations for back, belly, and jowl IV based on many different variables such as EFA, ADFI, and initial BW. The current study was used to validate the predictive equations and they were found to be moderately accurate for estimated backfat IV values, but they over estimate most backfat values; especially for pigs with backfat IV under 65 g/100 g. Belly fat IV was under predicted for most treatments with only 34% of the variation was explained by the model. This variation could be

due to various collection sites used in the literature to create the equations, as well as fewer total observations. Predicted jowl fat IV was highly accurate as means were within 3.43 g/100 g of actual treatment values and the model explained 72% of the variation.

To minimize the negative effects of feeding unsaturated fat sources, a withdrawal strategy can be utilized to improve the fatty acid profile of fat depots. When previously feeding a diet with 5% corn oil, Kellner et al. (2015) was able to show a similar result in jowl C18:2% and IV when using a 61 d withdrawal compared to pigs fed a control diet with no added oil. However, a 40 and 19 d withdrawal still maintained a difference of 5.5 and 6.4 percentage units for C18:2 as well as 5.5 and 8.7 g/100 g respectively for jowl fat when compared to pigs not fed a diet with added fat. Benz et al. (2011a) also reported that with an extended withdrawal period, a greater reduction in C18:2, PUFA, and IV can be observed in backfat and jowl fat when feeding 5% soybean oil. We observed similar responses in backfat as a 42 d withdrawal from pigs previously fed a 4% soybean oil diet resulted in 6.94 and 8.13 percentage unit decrease in C18:2 and PUFA respectively while also lowering IV by 11.55 g/100 g for backfat. As previous studies suggested, a withdrawal strategy also changed jowl fat as C18:2 and PUFA concentrations were lower (3.6 and 4.45 percentage units, respectively) while IV was also lower by 6.01 g/100 g.

The current research shows little numeric changes in MUFA, PUFA, SFA concentrations, or IV when adding beef tallow in late finishing, the same cannot be said for adding 4% soybean oil. By adding soybean oil to the diet for the final 42 d, C18:1 and MUFA concentrations were 5.53 and 6.74 percentage units lower, respectively, for backfat. Conversely, C18:2, PUFA, and IV values were 8.39 and 9.67 percentage units, and 11.55 g/100 g greater, respectively, for backfat. Adding soybean oil in late finishing also caused C18:2, PUFA, and IV values to be 4.52

and 5.47 percentage units, and 6.08 g/100 g greater, respectively, for jowl fat, while C18:1 and MUFA concentrations were 3.48 and 4.15 percentage units lower, respectively. Belly fat was similarly affected as C18:1 and MUFA concentrations were 3 and 5.33 percentage units lower, respectively, and C18:2, PUFA, and IV values were 6.35 and 7.6 percentage units, and 7.01 g/100 g greater, respectively. While these increases did not put IV over the threshold of 73 g/100 g suggested by Benz et al. (2011a) for backfat or jowl fat, adding soybean oil only for the final 42 d did increase belly fat IV over this threshold, as it was observed to be 75.11 g/100 g. Work by Kellner et al. (2014) would suggest that this is directly related to the increased intake of C18:2, which they found to be to be the best indicator of carcass IV.

Pigs fed tallow did not have a period effect for either backfat or belly fat in the current study with respect to IV. This could be due to the relatively low amount of linoleic acid found in beef tallow, which is one of the strongest indicators of carcass fat IV (Benz et al., 2011a; Kellner et al., 2014). Contrary to the previously discussed fat depots, jowl fat did not show a period effect in the current study. While few publications have evaluated this specific area, Browne et al. (2013a) showed that, by changing sources of fat from beef tallow to yellow grease or vice versa through the finishing phase, backfat IV can be altered; while in jowl fat no differences were noted amongst treatments, which would indicate that there is a longer turnover rate for this particular fat depot. This could be explained by Wiegand et al. (2011) who speculated that as the fattening patterns begin from distal ends and progress toward the visceral cavity, fat would be deposited earlier in the animal's life over the jowl and later over the loin and belly which causes the weak correlation between these fat depots.

Increased amount of PUFA's has been shown to inhibit de novo fat synthesis (Bee et al., 1999). Therefore, direct dietary fat deposition is then preferred by the animal which increases the

PUFA concentrations in pork fat depots. Increases in unsaturated fats have been correlated to decreased carcass fat quality (Widmer et al., 2008) which has been shown to present processing challenges as well as reduce shelf life (NRC, 2012). Results of our study show feeding soybean oil for extended durations increases the PUFA concentration of the fat which is consistent with Averette Gatlin (2002) and Benz et al. (2011a). By withdrawing soybean oil from the diet for the final 42 d, the PUFA concentration can be significantly reduced in both the belly and loin fat depot. This also agrees with Benz et al. (2011a) as they removed fat from the diet for either 14, 28, or 56 d before slaughter and showed a quadratic decrease in total PUFA concentrations for backfat as well as jowl fat, with lower concentrations correlating to longer withdrawals.

All three fat depots evaluated in this study maintained higher concentrations of SFA when pigs were fed beef tallow for 84 d compared to those fed soybean oil. This would agree with research by Bee et al. (2002), who fed pigs corn-soybean meal diets through finishing with either 5% soybean oil or 5% beef tallow and observed pigs fed beef tallow maintained a significantly higher concentration of total SFA in carcass backfat than those fed soybean oil. Browne et al. (2013b) also showed that feeding 5% beef tallow for 103 d resulted in a higher level of SFA in belly fat compared to pigs fed 4.7% yellow grease. Interestingly enough, Browne et al. (2013b) also showed that by feeding beef tallow during the final 2 or 3 phases of feeding after pigs had previously been fed yellow grease resulted in nearly equivalent SFA levels in both jowl and backfat compared to pigs fed beef tallow throughout all feeding phases. While the current study did not look at this directly, feeding beef tallow for either a single period or the duration of the study had minimal changes on total SFA levels for all three depots evaluated.

Total MUFA was found to have an inverse relationship to total PUFA concentrations in all three fat depots evaluated in this study, which would agree with Benz et al. (2010). Feeding

tallow maintained similar concentrations of total MUFA in all fat depots whether they were fed the additional fat for the duration of the study or only a single period when compared to those fed the control diet. However, pigs fed soybean oil had reduced levels of MUFA compared to pigs fed no additional fat or tallow. This would agree with Apple et al. (2009b), who found that feeding diets with animal fats elevated concentrations of MUFA while soybean oil reduced them.

In conclusion, added fat, whether from tallow, soybean oil, or a blend of soybean oil and tallow in some stages improved ADG and G:F. Feeding soybean oil will increase the amount of total PUFA in fat depots and consequently increases carcass fat IV; however, beef tallow can be utilized for improved growth characteristics without negatively impacting IV. Contrary to the other fat depots, jowl fat did not show a period effect and thus the timing of feeding additional fat to pigs, whether it be early or in the final phase, does not have an altering affect in the overall fatty acid composition or IV in this fat depot. This illustrates the slower turnover rate of the jowl fat depot and explains the weak correlation between jowl fat and belly fat (Wiegand et al. 2011).

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FIGURES AND TABLES

Table 1-1. Phase 1, 2 and 3 diet composition (as-fed basis)[1]

	Phase 1		Phase 2		Phase 3	
Item	Control	Added fat	Control	Added fat	Control	Added fat
Ingredient, %						
Corn	76.37	69.40	80.70	74.06	84.00	77.75
Soybean meal, 46.5% CP	20.95	23.90	17.00	19.60	14.00	16.25
Fat source[2]	---	4.00	---	4.00	---	4.00
Monocalcium, 21% P	0.49	0.48	0.38	0.38	0.31	0.31
Limestone	1.05	1.05	1.00	1.00	0.90	0.90
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.15	0.15	0.10	0.10	0.08	0.08
Trace mineral premix[4]	0.15	0.15	0.10	0.10	0.08	0.08
L-Lys HCl	0.28	0.28	0.23	0.23	0.20	0.20
DL-Met	0.05	0.07	0.01	0.03	---	---
L-Thr	0.08	0.09	0.05	0.07	---	---
Phytase[5]	0.08	0.08	0.08	0.08	0.08	0.08
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
Standard ileal digestible (SID) amino acids, %						
Lys	0.91	0.98	0.78	0.83	0.68	0.73
Ile:Lys	63	63	66	65	67	67
Leu:Lys	143	138	157	150	168	160
Met:Lys	32	32	29	30	31	31
Met+Cys:Lys	58	58	58	58	61	60
Thr:Lys	63	63	64	64	65	65
Trp:Lys	18	18	18	18	18	18
Val:Lys	71	70	75	74	78	76
SID Lys:NE, g/Mcal	3.65	3.65	3.08	3.08	2.68	2.68
ME, kcal/kg	3,301	3,506	3,312	3,517	3,322	3,528
NE, kcal/kg	2,492	2,670	2,521	2,701	2,544	2,726
Total Lys, %	1.03	1.10	0.88	0.94	0.78	0.83
CP, %	16.6	17.5	15.0	15.7	13.8	14.4
Ca, %	0.54	0.55	0.50	0.50	0.44	0.45
P, %	0.45	0.45	0.41	0.41	0.38	0.38
Available P, %	0.26	0.26	0.24	0.24	0.22	0.22
Crude fiber, %	2.3	2.3	2.3	2.2	2.2	2.2

[1] Phase 1, 2, and 3 diets were fed from d 0 to 28, d 28 to 56, and d 56 to 84, respectively.
[2] Fat sources were either tallow, soybean oil or a blend of 2% tallow and 2% soybean oil.
[3] Provided per kilogram 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 kilogram 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] Phytase was added to all diets at a rate of 0.08% to provide 778.4 phytase units (FTU)/kg of complete diet and a 0.12% P release.

Table 1-2. Diet analysis (as-fed basis)[1]

	Diets[2]											
	Phase 1				Phase 2				Phase 3			
Item,[3] %	Control	Tallow	Blend	Soy	Control	Tallow	Blend	Soy	Control	Tallow	Blend	Soy
DM	89.9	90.7	90.0	90.0	89.7	90.0	90.0	89.7	89.5	90.2	89.5	89.8
CP	17.9	18.7	17.5	18.3	16.1	16.0	16.3	16.7	15.0	15.2	15.3	14.9
ADF	2.6	3.6	3.3	3.4	3.3	3.2	3.0	3.4	1.9	2.4	2.8	2.3
NDF	6.5	8.0	8.0	6.6	5.9	5.2	6.0	5.4	7.1	8.4	8.4	6.8
Crude fiber	1.9	2.7	2.9	2.4	1.5	2.4	2.4	2.1	2.0	2.5	2.9	2.5
NFE[4]	63.1	58.2	59.4	58.2	65.0	61.5	60.9	61.4	66.3	62.1	62.3	63.0
Ether extract	3.0	6.7	6.2	6.5	2.3	6.3	6.7	5.5	3.1	7.1	5.9	6.4
Ash	3.85	4.20	4.27	4.29	3.65	3.64	3.71	3.37	3.64	3.87	3.78	3.59

[1] Phase 1, 2, and 3 diets were fed from d 0 to 28, d 28 to 56, and d 56 to 84, respectively.
[2] Control = no added fat; Tallow = 4% beef tallow; Blend = 2% tallow and 2% soybean oil; Soy = 4% soybean oil.
[3] Values represent the mean of one composite sample of each diet.
[4] Nitrogen free extract

Table 1-3. Fatty acid analysis of ingredients and diets

	Ingredients		Diets[1]											
			Phase 1				Phase 2				Phase 3			
Item	Tallow	Soy oil	Control	Tallow	Blend	Soy	Control	Tallow	Blend	Soy	Control	Tallow	Blend	Soy
C14:0, %	2.94	0.08	0.06	1.51	0.81	0.09	0.09	1.56	0.94	0.09	0.05	1.52	1.09	0.08
C16:0, %	24.09	9.61	16.83	20.78	16.92	12.85	16.78	21.06	17.42	13.59	16.17	20.80	18.38	13.36
C16:0, %	3.77	0.11	0.15	1.91	1.14	0.14	0.20	1.99	1.28	0.13	0.14	1.98	1.38	0.12
C18:0, %	16.91	4.34	2.48	10.49	7.00	3.68	2.56	10.50	7.87	3.89	2.01	10.40	8.85	3.86
C18:1 *cis*-9, %	38.38	24.52	20.99	28.51	25.88	23.06	21.61	29.70	25.63	21.47	22.45	28.71	26.15	21.79
C18:2n-6, %	5.07	51.80	51.11	27.36	39.08	50.77	50.31	26.32	36.98	50.42	52.14	27.12	35.17	50.60
C18:3n-3, %	0.32	6.81	2.31	1.45	3.01	4.71	2.47	1.41	3.80	6.07	2.07	1.61	2.94	5.99
C20:0, %	0.16	0.33	0.43	0.27	0.33	0.38	0.39	0.25	0.29	0.36	0.37	0.26	0.29	0.37
C20:1, %	0.26	ND[9]	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Other fatty acids, %	8.10	2.40	5.63	7.70	5.83	4.33	5.60	7.21	5.79	3.98	4.61	7.59	5.75	3.82
Total SFA,[2] %	45.72	15.10	24.24	36.48	28.13	19.79	24.19	36.20	29.27	20.50	22.24	36.03	31.20	20.14
Total MUFA,[3] %	47.57	26.04	22.15	34.10	29.34	24.48	22.86	35.45	29.53	22.82	23.43	34.61	30.26	23.09
Total PUFA,[4] %	6.71	58.86	53.61	29.43	42.52	55.73	52.96	28.35	41.20	56.68	54.33	29.36	38.54	56.77
UFA:SFA ratio[5]	1.19	5.62	3.13	1.74	2.55	4.05	3.13	1.76	2.42	3.88	3.50	1.78	2.21	3.97
PUFA:SFA ratio[6]	0.15	3.90	2.21	0.81	1.51	2.82	2.19	0.78	1.41	2.76	2.44	0.81	1.24	2.82
Iodine value,[7] g/100g	49.9	129.9	113.4	80.2	100.7	121.2	113.0	79.5	99.3	122.7	115.7	80.5	94.4	123.1
Analyzed IVP[8]	499.4	1298.9	34.0	53.8	62.4	78.8	26.0	50.1	66.5	67.5	35.9	57.2	55.7	78.8

[1] Control = no added fat; Tallow = 4% beef tallow; Blend = 2% tallow and 2% soybean oil; Soy = 4% soybean oil.

[2] Total SFA = ([C6:0] + [C8:0] + [C10:0] + [C11:0] + [C12:0] + [C14:0] + [C15:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C21:0] + [C22:0] + [C23:0] + [C24:0]); brackets indicate concentration.

[3] Total MUFA = ([C14:1] + [C15:1] + [C16:1] + [C18:1*n*99] + [C18:1n9t] + [C18:1n11t] + [C18:1n11c] + [C20:1] + [C22:1n9] + [C24:1]); brackets indicate concentration.

[4] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [CLA 9c11t] + [CLA10t,12c] + [CLA9c,11c] + [CLA9t,11t] + [C20:3n6] + [C20:3n3] + [C22:2] +[C20:5n3] +[C22:5n3] + [C22:6n3]; brackets indicate concentration.

[5] UFA:SFA = (total MUFA+PUFA)/ total SFA.

[6] PUFA:SFA = total PUFA/ total SFA.

[7] Calculated as iodine value (IV) = [C16:1] × 0.950 + [C18:1] × 0.860 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C20:4] × 3.201 + [C22:1] × 0.723 + [C22:5] × 3.697 + [C22:6] × 4.463; brackets indicate concentration.

[8] Iodine value of dietary lipids and diets were calculated from analyzed fatty acid composition × % analyzed lipids × 0.10.

[9] None detected

Table 1-4. Effects of source and duration of added fat on growth performance and carcass characteristics of finishing pigs[1]

Treatment[2]:	A	B	C	D	E	F	G	H	I	J							
d 0 to 42:	Control	Tallow	Tallow	Control	Blend	Blend	Control	Soy	Soy	Control		Contrasts[3,4,5,6], *P* <					
d 42 to 84:	Control	Tallow	Control	Tallow	Blend	Control	Blend	Soy	Control	Soy	SEM	1	2	3	4	5	6
BW, kg																	
d 0	45.6	45.7	45.6	45.6	45.9	45.4	45.8	45.6	45.5	45.5	1.097	0.844	0.492	0.659	0.902	0.606	0.695
d 42	84.5	86.9	87.5	85.2	85.6	84.8	84.0	86.8	85.4	82.8	1.864	0.179	0.089	0.067	0.078	0.832	0.121
d 84	129.9	132.5	132.2	130.3	134.2	128.7	128.8	134.1	130.3	129.8	2.536	0.089	0.006	0.606	0.444	0.553	0.864
d 0 to 42																	
ADG, kg	0.919	0.983	0.999	0.942	0.951	0.933	0.915	0.985	0.950	0.892	0.029	0.005	-	-	0.067	0.345	0.372
ADFI, kg	2.293	2.320	2.349	2.441	2.376	2.307	2.296	2.340	2.253	2.218	0.064	0.752	-	-	0.910	0.447	0.519
G:F	0.401	0.425	0.427	0.387	0.400	0.404	0.399	0.422	0.423	0.403	0.009	0.001	-	-	0.001	0.005	0.629
d 42 to 84																	
ADG, kg	1.085	1.085	1.063	1.074	1.124	1.045	1.067	1.127	1.049	1.117	0.031	0.052	-	-	0.586	0.362	0.145
ADFI, kg	3.218	3.091	3.227	3.139	3.242	3.094	2.996	3.179	3.208	3.030	0.086	0.177	-	-	0.967	0.863	0.895
G/F	0.341	0.353	0.331	0.343	0.347	0.338	0.357	0.356	0.331	0.368	0.008	0.001	-	-	0.645	0.189	0.078
d 0 to 84																	
ADG, kg	1.002	1.034	1.031	1.008	1.029	0.988	0.992	1.056	0.995	1.004	0.023	0.134	0.018	0.842	0.219	0.384	0.718
ADFI, kg	2.756	2.706	2.788	2.790	2.780	2.697	2.649	2.760	2.706	2.621	0.068	0.924	0.372	0.401	0.301	0.803	0.202
G:F	0.365	0.384	0.371	0.362	0.371	0.365	0.376	0.385	0.370	0.383	0.006	0.036	0.042	0.294	0.732	0.092	0.176
Carcass Characteristics																	
HCW, kg	97.24	99.14	98.51	96.50	96.62	96.56	98.00	98.17	97.75	96.64	2.519	0.801	0.717	0.787	0.631	0.822	0.798
Yield, %	74.6	74.1	74.5	73.8	74.1	74.5	74.5	74.2	74.3	74.5	0.499	0.455	0.548	0.671	0.510	0.950	0.552
LEA,[7] cm^2	59.8	59.8	62.5	60.0	61.3	60.2	60.8	59.4	62.0	60.6	2.354	0.862	0.541	0.493	0.980	0.953	0.932
BF,[7] mm	17.07	19.13	19.61	18.57	22.30	20.95	19.61	21.75	18.02	19.29	1.570	0.032	0.127	0.774	0.154	0.326	0.652
FFLI,[8] %	56.74	55.85	56.24	56.18	54.77	55.11	55.79	54.74	56.72	55.97	0.868	0.079	0.108	0.989	0.257	0.428	0.734

[1] A total of 160 finishing pigs (PIC 337 × 1050, initial BW of 45.6 kg) were used in an 84-d finishing trial with 2 pigs per pen and 8 pens per treatment.

[2] Control = no added fat; Tallow = 4% beef tallow; Blend = 2% tallow and 2% soybean oil; Soy = 4% soybean oil.

[3] There were no fat or fat source interactions $P > 0.05$.

[4] The period 1 (d 0 to 42) contrast statements are as follows 1 = no added fat vs. added fat (treatments A, D, G, and J vs. B, C, E, F, H, and I); 4 = tallow vs. blend (treatments B and C vs. E and F); 5 = blend vs. soy oil (treatments E and F vs. H and I); 6 = tallow vs. soy oil (treatments B and C vs. H and I).

[5] The period 2 (d 42 to 84) contrast statements are as follows 1 = no added fat vs. added fat (treatments A, C, F, and I vs. B, D, E, G, H, and J); 4 = tallow vs. blend (treatments B and D vs. E and G); 5 = blend vs. soy oil (treatments E and G vs. H and J); 6 = tallow vs. soy oil (treatments B and D vs. H and J).

[6] The overall (d 0 to 84) and carcass characteristics contrast statements are as follows: 1 = no added fat vs. added fat both periods (treatment A vs. B, E, and H); 2 = added fat both periods vs. added fat only during a single period (treatments B, E, H vs. C, D, F, G, I, and J); 3 = added fat only during period 1 vs. added fat only during period 2 (treatments C, F, I vs. D, G, and J); 4 = tallow vs. blend (treatments B,C, D vs. E, F, and G); 5 = blend vs. soy oil (treatments E, F, G, vs. H, I, and J); 6 = tallow vs. soy oil (treatments B, C, D, vs. H, I, and J).

[7] Adjusted using HCW as a covariate.

[8] Fat Free Lean Index was calculated using NPPC (2001) equation.

Table 1-5. Effects of source and duration of feeding fat on backfat quality of finishing pigs[1,2]

Treatment[3]:	A	B	C	D	E	F	G	H	I	J		Contrasts[4,5], *P* <					
d 0 to 42:	Control	Tallow	Tallow	Control	Blend	Blend	Control	Soy	Soy	Control							
d 42 to 84:	Control	Tallow	Control	Tallow	Blend	Control	Blend	Soy	Control	Soy	SEM	1	2	3	4	5	6
C16:1, %																	
d 0[a]	3.51	3.81	3.40	3.89	3.27	3.43	3.99	3.35	3.50	3.46	0.13						
d 42[a,b,d]	2.72	2.58	2.83	3.04	2.16	2.22	3.01	2.07	1.86	2.83	0.13						
d 84[e,f,g,h]	2.51	2.55	2.61	2.51	2.14	2.37	2.38	1.81	2.21	1.94	0.10	0.180	0.881	0.130	0.567	0.146	0.353
Total C18:1,[6] %																	
d 0	40.36	41.00	41.75	40.49	40.33	42.25	42.81	41.12	39.21	40.34	0.76						
d 42[a,b,c,d]	42.15	43.97	44.60	43.24	40.78	40.87	44.20	39.34	37.73	43.64	0.76						
d 84[e,f,g,h]	42.14	44.32	43.19	44.11	41.11	41.76	41.70	36.91	40.41	38.11	0.61	0.173	0.069	0.001	0.386	0.053	0.004
Total C18:2,[7] %																	
d 0	13.07	12.24	12.24	12.84	12.78	12.13	11.94	12.79	14.07	14.08	0.65						
d 42[a,b,c,d]	10.61	10.05	10.88	9.32	15.13	15.58	9.25	17.83	21.15	10.52	0.65						
d 84[e,f,g,h]	12.28	11.72	12.15	11.10	16.48	14.16	14.38	22.29	15.35	18.91	0.53	0.009	0.001	0.001	0.186	0.001	0.001
Total C18:3,[8] %																	
d 0	0.62	0.65	0.63	0.65	0.67	0.63	0.61	0.66	0.81	0.70	0.07						
d 42[a,b,c,d]	0.65	0.44	0.51	0.43	0.99	1.08	0.45	1.34	1.56	0.49	0.07						
d 84[e,f,g,h]	0.69	0.61	0.58	0.60	1.35	0.92	1.14	2.14	1.01	1.82	0.06	0.001	0.001	0.001	0.073	0.001	0.001
C20:1, %																	
d 0	0.60	0.63	0.55	0.63	0.63	0.63	0.63	0.64	0.55	0.59	0.03						
d 42[a,d]	0.72	0.71	0.66	0.69	0.64	0.64	0.66	0.61	0.59	0.67	0.03						
d 84[e,f,g,h]	0.68	0.68	0.66	0.71	0.65	0.65	0.61	0.53	0.64	0.55	0.03	0.547	0.029	0.104	0.063	0.343	0.004
C22:5n3, %																	
d 0	0.21	0.16	0.12	0.12	0.19	0.12	0.12	0.12	0.11	0.12	0.03						
d 42	0.11	0.06	0.07	0.11	0.13	0.09	0.11	0.09	0.10	0.07	0.03						
d 84[h]	0.07	0.07	0.07	0.08	0.12	0.09	0.10	0.14	0.09	0.13	0.02	0.397	0.938	0.347	0.848	0.765	0.615
Total SFA,[9] %																	
d 0	38.11	38.45	38.71	38.04	38.78	38.02	37.44	38.36	38.20	38.02	0.75						
d 42[a,b,c,d]	40.41	40.50	38.61	41.04	38.16	37.80	40.48	37.03	35.15	40.26	0.75						
d 84[e,f,g,h]	40.01	38.27	39.06	39.04	36.17	38.24	37.85	34.33	38.52	36.67	0.63	0.219	0.121	0.005	0.722	0.180	0.081
Total MUFA,[10] %																	
d 0	46.57	47.24	47.25	46.98	46.30	47.96	48.83	46.76	45.41	46.01	0.67						
d 42[a,b,c,d]	47.16	48.01	48.93	48.26	44.44	44.32	48.87	42.65	40.84	47.95	0.67						
d 84[e,f,g,h]	45.99	48.22	47.14	48.07	44.61	45.47	45.42	39.79	43.94	41.21	0.54	0.090	0.024	0.001	0.334	0.011	0.001
Total PUFA,[11] %																	
d 0[d]	15.28	14.31	14.00	15.01	14.89	14.00	13.72	14.89	16.36	16.05	0.75						
d 42[a,b,c,d]	12.40	11.48	12.41	10.73	17.37	17.85	10.64	20.33	23.97	11.87	0.75						
d 84[e,f,g,h]	13.58	13.04	13.32	12.45	18.58	15.74	16.18	25.10	16.97	21.54	0.61	0.007	0.001	0.001	0.234	0.001	0.001

Iodine value,[12] g/100g																	
d 0	67.36	65.91	64.97	66.64	66.80	65.79	65.93	66.01	68.71	67.52	1.28						
d 42 [a,b,c,d]	63.03	60.48	62.85	60.63	68.29	68.86	60.58	71.98	76.75	61.60	1.28						
d 84 [e,f,g,h]	63.29	64.03	63.82	62.72	71.25	66.85	67.74	79.43	67.88	73.90	1.05	0.038	0.003	0.001	0.276	0.007	0.001

[1] A total of 160 finishing pigs (PIC 337 × 1050, initial BW of 45.6 kg) were used in an 84-d finishing trial with 2 pigs per pen and 8 pens per treatment.

[2] C22:6n3 not included, all values were equal to or less than 0.003.

[3]Control = corn soybean meal diet with no fat; Tallow = 4% beef tallow; Blend = 2% tallow and 2% soybean oil; Soy= 4% soybean oil.

[4]There was a treatment × day interaction ($P < 0.001$) for all variables except C 22:5n3 ($P = 0.3066$).

[5] The d 84 contrast statements for interactions are as follows: 1 = feeding duration (84-d vs. 42-d) × fat source (tallow vs. blend); 2 = feeding duration (84-d vs. 42-d) × fat source (blend vs. soy oil); 3 = feeding duration (84-d vs. 42-d) × fat source (tallow vs. soy oil); 4 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (tallow vs. blend); 5 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (blend vs. soy oil); 6 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (tallow vs. soy oil).

[a,b,c,d] Within a row, superscripts represent significant ($P < 0.05$) main effects where a = control vs. fat (treatments A, D, G, and J vs. B, C, E, F, H, and I); b = tallow vs. blend (treatments B and C vs. E and F); c = blend vs. soy oil (treatments E and F vs. H and I); d = tallow vs. soy oil (treatments B and C vs. H and I).

[e,f,g,h] Within a row, superscripts represent significant ($P < 0.05$) main effects where e = control vs. fat (treatments A, C, F, and I vs. B, D, E, G, H, and J); f = tallow vs. blend (treatments B and D vs. E and G); g = blend vs. soy oil (treatments E and G vs. H and J); h = tallow vs. soy oil (treatments B and D vs. H and J).

[6] Total C18:1= ([C18:1n9t] + [C18:1n11t] + [C18:1n9c] + [C18:1n11c]); brackets indicate concentration.

[7] Total C18:2= ([C18:2n6t] + C18:2n6c]); brackets indicate concentration.

[8] Total C18:3= ([C18:3n6] + [C18:3n3]); brackets indicate concentration.

[9] Total SFA= ([C6:0] + [C8:0] + [C10:0] + [C11:0] + [C12:0] + [C14:0] + [C15:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C21:0] + [C22:0] + [C23:0] + [C24:0]); brackets indicate concentration.

[10]Total MUFA= ([C14:1] + [C16:1] + [C17:1] + [C18:1n9t] + [C18:1n11t] + [C18:1n9c] + [C18:1n11c] + [C20:1] + [C22:1n9] + [C24:1]); brackets indicate concentration.

[11]Total PUFA=([C18:2n6t] + [C18:2n6c] + [C18:3n6] + [C18:3n3] + [CLA 9c11t] + [CLA 10t12c] + [CLA 9c11c] + [CLA 9t11t] + [C20:2] +[C20:3n6] + [C20:3n3] + [C22:2] + [C20:5n3] + [C22:5n3] + [C22:6n3]); brackets indicate concentration.

[12] Calculated as IV value= [C16:1] × 0.9502 + [C18:1] × 0.8598 + [C18:2] × 1.7315] + [C18:3] × 2.6125 + [C20:1] × 0.7852 + [C22:1n9] × 3.2008 + [C22:5n3] × 3.6974 + [C22:6n3] × 4.4632; brackets indicate concentrations.

Table 1-6. Effects of source and duration of added fat on belly fat quality of finishing pigs[1,2]

Treatment[3]:	A	B	C	D	E	F	G	H	I	J		Contrasts[4,5], *P* <					
d 0 to 42:	Control	Tallow	Tallow	Control	Blend	Blend	Control	Soy	Soy	Control							
d 42 to 84:	Control	Tallow	Control	Tallow	Blend	Control	Blend	Soy	Control	Soy	SEM	1	2	3	4	5	6
C16:1, %																	
d 0	4.58	4.86	4.78	4.81	4.38	4.71	5.14	4.64	5.01	5.03	0.16						
d 42 [a,b,d]	3.96	3.75	3.67	4.24	3.20	3.29	4.13	2.91	3.25	3.93	0.16						
d 84 [e,f,h]	3.21	3.12	3.29	3.31	2.64	2.91	2.93	2.43	2.86	2.65	0.13	0.635	0.832	0.482	0.997	0.373	0.353
Total C18:1,[6] %																	
d 0	42.51	43.63	42.70	42.86	42.31	43.28	43.45	42.65	43.34	41.21	0.81						
d 42 [a,b,c,d]	45.27	46.97	45.56	46.29	43.22	43.43	46.21	40.74	41.00	44.88	0.81						
d 84 [e,f,g,h]	45.60	46.50	46.13	47.09	43.77	45.01	44.46	40.77	44.06	41.88	0.65	0.407	0.227	0.038	0.213	0.189	0.008
Total C18:2,[7] %																	
d 0	11.43	10.51	11.10	10.94	10.85	10.42	10.35	11.31	10.52	11.50	0.62						
d 42 [a,b,c,d]	9.52	9.42	10.89	8.06	12.48	13.37	8.62	16.16	16.10	9.30	0.62						
d 84 [e,f,g,h]	9.87	9.85	10.13	8.93	13.77	11.83	11.96	18.20	13.05	15.65	0.51	0.044	0.012	0.001	0.148	0.008	0.001
Total C18:3,[8] %																	
d 0	0.54	0.49	0.55	0.51	0.64	0.52	0.49	0.53	0.50	0.54	0.05						
d 42 [a,b,c,d]	0.42	0.42	0.56	0.35	0.78	0.87	0.38	1.18	1.18	0.41	0.05						
d 84 [e,f,g,h]	0.45	0.45	0.44	0.41	1.04	0.66	0.85	1.67	0.80	1.39	0.04	0.001	0.001	0.001	0.001	0.001	0.001
C20:1, %																	
d 0	0.60	0.63	0.61	0.60	0.63	0.61	0.61	0.62	0.62	0.61	0.03						
d 42 [b,d]	0.66	0.74	0.69	0.67	0.66	0.64	0.68	0.60	0.62	0.65	0.03						
d 84 [e,g,h]	0.67	0.66	0.64	0.68	0.64	0.65	0.61	0.54	0.63	0.57	0.03	0.579	0.057	0.169	0.134	0.516	0.026
C22:5n3, %																	
d 0	0.10	0.09	0.16	0.20	0.20	0.16	0.16	0.18	0.15	0.21	0.03						
d 42 [b,d]	0.12	0.05	0.11	0.08	0.18	0.14	0.11	0.19	0.17	0.17	0.03						
d 84 [h]	0.05	0.06	0.05	0.06	0.09	0.07	0.08	0.11	0.08	0.10	0.03	0.698	0.864	0.567	0.866	0.931	0.790
Total SFA,[9] %																	
d 0	38.01	37.65	37.37	37.22	37.66	37.74	37.15	37.18	37.36	37.75	0.64						
d 42 [a]	37.94	36.78	36.30	38.50	36.87	36.01	37.97	35.56	35.34	38.11	0.64						
d 84 [e,g,h]	38.81	37.75	37.83	38.01	36.41	37.35	37.62	34.68	37.09	36.22	0.53	0.258	0.263	0.022	0.926	0.234	0.252
Total MUFA,[10] %																	
d 0	48.94	50.32	49.73	50.07	49.32	50.17	50.77	49.66	50.48	48.87	0.78						
d 42 [a,b,c,d]	51.04	52.29	51.03	52.17	48.44	48.46	52.07	45.62	46.00	51.01	0.78						
d 84 [e.f.g,h]	50.06	50.93	50.71	51.75	47.66	49.22	48.61	44.26	48.16	45.68	0.62	0.336	0.164	0.017	0.166	0.121	0.002
Total PUFA,[11] %																	
d 0	12.60	11.58	12.46	12.27	12.51	11.69	11.66	12.67	11.76	12.93	0.70						
d 42 [a,b,c,d]	10.56	10.49	12.20	8.98	14.12	15.02	9.57	18.15	18.06	10.49	0.70						
d 84 [e,f,g,h]	11.11	11.32	11.46	10.24	15.92	13.43	13.76	21.05	14.79	18.09	0.57	0.032	0.009	0.001	0.13	0.004	0.001

Iodine value,[12] g/100 g																	
d 0	69.59	68.73	70.42	70.92	70.77	69.62	70.04	70.95	69.71	71.08	1.03						
d 42 [a,b,c,d]	67.89	67.63	70.23	65.65	72.17	73.40	66.98	77.36	77.21	68.10	1.03						
d 84 [e,f,g,h]	66.53	67.25	67.51	66.22	72.53	69.90	70.08	79.45	71.49	75.11	0.86	0.081	0.004	0.001	0.316	0.022	0.001

[1] A total of 160 finishing pigs (PIC 337 × 1050, initial BW of 45.6 kg) were used in an 84-d finishing trial with 2 pigs per pen and 8 pens per treatment.

[2] C22:6n3 not included, all values were equal to or less than 0.003.

[3]Control= corn soybean meal diet with no fat; Tallow = 4% beef tallow; Blend = 2% tallow and 2% soybean oil; Soy = 4% soybean oil.

[4]There was a treatment × day interaction ($P < 0.001$) for all variables except C 20:1 ($P = 0.004$) and C 22:5n3 ($P = 0.7639$).

[5] The d 84 contrast statements for interactions are as follows: 1= feeding duration (84-d vs. 42-d) × fat source (tallow vs. blend); 2 = feeding duration (84-d vs. 42-d) × fat source (blend vs. soy oil); 3 = feeding duration (84-d vs. 42-d) × fat source (tallow vs. soy oil); 4 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (tallow vs. blend); 5 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (blend vs. soy oil); 6 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (tallow vs. soy oil).

[a,b,c,d] Within a row, superscripts represent significant ($P < 0.05$) main effects where a = control vs. fat (treatments A, D, G, and J vs. B, C, E, F, H, and I); b = tallow vs. blend (treatments B and C vs. E and F); c = blend vs. soy oil (treatments E and F vs. H and I); d = tallow vs. soy oil (treatments B and C vs. H and I).

[e,f,g,h] Within a row, superscripts represent significant ($P < 0.05$) main effects where e = control vs. fat (treatments A, C, F, and I vs. B, D, E, G, H, and J); f = tallow vs. blend (treatments B and D vs. E and G); g = blend vs. soy oil (treatments E and G vs. H and J); h = tallow vs. soy oil (treatments B and D vs. H and J).

[6] Total C18:1= ([C18:1n9t] + [C18:1n11t] + [C18:1n9c] + [C18:1n11c]); brackets indicate concentration.

[7] Total C18:2= ([C18:2n6t] + C18:2n6c]); brackets indicate concentration.

[8] Total C18:3= ([C18:3n6] + [C18:3n3]); brackets indicate concentration.

[9] Total SFA= ([C6:0] + [C8:0] + [C10:0] + [C11:0] + [C12:0] + [C14:0] + [C15:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C21:0] + [C22:0] + [C23:0] + [C24:0]); brackets indicate concentration.

[10]Total MUFA= ([C14:1] + [C16:1] + [C17:1] + [C18:1n9t] + [C18:1n11t] + [C18:1n9c] + [C18:1n11c] + [C20:1] + [C22:1n9] + [C24:1]); brackets indicate concentration.

[11]Total PUFA=([C18:2n6t] + [C18:2n6c] + [C18:3n6] + [C18:3n3] + [CLA 9c11t] + [CLA 10t12c] + [CLA 9c11c] + [CLA 9t11t] + [C20:2] +[C20:3n6] + [C20:3n3] + [C22:2] + [C20:5n3] + [C22:5n3] + [C22:6n3]); brackets indicate concentration.

[12] Calculated as IV value= [C16:1] × 0.9502 + [C18:1] × 0.8598 + [C18:2] × 1.7315] + [C18:3] × 2.6125 + [C20:1] × 0.7852 + [C22:1n9] × 3.2008 + [C22:5n3] × 3.6974 + [C22:6n3] × 4.4632; brackets indicate concentrations.

Table 1-7. Effects of source and duration of added fat on jowl fat quality of finishing pigs[1,2]

Treatment[3]:	A	B	C	D	E	F	G	H	I	J							
d 0 to 42:	Control	Tallow	Tallow	Control	Blend	Blend	Control	Soy	Soy	Control		Contrasts[4,5], *P* <					
d 42 to 84:	Control	Tallow	Control	Tallow	Blend	Control	Blend	Soy	Control	Soy	SEM	1	2	3	4	5	6
C16:1, %																	
d 0[a]	4.30	4.49	4.31	4.38	4.02	4.10	4.58	4.04	4.46	4.64	0.18						
d 42[a,d]	3.42	3.19	3.36	3.51	3.07	3.30	3.31	2.72	2.98	3.37	0.18						
d 84[e,h]	3.35	3.12	3.41	3.27	2.78	2.98	3.09	2.59	2.86	2.79	0.14	0.885	0.934	0.951	0.337	0.503	0.774
Total C18:1,[6] %																	
d 0	43.38	43.64	44.68	44.30	44.81	44.23	44.88	44.01	44.48	43.44	0.76						
d 42[a,b,c,d]	47.27	49.98	48.84	49.34	47.80	47.16	50.80	43.36	42.74	48.00	0.76						
d 84[f,g,h]	47.82	48.54	48.36	48.82	46.52	47.02	47.11	42.97	44.90	44.52	0.62	0.590	0.196	0.063	0.739	0.667	0.424
Total C18:2,[7] %																	
d 0	13.19	12.55	11.81	12.43	12.30	12.48	12.19	12.80	12.15	13.06	0.61						
d 42[a,b,c,d]	11.49	10.22	10.65	9.54	12.59	13.20	9.83	17.22	17.01	10.08	0.61						
d 84 [e,f,g,h]	10.32	10.20	10.30	9.72	13.31	12.11	11.89	17.83	14.23	14.60	0.53	0.095	0.002	0.001	0.66	0.466	0.222
Total C18:3,[8] %																	
d 0	0.66	0.63	0.59	0.61	0.62	0.62	0.61	0.63	0.58	0.67	0.07						
d 42 [a,b,c,d]	0.53	0.46	0.49	0.43	0.79	0.84	0.44	1.28	1.24	0.46	0.07						
d 84 [e,f,g,h]	0.46	0.46	0.44	0.44	0.94	0.67	0.76	1.51	0.88	1.17	0.06	0.001	0.001	0.001	0.082	0.001	0.001
C20:1, %																	
d 0	0.62	0.70	0.69	0.72	0.71	0.66	0.66	0.66	0.69	0.64	0.03						
d 42[d]	0.72	0.74	0.75	0.73	0.76	0.74	0.69	0.68	0.70	0.67	0.03						
d 84[f,g,h]	0.81	0.86	0.81	0.88	0.82	0.79	0.78	0.70	0.78	0.73	0.03	0.555	0.031	0.109	0.171	0.358	0.017
C22:5n3, %																	
d 0[a,c]	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.09	0.01						
d 42[a,b,c,d]	0.05	0.05	0.05	0.05	0.07	0.07	0.05	0.09	0.08	0.06	0.01						
d 84[e.f.g.h]	0.05	0.05	0.04	0.05	0.07	0.06	0.06	0.09	0.06	0.07	0.00	0.110	0.315	0.009	0.717	0.787	0.508
Total SFA,[9] %																	
d 0	35.76	35.97	35.98	35.57	35.65	36.00	35.20	35.72	35.45	35.05	0.71						
d 42 [a]	34.93	33.57	34.01	34.85	33.13	32.80	33.43	32.70	33.27	35.73	0.71						
d 84 [e,h]	35.75	34.98	35.01	35.20	33.79	34.78	34.69	32.57	34.70	34.51	0.57	0.364	0.233	0.033	0.797	0.927	0.717
Total MUFA,[10] %																	
d 0	49.46	49.90	50.71	50.37	50.54	49.96	51.10	49.80	50.77	49.99	0.80						
d 42 [a,b,c,d]	52.18	54.74	53.78	54.25	52.35	51.95	55.46	47.41	47.11	52.76	0.80						
d 84 [e,f,g,h]	52.57	53.23	53.25	53.63	50.72	51.42	51.62	46.79	49.15	48.61	0.66	0.540	0.185	0.049	0.879	0.533	0.414
Total PUFA,[11] %																	
d 0	14.89	14.20	13.34	14.01	13.87	14.04	13.73	14.42	13.70	14.86	0.67						
d 42 [a,b,c,d]	13.01	11.76	12.24	10.83	14.57	15.25	11.13	19.82	19.52	11.40	0.67						
d 84 [e,f,g,h]	11.68	11.79	11.73	11.17	15.46	13.85	13.70	20.64	16.19	16.87	0.58	0.069	0.001	0.001	0.63	0.361	0.144

Iodine value,[12] g/100 g																	
d 0	68.43	67.15	66.57	67.36	67.19	67.09	67.56	67.82	67.37	68.83	0.99						
d 42 [a,b,c,d]	66.96	66.50	66.59	64.97	69.55	70.48	66.51	74.93	74.08	64.80	0.99						
d 84 [e,f,g,h]	65.03	65.18	65.40	64.72	69.88	67.61	67.66	75.94	69.93	70.88	0.84	0.067	0.005	0.001	0.598	0.518	0.220

[1] A total of 160 finishing pigs (PIC 337 × 1050, initial BW of 45.6 kg) were used in an 84-d finishing trial with 2 pigs per pen and 8 pens per treatment.

[2] C22:6n3 not included, all values were equal to or less than 0.01.

[3] Control = no added fat; Tallow = 4% beef tallow; Soy = 4% soybean oil; Blend = 2% tallow and 2% soybean oil

[4]There was a treatment × day interaction ($P < 0.001$) for all variables except C 16:1 ($P = 0.1233$), C 20:1 ($P = 0.0326$), and saturated ($P = 0.074$).

[5] The d 84 contrast statements for interactions are as follows: 1= feeding duration (84-d vs. 42-d) × fat source (tallow vs. blend); 2 = feeding duration (84-d vs. 42-d) × fat source (blend vs. soy oil); 3 = feeding duration (84-d vs. 42-d) × fat source (tallow vs. soy oil); 4 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (tallow vs. blend); 5 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (blend vs. soy oil); 6 = feeding period (d 0 to 42 vs. d 42 to 84) × fat source (tallow vs. soy oil).

[a,b,c,d] Within a row, superscripts represent significant ($P < 0.05$) main effects where a = control vs. fat (treatments A, D, G, and J vs. B, C, E, F, H, and I); b = tallow vs. blend (treatments B and C vs. E and F); c = blend vs. soy oil (treatments E and F vs. H and I); d = tallow vs. soy oil (treatments B and C vs. H and I).

[e,f,g,h] Within a row, superscripts represent significant ($P < 0.05$) main effects where e = control vs. fat (treatments A, C, F, and I vs. B, D, E, G, H, and J); f = tallow vs. blend (treatments B and D vs. E and G); g = blend vs. soy oil (treatments E and G vs. H and J); h = tallow vs. soy oil (treatments B and D vs. H and J).

[6] Total C18:1= ([C18:1n9t] + [C18:1n11t] + [C18:1n9c] + [C18:1n11c]); brackets indicate concentration.

[7] Total C18:2= ([C18:2n6t] + C18:2n6c]); brackets indicate concentration.

[8] Total C18:3= ([C18:3n6] + [C18:3n3]); brackets indicate concentration.

[9] Total SFA= ([C6:0] + [C8:0] + [C10:0] + [C11:0] + [C12:0] + [C14:0] + [C15:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C21:0] + [C22:0] + [C23:0] + [C24:0]); brackets indicate concentration.

[10]Total MUFA= ([C14: 1] + [C16:1] + [C17:1] + [C18:1n9t] + [C18:1n11t] + [C18:1n9c] + [C18:1n11c] + [C20:1] + [C22:1n9] + [C24:1]); brackets indicate concentration.

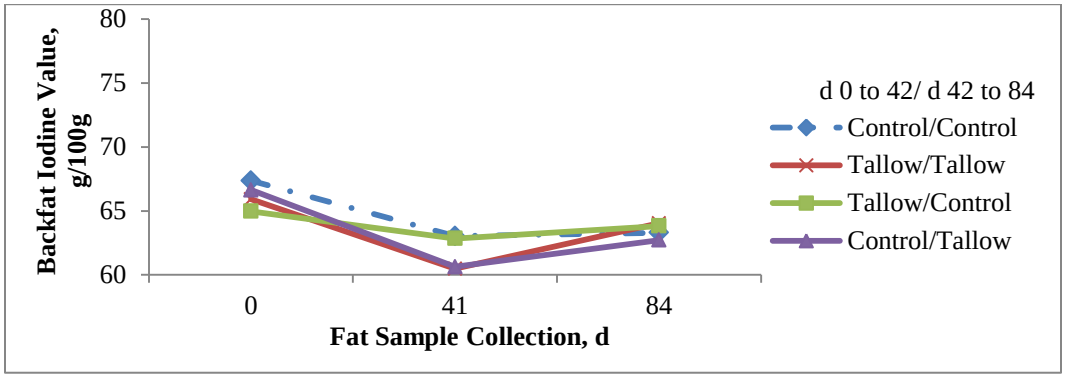
[11]Total PUFA=([C18:2n6t] + [C18:2n6c] + [C18:3n6] + [C18:3n3] + [CLA 9c11t] + [CLA 10t12c] + [CLA 9c11c] + [CLA 9t11t] + [C20:2] +[C20:3n6] + [C20:3n3] + [C22:2] + [C20:5n3] + [C22:5n3] + [C22:6n3]); brackets indicate concentration.

[12] Calculated as IV value= [C16:1] × 0.9502 + [C18:1] × 0.8598 + [C18:2] × 1.7315] + [C18:3] × 2.6125 + [C20:1] × 0.7852 + [C22:1n9] × 3.2008 + [C22:5n3] × 3.6974 + [C22:6n3] × 4.4632; brackets indicate concentrations.

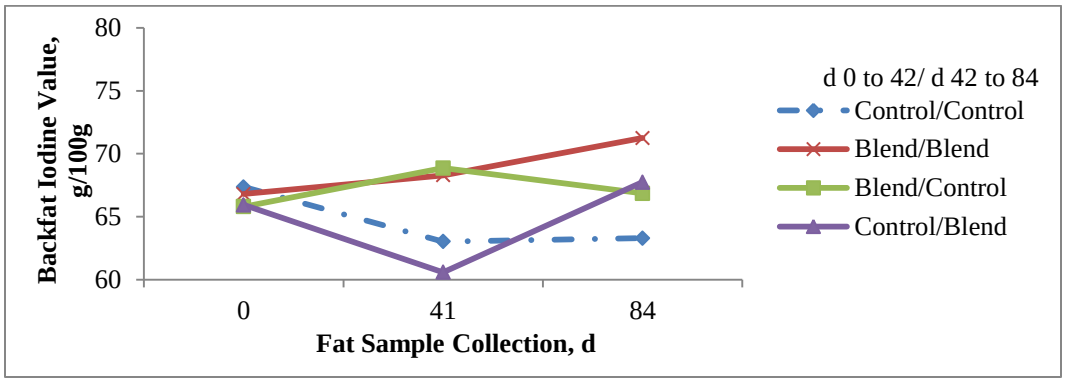
Figure 1-1. Effect of feeding duration of added fat on backfat iodine value. A total of 160 finishing pigs (PIC 337 × 1050, initial BW of 45.6 kg) were used in an 84-d finishing trial with 2 pigs per pen and 8 pens per treatment. Values represent the mean of 8 pigs per treatment, representing 1 pig per pen. Fat was added to the diet either during period 1 (d 0 to 42), period 2 (d 42 to 84), or the duration of the study (d 0 to 84). Biopsy samples were taken on d 0, 41, and 84 for analysis.

A. Effects of 4% tallow on backfat IV
B. Effects of 2% soybean oil and 2% tallow on backfat IV
C. Effects of 4% soybean oil on backfat IV

A



B



C

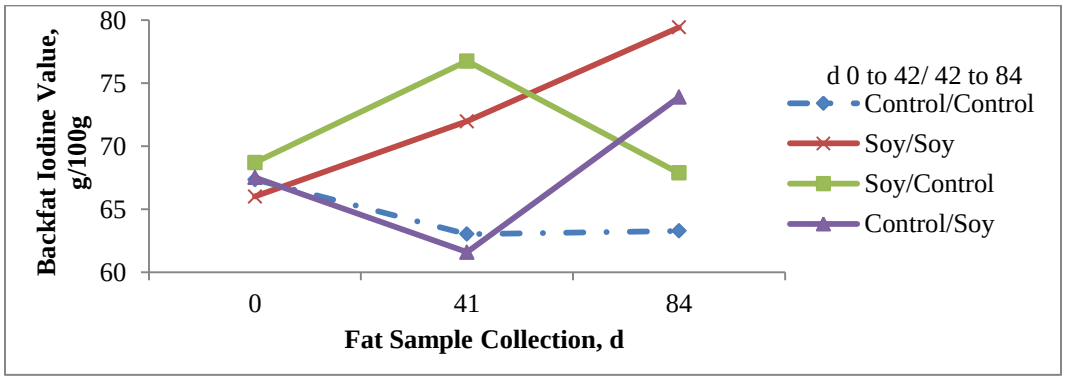
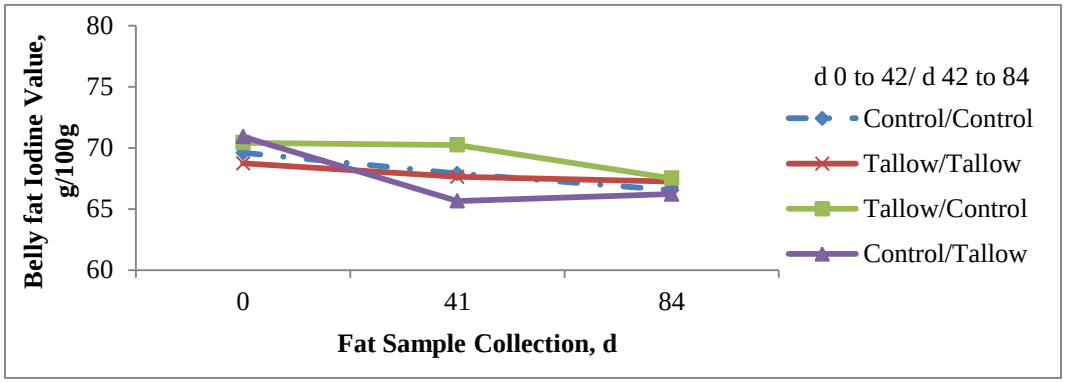


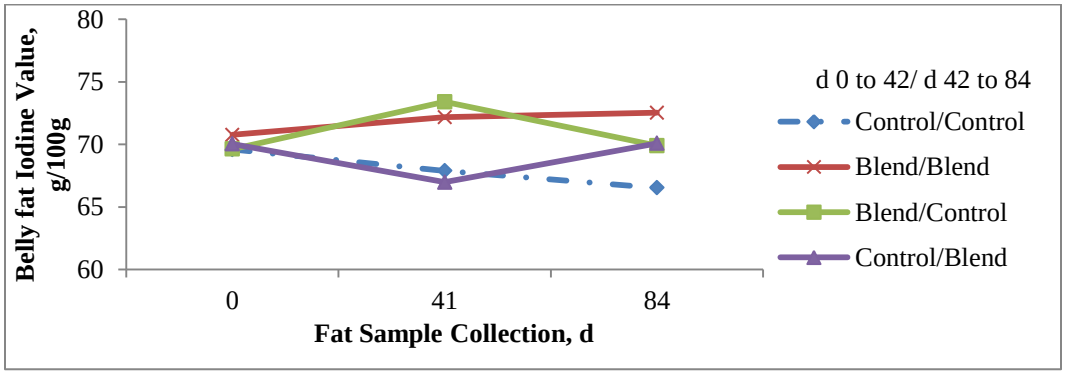
Figure 1-2. Effect of feeding duration of added fat on belly iodine value. A total of 160 finishing pigs (PIC 337 × 1050, initial BW of 100.5 kg) were used in an 84-d finishing trial with 2 pigs per pen and 8 pens per treatment. Values represent the mean of 8 pigs per treatment, representing 1 pig per pen. Fat was added to the diet either during period 1 (d 0 to 42), period 2 (d 42 to 84), or the duration of the study (d 0 to 84). Biopsy samples were taken on d 0, 41, and 84 for analysis.

A. Effects of 4% tallow on belly IV
B. Effects of 2% soybean oil and 2% tallow on belly IV
C. Effects of 4% soybean oil on belly IV

A



B



C

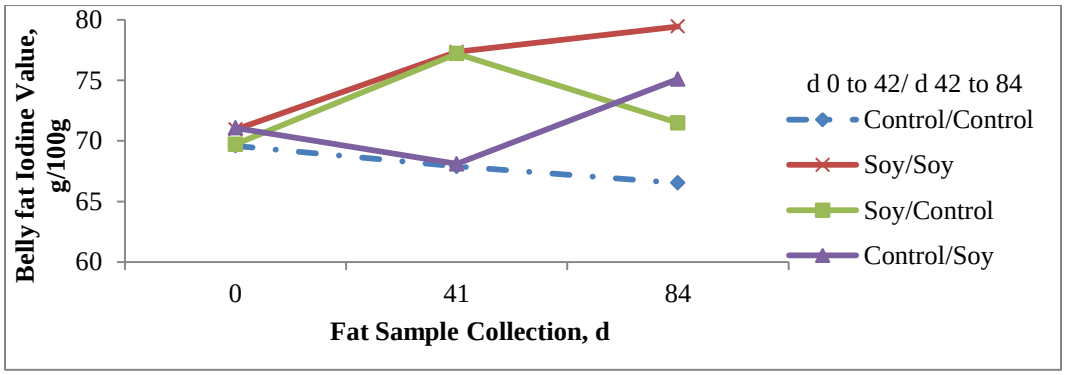
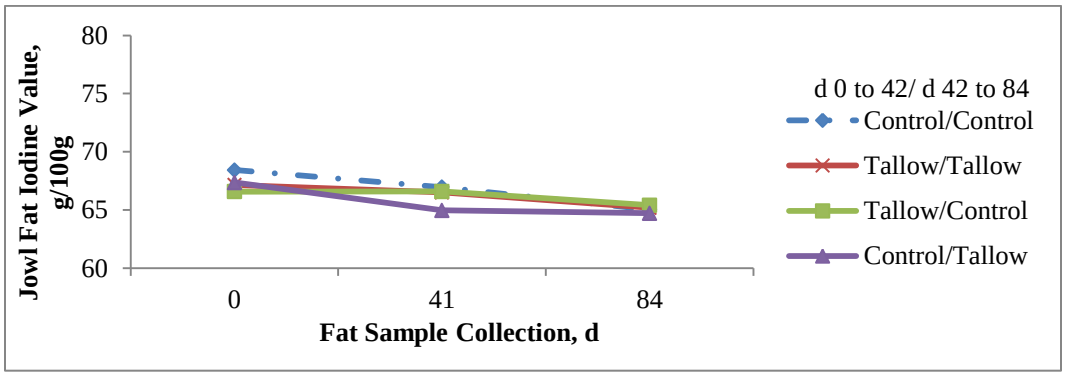


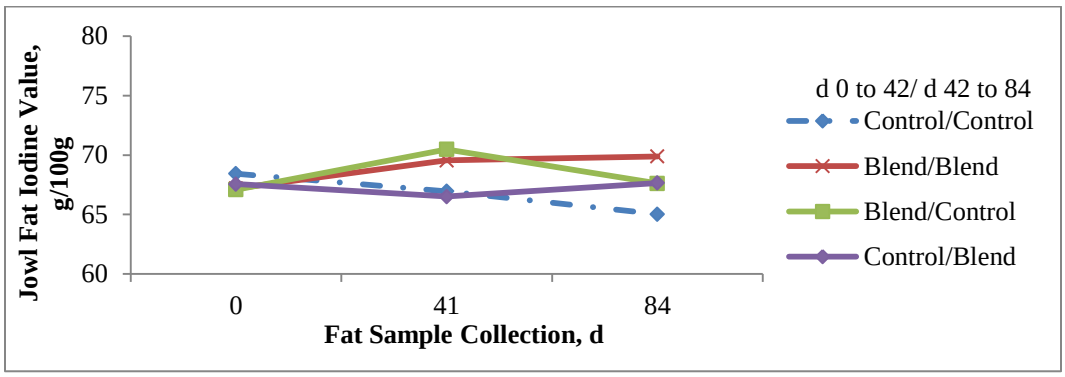
Figure 1-3. Effect of feeding duration of added fat on jowl iodine value. A total of 160 finishing pigs (PIC 337 × 1050, initial BW of 100.5 kg) were used in an 84-d finishing trial with 2 pigs per pen and 8 pens per treatment. Values represent the mean of 8 pigs per treatment, representing 1 pig per pen. Fat was added to the diet either during period 1 (d 0 to 42), period 2 (d 42 to 84), or the duration of the study (d 0 to 84). Biopsy samples were taken on d 0, 41, and 84 for analysis.

A. Effects of 4% tallow on jowl IV
B. Effects of 2% soybean oil and 2% tallow on jowl IV
C. Effects of 4% soybean oil on jowl IV

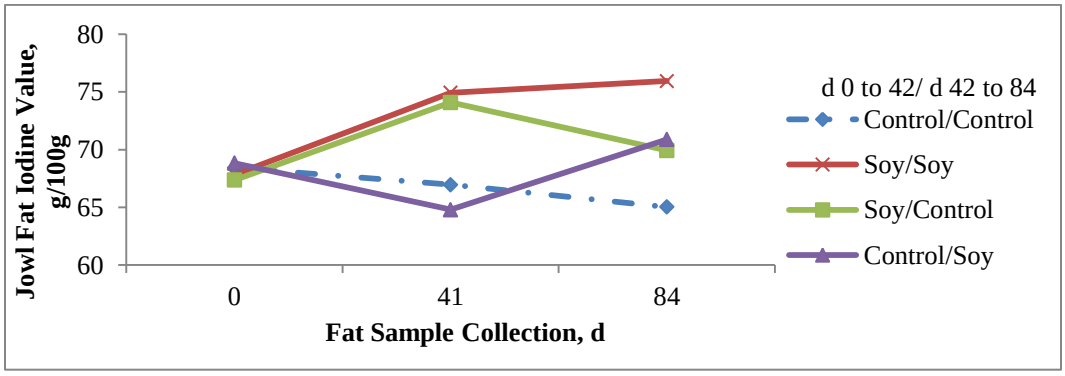
A



B



C



Chapter 2 - Effects of a dietary protease enzyme (CIBENZA DP100) on finishing pig growth performance and carcass characteristics

ABSTRACT

A total of 1,170 pigs (PIC 337 × 1050; initial BW 25.5 ± 4.4 kg) were used in a 131-d study to determine the effects of a dietary protease enzyme on growth performance and carcass characteristics of finishing pigs. Pens of pigs were randomly allotted to 1 of the 3 treatments with 26 pigs per pen and 15 replicates per treatment. Dietary treatments consisted of: (1) a positive control diet formulated at 90% of the estimated standardized ileal digestible (SID) Lys requirement; (2) a negative control diet formulated to the same SID Lys requirement minus the expected nutrient release (both AA and dietary energy) contributed from the protease enzyme (CIBENZA DP100, Novus International, Inc., St. Charles, MO), and (3) the negative control diet with the addition of 0.05% CIBENZA DP100. The diets were formulated such that the negative control diet containing the protease enzyme had calculated nutrient concentrations similar to the positive control.

Overall (d 0 to 131), pigs fed the positive control diet had increased ($P < 0.05$) ADG compared to pigs fed the negative control diet. Pigs fed the negative control diet plus CIBENZA DP100 had improved ($P < 0.05$) ADFI and a tendency for improved ($P = 0.09$) ADG compared to pigs fed the negative control diet without the enzyme. No differences were observed in ADG, ADFI, or G:F ($P > 0.10$) between pigs fed the positive control diet and those fed the negative control diet plus the protease enzyme, which suggests that the nutrient release values attributed to the enzyme were accurate. The only observed effect on carcass characteristics was for yield, in which the pigs fed the negative control diet with the enzyme had decreased ($P < 0.05$) carcass yield compared to pigs fed the negative control diet without the enzyme. These data suggest that

the protease enzyme, CIBENZA DP100, will elicit improved growth performance when added to diets formulated at 90% of the pig's estimated SID Lys requirement.

INTRODUCTION

With ever-increasing feed prices, the swine industry continues to search for alternatives to reduce feed cost and extract more nutrients from feed ingredients. While the addition of carbohydrase and protease enzymes have yielded positive growth performance responses in poultry (Angel et al., 2011; Olukosi et al., 2007a), varying results have been reported in swine (O'Shea et al., 2014; Wang et al., 2011). A vast majority of the previous research with enzyme supplementation in swine diets has evaluated the use of phytase or carbohydrase enzymes and only recently has research been conducted with a single exogenous protease enzyme as opposed to the protease being supplemented in combination with other enzymes (Adeola and Cowieson, 2011).

Proteases are endogenous enzymes that are required for the digestion and utilization of dietary proteins. For many years, exogenous proteases had been added to swine diets in combination along with other enzyme types. Recently, exogenous proteases have gained interest in being used as a single product in diets (Adeola and Cowieson, 2011). Preliminary results indicate that a new protease enzyme (CIBENZA DP100, Novus International, Inc., St. Charles, MO) may be able to increase digestibility of dietary protein and increase dietary energy utilization, consequently eliciting improved nursery growth performance (Wang et al., 2011). However, no data is available to verify this response in finishing pigs. Therefore, the objective of this study was to determine if the addition of a protease enzyme, CIBENZA DP100, could improve growth performance and carcass characteristics of finishing pigs housed in a commercial setting.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at a commercial research-finishing site in southwest Minnesota. The barn was naturally ventilated and double-curtain-sided. Each pen was equipped with a 4-hole stainless steel feeder and bowl waterer for ad libitum access to feed and water. Feed additions to each individual pen were made and recorded by a robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN).

Animals and Diets

A total of 1,170 mixed sex pigs (PIC 337 × 1050; initial BW 25.5 ± 4.4 kg) were used in a 131-d study. Pens were blocked by BW and were randomly assigned to 1 of 3 dietary treatments with 15 pens per treatment and 26 pigs per pen. Dietary treatments consisted of: (1) a positive control diet, formulated at 90% of the estimated standardized ileal digestible (SID) Lys requirement for these pigs; 2) a negative control diet, formulated to provide 90% of the SID Lys requirement minus the expected nutrient release (both AA and dietary energy) from the protease enzyme (CIBENZA DP100), and (3) the negative control diet with the addition of 0.05% CIBENZA DP100, which has an activity of 600,000 U/g (Tables 1 and 2). The diets were formulated such that the negative control diet containing the protease enzyme had calculated nutrient concentrations similar to the positive control. Previous research conducted by Main et al. (2008) and Shelton et al. (2011) determined the SID Lys requirement of pigs in this research facility and was the basis of the requirement estimates used in this study. Nutrient release values expected from CIBENZA DP100 were provided by the supplier (Table 3) and were dependent on the basal diet formulation which consequently is the reason that the release values changed for

each phase. These release values were adapted from Escobar et al. (2013). All diets were corn-soybean meal based and contained 30% dried distillers grains with solubles (DDGS).

Sample Collection

Samples of each diet were collected from feeders for each phase. Samples were then subsampled and analyzed (Ward Laboratories, Inc. Kearney, NE) for DM (method 934.01; AOAC, 2006), CP (method 990.03; AOAC, 2006), CF (method 978.10; AOAC, 2006), crude fat (method 920.39; AOAC, 2006), ash (method 942.05; AOAC, 2006), ADF, and NDF (Van Soest, 1963; Table 4).

Pens of pigs were weighed and feeder measurements were recorded on d 0, 12, 26, 45, 63, 81, 94, 108, and 131 to calculate ADG, ADFI, G:F, and caloric efficiency. Caloric efficiency was calculated by multiplying feed intake per pen and the ME of the diet, then dividing by the gain of the pen. On d 108, the 3 heaviest pigs in each pen were weighed, removed from the pens, and marketed according to standard farm procedures. Prior to marketing, the remaining pigs were individually tattooed with a pen ID number to allow for carcass measurements to be recorded on a pen basis. On d 131, final pen weights were taken, and pigs were transported approximately 94 km to a commercial packing plant (JBS Swift and Company, Worthington, MN) for processing and carcass data collection. Carcass measurements taken at the plant included HCW, 10^{th} rib loin depth, backfat, and percentage lean. Carcass yield was calculated by dividing the HCW at the plant by the pig's average pen live weight at the farm before transport to the plant. Fat depth and loin depth were measured with an optical probe inserted between the third and fourth last rib (counting from the ham end of the carcass) at a distance approximately 7 cm from the dorsal midline.

Statistical Analysis

The experimental data were analyzed as a randomized complete block design using the GLIMMIX procedure of SAS (SAS Institute, Cary, NC) with pen as the experimental unit and initial BW as a blocking factor. Carcass weight was adjusted to a common weight to analyze backfat, loin depth, and lean percentage. Pairwise comparisons were used to determine treatment differences, with $P < 0.05$ being a significant difference and a tendency being between $P > 0.05$ and $P \leq 0.10$.

RESULTS

Analysis of diets revealed that nutrients were similar to calculated values considering normal analytical variation. Overall (d 0 to 131), pigs fed the positive control diet had increased ($P < 0.05$) ADG compared to pigs fed the negative control diet, which illustrates that diets were below their estimated SID lysine requirement (Table 5). Pigs fed the negative control diet plus CIBENZA DP100 had increased ($P < 0.05$) ADFI, which led to a tendency for improved ($P < 0.10$) ADG compared to pigs fed the negative control diet without the enzyme. Final BW was greater ($P < 0.05$) for pigs fed the positive control diet compared to those fed the negative control diet, with the pigs fed the negative control diet plus enzyme being intermediate. Overall feed and caloric efficiency were unaffected by treatments. The only impact for carcass characteristics observed was for yield, in which the pigs fed the negative control diet with the enzyme had lower ($P < 0.05$) yield than pigs fed the negative control diet without the enzyme.

DISCUSSION

The inclusion of exogenous enzymes is not new to the swine industry. Phytase is commonly used to increase phosphorus digestibility and reduce P excretion (Almeida and Stein, 2010). Phytase has also been shown to improve growth performance of swine (Adeola et al.,

2004). The use of carbohydrases, used to degrade non starch polysaccharides, has shown mixed results on growth performance in wheat (Omogbenigun et al., 2004; Kiarie et al. 2007; Olukosi et al., 2007b) or corn-soybean meal based diets (Jacela et al., 2010; Yoon et al., 2010).

The use of a single exogenous protease in animal feed has been evaluated to some degree with varying results. The majority of research with single exogenous protease supplementation for monogastric animals has been conducted in poultry. Positive results have been shown for increased BW gain (Odetallah et al., 2003; Odetallah et al., 2005; Wang et al., 2007) and feed efficiency (Angel et al., 2011; Freitas et al., 2011) for broilers fed a protease-supplemented diet. Results, however, have not been as consistent with pigs.

Wang et al. (2011) observed that a dietary protease increased total tract digestibility for GE, CP, and P in pigs weaned at 30 d of age. The protease enzyme also resulted in decreased ADFI and improved ADG and feed efficiency compared to pigs fed a diet without protease supplementation for 21 d after weaning. O'Shea et al. (2014) also observed an increase in apparent ileal digestibility of N for finishing pigs fed a protease supplemented diet. Conversely, O'Doherty et al. (1999) observed no effect of protease addition on apparent nutrient digestibility for finishing pigs fed diets primarily made up of peas, barley, wheat, and soybean meal.

While digestibility research has shown some benefits, growth performance has not consistently been improved when proteases are fed to finishing pigs. O'Shea et al. (2014) reported a decrease in overall ADG for pigs fed a protease-supplemented diet compared to those fed a non-supplemented diet comprised of mostly wheat, barley, rapeseed meal, and wheat DDGS. This decrease in ADG was the result of lower ADFI observed in these pigs. Thacker (2005) observed no differences in pigs fed a protease supplemented diet compared to a corn-soybean meal diet without protease. O'Doherty et al. (1999) also did not find any differences in

ADG or feed efficiency for pigs fed a protease-supplemented diet compared to pigs fed a non-supplemented diet with 40% raw peas.

The present data shows that including a protease in a diet containing 30% DDGS can increase feed intake and tend to increase ADG compared to pigs fed a negative control without protease. One possible explanation that the current study may have been able to observe this response could be related to the negative control diet formulated below the pig's requirements, which was not typical of the previous studies. By formulating diets below the animal's requirement an opportunity was created for the enzyme to elicit a response which may not have been possible if diets were formulated in excess of the pig's requirements. Another factor that could have influenced our ability to observe a protease response could be the fact that our study was conducted under commercial conditions, whereas previous studies were performed in a university setting. De la Llata et al. (2001) observed that pigs in a commercial setting have reduced ADFI compared to a university research setting. While using similar basal ingredients, the current study showed numerically lower ADFI in comparison to the previously mentioned growth performance trial performed by Thacker et al. (2005). Both the current study and work performed by O'Doherty et al. (1999) and O'Shea et al (2014) found fairly similar levels of ADFI, however, these diets were formulated with vastly different ingredients. In particular, O'Doherty et al. (1999) used dietary raw peas with tannin levels of 12 mg/g, which could have depressed ADFI as well as slowed enzymatic digestion (Jezierny et al. 2010). In addition, feed intake also was not offered ad libitum in their experiment, which may have influenced the response.

In summary, the addition of the dietary protease enzyme (CIBENZA DP100) used in this study to a nutrient deficient diet increased ADFI and tended to increase ADG, which supports the

hypothesis that the enzyme allowed for better nutrient utilization. Additional research should be conducted to determine if a similar improvement in growth performance will be observed when pigs are fed diets formulated at, rather than below, their nutrient requirement estimates.

LITERATURE CITED

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FIGURES AND TABLES

Table 2-1. Phase 1, 2, and 3 diet composition (as-fed basis)[1]

	Phase 1			Phase 2			Phase 3		
Item	PC[2]	DP100	NC	PC	DP100	NC	PC	DP100	NC
Ingredient, %									
Corn	45.22	49.91	49.96	49.38	52.20	52.25	52.33	55.01	55.06
Soybean Meal, 46.5% CP	19.58	15.50	15.50	15.49	13.30	13.30	12.61	10.50	10.50
DDGS[3]	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Beef tallow	3.00	2.20	2.20	3.00	2.25	2.25	3.00	2.30	2.30
Limestone	1.40	1.40	1.40	1.35	1.35	1.35	1.30	1.30	1.30
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
L-Thr	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
L-Lys sulfate[4]	0.26	0.34	0.34	0.24	0.27	0.27	0.23	0.25	0.25
Dicalcium P, 18% P	0.00	0.05	0.05	0.00	0.05	0.05	0.00	0.05	0.05
Phytase[5]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Vitamin premix[6]	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix[7]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Enzyme[8]	0.00	0.05	0.00	0.00	0.05	0.00	0.00	0.05	0.00
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis									
Standard ileal digestible (SID) amino acids, %									
Lys	0.99	0.99	0.95	0.87	0.87	0.84	0.79	0.79	0.75
Ile:Lys	73	71	67	66	66	62	61	61	57
Leu:Lys	182	178	173	172	172	167	165	165	160
Met:Lys	32	32	31	31	31	30	29	29	28
Met+Cys:Lys	62	61	59	58	59	56	55	56	53
Thr:Lys	66	66	61	60	62	57	56	58	53
Trp:Lys	18	17	16	16	16	15	15	14	13
Val:Lys	80	80	75	74	76	70	69	71	66
SID Lys:ME, g/Mcal	2.90	2.91	2.82	2.55	2.56	2.48	2.31	2.32	2.23
ME, kcal/kg	3,400	3,401	3,370	3,406	3,403	3,374	3,410	3,409	3,381
CP, %	22.2	21.6	20.8	20.5	20.4	19.7	19.3	19.2	18.5
Ca, %	0.60	0.60	0.60	0.57	0.58	0.58	0.54	0.55	0.55

P, %	0.47	0.47	0.47	0.45	0.45	0.46	0.44	0.44	0.44
Available P, %	0.31	0.31	0.31	0.30	0.31	0.31	0.30	0.31	0.31
Standard digestible P, %	0.30	0.30	0.30	0.30	0.30	0.30	0.29	0.30	0.30

[1] Phase 1, 2, and 3 diets were fed from d 0 to 26, d 26 to 45, and d 45 to 63, respectively.

[2] Treatments were designed as follows: PC (positive control) = 90% of SID lysine requirement of pigs in each phase; DP100 = negative control plus nutrient release expected from CIBENZA DP100 to meet the nutrient contribution of the positive control; and NC = negative control.

[3] Dried distillers grains with solubles.

[4] L-lys sulfate provided by Biolys (Evonik Corporation, Kennesaw, GA).

[5] Optiphos 2000 (Enzyvia LLC, Sheridan, IN) provided 227 phytase units (FTU)/lb, with a release of 0.07% available P.

[6] Provided per kilogram of premix: 1,451,494 IU vitamin A; 362,874 IU vitamin D; 10,885 IU vitamin E; 726 mg vitamin K; 13,608 mg Niacin, 4,536 mg pantothenic acid; 1,361 mg riboflavin, 6.4 mg vitamin B_{12}

[7] Provided per kilogram of premix: 3,402 mg Cu from copper sulfate or copper chloride; 68 mg I from ethylenediamine dihydriodide or calcium iodate; 22,680 mg Fe from ferrous sulfate; 6.804 mg of Mn from manganese sulfate or manganese oxide; 300 mg of Se from sodium selenite; 22,680 mg of Zn from zinc sulfate or zinc oxide.

[8] CIBENZA DP100 (Novus International, St. Charles, MO).

Table 2-2. Phase 4 and 5 diet composition (as-fed basis)[1]

	Phase 4			Phase 5		
Item	PC[2]	DP100	NC	PC	DP100	NC
Ingredient, %						
Corn	55.22	57.07	57.12	58.14	59.74	59.79
Soybean meal, 46.5% CP	9.78	8.50	8.50	6.88	5.80	5.80
DDGS[3]	30.00	30.00	30.00	30.00	30.00	30.00
Beef tallow	3.00	2.35	2.35	3.00	2.40	2.40
Limestone	1.25	1.25	1.25	1.25	1.25	1.25
Salt	0.35	0.35	0.35	0.35	0.35	0.35
L-Thr	0.00	0.00	0.00	0.00	0.00	0.00
L-Lys sulfate[4]	0.21	0.22	0.22	0.20	0.20	0.20
Dicalcium P, 18% P	0.00	0.03	0.03	0.00	0.03	0.03
Phytase[5]	0.01	0.01	0.01	0.01	0.01	0.01
Vitamin premix[6]	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix[7]	0.10	0.10	0.10	0.10	0.10	0.10
Enzyme[8]	0.00	0.05	0.00	0.00	0.05	0.00
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis						
Standard ileal digestible (SID) amino acids, %						
Lys	0.71	0.71	0.68	0.62	0.62	0.59
Ile:Lys	56	57	54	51	52	49
Leu:Lys	158	160	155	151	153	149
Met:Lys	28	28	27	26	27	26
Met+Cys:Lys	53	54	52	50	51	49
Thr:Lys	52	55	50	48	51	46
Trp:Lys	13	13	12	12	12	11
Val:Lys	65	68	63	60	64	58
SID Lys:ME, g/Mcal	2.07	2.08	2.00	1.82	1.83	1.75
ME, kcal/kg	3,414	3,413	3,387	3,417	3,415	3,392
CP, %	18.2	18.3	17.7	17.0	17.2	16.6
Ca, %	0.52	0.52	0.52	0.51	0.51	0.51
P, %	0.43	0.43	0.43	0.42	0.42	0.42

Available P, %	0.29	0.30	0.30	0.29	0.30	0.30
Standard Digestible P, %	0.29	0.29	0.29	0.28	0.29	0.29

[1] Phase 4 and 5 diets were fed from d 63 to 94 and d 94 to 131, respectively.
[2] Treatments were designed as follows: PC (positive control) = 90% of SID lysine requirement of pigs in each phase; NC + DP100 = negative control plus nutrient release expected from CIBENZA DP100 to meet the nutrient contribution of the positive control; and NC = negative control.
[3] Dried distillers grains with solubles.
[4] L-lys sulfate provided by Biolys (Evonik Corporation, Kennesaw, GA).
[5] Optiphos 2000 (Enzyvia LLC, Sheridan, IN) provided 227 phytase units (FTU)/lb, with a release of 0.07% available P.
[6] Provided per kilogram of premix: 1,451,494 IU vitamin A; 362,874 IU vitamin D; 10,885 IU vitamin E; 726 mg vitamin K; 13,608 mg Niacin, 4,536 mg pantothenic acid; 1,361 mg riboflavin, 6.4 mg vitamin B_{12}
[7] Provided per kilogram of premix: 3,402 mg Cu from copper sulfate or copper chloride; 68 mg I from ethylenediamine dihydriodide or calcium iodate; 22,680 mg Fe from ferrous sulfate; 6.804 mg of Mn from manganese sulfate or manganese oxide; 300 mg of Se from sodium selenite; 22,680 mg of Zn from zinc sulfate or zinc oxide.
[8] CIBENZA DP100 (Novus International, St. Charles, MO).

Table 2-3. Nutrient release of CIBENZA DP100[1]

Item	Phase 1[2]	Phase 2	Phase 3	Phase 4	Phase 5
ME, kcal/kg	31.0	29.0	28.0	26.0	23.0
Standardized ileal digestible AA, %					
Lys	0.039	0.036	0.036	0.033	0.030
Thr	0.050	0.048	0.048	0.044	0.041
Met	0.010	0.010	0.009	0.009	0.009
Met & Cys	0.027	0.026	0.026	0.024	0.022
Trp	0.007	0.007	0.007	0.006	0.006
Ile	0.038	0.036	0.035	0.031	0.026
Val	0.055	0.054	0.055	0.053	0.053
Arg	0.021	0.019	0.019	0.016	0.014
His	0.018	0.017	0.017	0.015	0.013
Leu	0.049	0.047	0.047	0.043	0.039
Phe	0.036	0.035	0.035	0.033	0.032
Phe &Tyr	0.049	0.048	0.047	0.045	0.043

[1] Release values change for each phase due to substrate availability and actual release values for each phase were provided by the supplier.
[2] Phase 1, 2, 3, 4, and 5 were fed from d 0 to 26, d 26 to 45, d 45 to 63, d 63 to 94, and d 94 to 131, respectively.

Table 2-4. Proximate analysis of diets (as-fed basis)[1]

	Phase 1[2]			Phase 2			Phase 3			Phase 4			Phase 5		
Item, %[3]	PC	DP100	NC	PC	DP100	NC	PC	DP100	NC	PC	DP100	NC	PC	DP100	NC
DM	89.3	89.20	89.3	88.3	88.6	88.2	88.8	88.8	88.5	89.1	89.1	89.2	89.1	88.8	89.0
CP	20.5	19.2	20.2	19.6	18.3	16.9	18.9	18.2	17.9	17.8	17.6	17.2	17.3	17.3	16.7
ADF	4.9	5.2	5.1	4.3	4.6	4.4	5.2	4.8	5.4	4.9	5.1	5.5	5.7	5.4	5.1
NDF	11.7	12.0	12.7	12.5	12.0	11.8	13.3	12.1	12.4	11.6	12.1	13.5	13.2	11.7	12.8
Crude fiber	3.6	3.6	3.6	3.4	3.2	2.9	3.8	3.4	3.8	4.0	4.3	3.9	3.5	3.0	3.4
NFE[4]	54.2	55.7	54.2	55.1	56.8	58.8	54.5	56.3	56.3	53.4	55.7	55.7	56.7	56.2	57.6
Fat	6.5	6.0	6.3	5.8	5.4	4.9	7.1	6.4	6.4	9.6	7.9	7.9	6.9	6.7	6.8
Ash	4.22	4.15	4.41	4.42	4.37	4.07	4.10	4.11	3.64	4.40	3.84	3.95	3.65	4.25	3.78

[1] Phase 1, 2, 3,4, and 5 diets were fed from d 0 to 26, d 26 to 45, d 45 to 63, d 63 to 94, and d 94 to 131, respectively.

[2] PC = positive control, DP100 = negative control with the addition of CIBENZA DP100, NC = negative control.

[3] Values represent the mean of samples collected from feeders, then pooled and subsampled, and one composite sample of each diet was finally analyzed.

[4] Nitrogen Free Extract.

Table 2-5. The effects of CIBENZA DP100 on finishing pig growth performance[1,2]

Item	PC[3]	DP100	NC	SEM	Probability, $P <$ Treatment
BW, kg					
d 0	25.5	25.5	25.5	0.477	0.988
d 131	133.3[a]	132.6[ab]	130.2[b]	1.253	0.090
d 0 to 131					
ADG, kg	0.831[a]	0.826[ab,x]	0.811[b,y]	0.006	0.074
ADFI, kg	2.18[ab]	2.21[a]	2.15[b]	0.021	0.090
G:F	0.381	0.375	0.378	0.003	0.429
Caloric efficiency					
ME Mcal/kg	10.98	10.97	10.94	0.116	0.967
Carcass characteristics					
HCW, kg	98.4	97.4	96.8	0.903	0.277
Yield, %	73.8[ab]	73.5[a]	74.4[b]	0.262	0.048
Backfat, mm[4]	19.3	19.1	19.0	0.308	0.796
Loin depth, cm[4]	6.67	6.74	6.68	0.088	0.849
Lean, %[4]	55.1	55.3	55.3	0.260	0.859

[a,b] Within row, means without common superscript differ ($P < 0.05$).

[x,y] Within row, means without common superscript differ ($P < 0.10$).

[1] A total of 1,170 (PIC 337 × 1050) were used with 26 pigs per pen and 15 reps per treatment.

[2] Treatments were designed as follows: Positive control = 90% of SID lysine requirement of pigs in each phase; negative control + DP100 = negative control plus nutrient release expected from CIBENZA DP100 to meet the nutrient contribution of the positive control; and negative control.

[3] PC = positive control, DP100 = negative control with the addition of CIBENZA DP100, NC = negative control.

[4] Adjusted to a common HCW for analysis.

Chapter 3 - The effects of increasing levels of organic or inorganic zinc on growth performance and carcass characteristics of finishing pigs

ABSTRACT

A total of 3,390 pigs (PIC 337 × 1050; initial BW 28.67 kg) were used in this study, housed in 3 replicate barns, to determine the influence of increasing levels of either an organic or inorganic zinc source on growth performance and carcass characteristics of finishing pigs. A total of 126 pens of pigs were allotted to 1 of 7 dietary treatments with 24 to 27 pigs per pen and 14 to 17 replications per treatment. All diets contained a trace mineral premix that provided 55 ppm of zinc from ZnSO4. The 7 experimental treatments were a control diet with no additional zinc included in the diet, the control diet with an additional 25, 50, or 75 ppm of zinc from a zinc AA complex (ZnAA; Availa-Zn; Zinpro, Eden Prarie, MN), or the control diet with an additional 25, 50, or 75 ppm of zinc from ZnO. Diets were fed in meal form in 5 dietary phases and formulated to maintain a constant standardized ileal digestible Lys:NE ratio within phase.

Overall, a zinc source × level interaction (quadratic; $P < 0.05$) was observed for ADG as pigs fed increasing levels of ZnO had similar ADG, while pigs fed added levels of 25 and 50 ppm ZnAA had decreased performance compared to those fed the highest level of ZnAA. A zinc source × level interaction (quadratic; $P < 0.05$) was also observed for overall G:F. This was due to pigs fed diets with 25 or 50 ppm zinc from ZnAA having decreased G:F compared to pigs fed similar levels of ZnO. The interaction in ADG also led to a tendency (quadratic; $P < 0.10$) for a zinc source × level interaction for final BW. No differences were observed for ADFI. For carcass characteristics, a zinc source × level interaction ($P < 0.05$) was observed for HCW as pigs fed diets with 25 or 50 ppm zinc from ZnAA had decreased HCW compared with those fed 75 ppm

zinc from ZnAA, while increasing ZnO did not influence HCW. Loin depth and percentage lean tended to increase then decrease (quadratic; $P < 0.10$) as the level of supplemental ZnAA increased; however, a similar response was not observed for increasing levels of ZnO. These data suggest that in finishing pigs supplemental ZnO did not impact growth performance, but low inclusion levels of ZnAA reduced G:F and final BW.

INTRODUCTION

Zinc is a component of many metalloenzymes, including DNA and RNA synthetases and transferases, and many digestive enzymes, and is associated with the hormone, insulin (NRC, 2012). Concerns of adverse environmental impacts from feeding levels of inorganic Zn have been noted because of its low bioavailability. To overcome these concerns, other researchers have observed that Zn from an organic source has improved bioavailability compared to an inorganic source (Hahn and Baker, 1993; Nitrayova et al., 2012).

The NRC (2012) estimates the dietary Zn requirement for a growing pig weighing from 25 to 135 kg ranges from 50 to 60 ppm. Historically, the trace mineral premix provides the sole source of supplemental Zn for meeting and/or exceeding the NRC requirement estimate for growing and finishing pigs. Recently, research has reported growth performance benefits from even higher levels of supplemental Zn when included in diets containing ractopamine (Fry et al., 2013; Rambo, 2013). However, Paulk et al. (2015) added either ZnO or an organic Zn source at 75, 150, or 225 ppm of the diet starting at 35 or 41 d before slaughter in diets containing ractopamine and observed no benefit from the supplemental Zn nor a difference between Zn sources. It is not clear if supplementing Zn at levels greater than that supplied by the trace mineral premix and for the entire finishing period will lead to growth or carcass performance benefits.

Previous studies with Zn additions to grow-finish diets were performed in university research settings. However, under a commercial environment, pigs have lower feed intake and growth rates due to higher stocking density and other detrimental environmental factors (De la Llata et al., 2001). Therefore, the objective of this study was to determine the influence of increasing Zn, from either an organic or inorganic source, on growth performance and carcass characteristics of grow-finish pigs housed in a commercial facility.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted in 3 barns at a commercial research-finishing facility in southwest Minnesota. The 3 barns were similar in design with completely slatted concrete floors, natural ventilation, and double-curtain-sides. Each pen was equipped with a 4-hole stainless steel feeder and bowl waterer for ad libitum access to feed and water. Feed additions to each individual pen were made and recorded by a robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN).

Animals and Diets

A total of 3,390 mixed sex pigs (PIC 337 × 1050; initial BW 28.67 kg) were used in this study housed in 3 replicate barns. Barn 1 utilized 1,122 pigs for 112 d, barn 2 used 1,159 pigs for 114 d, while group 3 included 1,109 pigs fed for 120 d. On d 0 within each barn, pens of pigs (24 to 27 pigs per pen) were ranked by average pig weight, and randomly assigned within weight blocks to 1 of 7 dietary treatments, resulting in 6 replicates per barn in a randomized complete block design. All diets contained a trace mineral premix that provided 55 ppm of Zn from $ZnSO_4$. The treatments were arranged as a 2 × 3 + 1 factorial with 2 Zn sources and 3 levels of

additional Zn added at the expense of corn. The 7 experimental treatments were a control diet with no additional Zn included in the diet, the control diet with an additional 25, 50, or 75 ppm of Zn from ZnAA (Availa-Zn; Zinpro; Eden Prarie, MN), or the control diet with an additional 25, 50, or 75 ppm of Zn from ZnO. Diets were fed in meal form in 5 dietary phases (27 to 45, 45 to 61, 61 to 77, 77 to 104, 104 to 127 kg; Table 1). Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN) was included at 5 ppm in all diets in the final phase. Diets were formulated to maintain a constant standardized ileal digestible Lys:NE ratio within phase based on previous research conducted by Main et al. (2008) and Shelton et al. (2011) in the same research facility.

Due to a malfunction of the robotic feeding system that resulted in interrupted feed delivery, 6 pens from replicate barn 1 and 8 pens from barn 2 were removed from the study. Additionally, 2 pens were removed from the dataset in barn 3 due to a broken gate allowing pigs from 2 pens to comingle. For pens removed from the data set, data for all phases was eliminated. This resulted in 14 replicates for pigs fed the control diet, 17 replicates per treatment for pigs fed either 25, 50, or 75 ppm Zn from ZnAA, and 17, 14, and 14 replicates for pens of pigs fed either 25, 50, or 75 ppm Zn from ZnO, respectively.

Sample Collection

Samples from each diet and group were collected for each phase. Samples were then combined for a composite and analyzed (Ward Laboratories, Inc. Kearney, NE) for DM (method 934.01; AOAC, 2006), CP (method 990.03; AOAC, 2006), crude fiber (method 978.10; AOAC, 2006), ether extract (method 920.39; AOAC, 2006), ash (method 942.05; AOAC, 2006), ADF, NDF (Van Soest, 1963), and Zn (Kovar, 2003; Tables 2, 3, and 4). Additional Zn analysis was also conducted using method 985.01 (AOAC, 2006; Cumberland Valley Analytical Services

(Hagerstown, MD). Results of Zn analysis from both labs were combined and the mean analytical values are reported.

Pens of pigs were weighed and feeder measurements were recorded approximately every 2 to 3 wk to calculate ADG, ADFI, and G:F. On d 99, 97, and 103, the 4, 3, or 4 heaviest pigs in barns 1, 2 and 3, respectively, were marketed according to standard farm procedures. Prior to marketing, pigs were individually tattooed with a pen ID number to allow for carcass measurements to be recorded on a pen basis. On d 112, 114, and 120 for barns 1, 2, and 3, respectively, final pen weights were taken, and pigs were transported approximately 94 km to a commercial packing plant (JBS Swift and Company, Worthington, MN) for processing and carcass data collection. Carcass measurements taken at the plant included HCW, 10^{th} rib loin depth, backfat, and percentage lean. Percentage carcass yield was also calculated by dividing the individual HCW at the plant by the pig's pen average final live weight at the farm. Fat depth and loin depth were measured with an optical probe inserted between the third and fourth last rib (counting from the ham end of the carcass) at a distance approximately 7 cm from the dorsal midline.

Statistical Analysis

The experimental data were analyzed as a randomized incomplete block design using the GLIMMIX procedure of SAS (SAS Institute, Cary, NC) with pen as the experimental unit. Data from barns 1, 2, and 3 were analyzed as a combined data set and the statistical model included the fixed effect of dietary treatment and the random effects of barn and block within barn. Studentized residuals were evaluated and no evidence of departure from normality was observed. Also, data were evaluated for heterogeneity of variance and no evidence for heterogeneity of variation was found across replicate barn, blocks, or treatments. Orthogonal contrasts were

constructed to test the linear and quadratic effects of Zn, Zn source, and Zn source by dose interactions. Backfat, loin depth, and lean percentage were adjusted to a common carcass weight for analysis. Significant differences were recognized at $P < 0.05$ while a tendency was recorded between $P > 0.05$ and $P \leq 0.10$.

RESULTS

A calculated concentration for Zn in diets was determined by using book values provided by NRC (2012) for ingredients used in this study. The control diets for phase 1, 2, 3, 4, and 5 were calculated to contain 85, 84, 82, 81, and 81 ppm, respectively. Analyzed Zn concentrations for many of the diets were lower than the estimated inclusion rates indicating that basal ingredients may not have contained as much Zn as NRC values indicated. Conversely, the control diet in phase 4 had a greater analyzed Zn concentration than expected. Although the variation in analyzed levels of Zn existed, analyzed Zn content still increased with increasing Zn treatments.

For the grower period (phase 1 to 3), there were no Zn source × level interactions ($P > 0.05$). A Zn source effect was observed as pigs fed added ZnO had greater G:F ($P = 0.036$) compared to pigs fed ZnAA (Table 5). A Zn level effect was also observed (quadratic; $P = 0.023$) as pigs fed 25 and 50 ppm added Zn had poorer G:F than pigs fed 75 ppm of added Zn. This was driven by a G:F response (quadratic; $P = 0.007$) that was observed for pigs fed supplemental ZnAA with pigs being fed 25 and 50 ppm of Zn from ZnAA having poorer G:F compared with pigs fed a diet containing 75 ppm of Zn from ZnAA. No treatment differences were observed for ADG, ADFI, or BW during the grower period.

Within the finishing period (phase 4 to 5), a Zn source × level interaction was observed (quadratic, $P < 0.05$) for ADG as pigs fed increasing levels of ZnO were similar in performance;

however, pigs fed 25 and 50 ppm Zn from ZnAA had poorer ADG than pigs fed 75 ppm of Zn from ZnAA, which had ADG similar to pigs fed the control diet. A tendency (quadratic; $P < 0.10$) for a Zn source × level interaction was also observed for final BW, as pigs fed increasing levels of ZnO had similar BW; however, pigs fed 25 or 50 ppm of Zn from ZnAA weighed less than pigs fed 75 ppm of Zn from ZnAA. A tendency for a Zn source × level interaction (quadratic, $P < 0.10$) was also observed for G:F as pigs fed increasing levels of ZnAA were observed to have poorer G:F at lower inclusion levels of Zn in comparison to pigs fed increasing levels of ZnO. A Zn level effect was observed ($P = 0.017$) for ADFI, as pigs fed diets with 25 or 50 ppm of added Zn had lower feed intake compared to pigs fed diets with 75 ppm of added Zn. An effect of ADFI was also observed (quadratic; $P = 0.014$) for pigs fed ZnAA. Similar to the Zn level effect, a reduction in ADFI was observed for pigs fed diets with 25 and 50 ppm of Zn from ZnAA.

Overall, Zn source × level interactions (quadratic; $P < 0.05$) were observed for ADG and G:F. The ADG response was due to pigs fed increasing levels of ZnO having consistent ADG across treatments, while pigs being fed 25 or 50 ppm of added Zn from ZnAA had reduced ADG compared to pigs fed 75 ppm of Zn from ZnAA. The interaction for G:F was due to pigs fed 25 or 50 ppm of Zn from ZnAA having poorer G:F than those fed 75 ppm of Zn from ZnAA, while pigs fed supplemental ZnO had similar feed efficiency as Zn level increased. No differences were observed for overall ADFI.

Similar to overall ADG and final BW, a Zn source × level interaction (quadratic; $P < 0.05$) was observed for HCW. The response was observed because there were no differences in HCW amongst ZnO treatments, however, pigs fed 25 or 50 ppm of Zn from ZnAA had lower HCW than pigs fed the diet with 75 ppm of Zn from ZnAA. Tendencies (quadratic, $P < 0.10$) for

increases in loin depth and percentage lean were also observed for pigs fed increasing levels of ZnAA, with values peaking at 25 and 50 ppm of Zn from supplemented ZnAA, respectively. No differences ($P > 0.10$) were observed for carcass yield and backfat.

DISCUSSION

Grow-finish diets in swine have commonly been supplemented Zn through a trace mineral premix. The need for increased Zn concentrations in these diets can be illustrated through work by Liptrap et al. (1970), as these authors observed decreased ADG and ADFI in pigs fed a diet containing 22 ppm Zn compared to pigs fed a diet containing 53 or 80 ppm Zn. However, work conducted by Gowanlock et al. (2013) showed that pigs, ranging in weight from 24 to 118 kg, fed a basal diet containing no additional Zn had similar performance to pigs fed diets with 50 or 100% of the recommended Zn level from NRC (2012). These authors suggested that the inclusion of phytase, which has been reported to increase micro-mineral availability (Jolliff and Mahan, 2012), may have impacted the need of a supplemental micro-mineral. While the current study did not evaluate feeding levels of Zn below the requirement, the data would suggest that increasing Zn beyond that of recommendations by NRC (2012) will not improve growth performance.

There has been more emphasis in evaluating the difference in organic and inorganic minerals in young pigs compared to grow-finish. Research from Case and Carlson (2002) and Hollis et al. (2005) have shown that feeding ZnO or an organic Zn source at 500 ppm in weanling pigs results in similar performance. More recently, Hill et al. (2014) fed more moderate concentrations (0, 25, 50, 75, and 100 ppm) of organic or inorganic Zn to nursery pigs for 35 d. These authors observed an increase of metallothionein in the liver and duodenum of pigs provided a diet with increased levels of Zn regardless of source on d 35. This increase in metallothionein was

correlated with a quadratic increase in ADG for both pigs fed either increasing $ZnSO_4$ or organic Zn. Creech et al. (2004) evaluated the differences in growth performance for pigs fed a control diet supplemented 150 and 100 ppm for the nursery and grow-finish period, respectively; compared to pigs fed a reduced Zn diet containing 25 ppm Zn from an inorganic source or from a 50% chelated and 50% inorganic source throughout the study. In the nursery phase, there were no differences between the control pigs or those fed a reduced trace mineral diet, but pigs fed the 50% chelated Zn diet had better feed efficiency than those fed the same reduced trace mineral diet solely from an inorganic form. During the total grower and finisher phases, no differences were observed between any of the three treatments. Conversely, the current study would indicate that adding an organic Zn source could potentially decrease feed intake and ADG.

Dietary ractopamine administration increases growth performance and carcass lean (NRC, 2012). Recently, several studies have evaluated the effects of adding supplemental levels of Zn in late finishing diets containing ractopamine with mixed results reported. Fry et al. (2013) conducted 3 experiments and reported a tendency for improved G:F in pigs fed 40 ppm supplemental Zn in ractopamine containing diets in one experiment. However, in the following two experiments, the authors reported that supplemental Zn did not further improve growth performance above that observed from dietary ractopamine alone.

Research has been conducted to evaluate the effects of adding a lower inclusion rate of an organic Zn source to reduce the environmental impact and achieve similar growth performance to that observed with inorganic Zn sources. Some have shown that organic sources of Zn have a higher bioavailability to the pig and therefore should be able to be used at lower inclusion levels compared to inorganic sources (Liu et al., 2014; Nitrayova et al., 2012). In one study, Rambo (2013) reported an increase in ADG and a tendency for improved G:F for pigs fed an organic Zn

source compared to pigs fed supplemental ZnO at 50 ppm in the final 21 d of finishing. However, in a subsequent study, they reported no differences among Zn source or level (25 or 50 ppm) when ractopamine was added to the diet. The author speculated that the differences observed between studies could have been due to an immune function response, as pigs in the first experiment were diagnosed influenza-positive at the onset of the study while those used in the subsequent study were of high health. In another study, Paulk et al. (2015) evaluated the effects of adding 50, 100, or 150 ppm of Zn from ZnO or 50 ppm of Zn from an organic Zn source to ractopamine containing diets and observed a tendency for a linear improvement in feed efficiency when pigs were fed increasing ZnO and a tendency for increased ADG when pigs were fed 50 ppm of Zn from the organic Zn source. In another study, the same authors added 75, 150, or 225 ppm of an organic Zn source or ZnO to a ractopamine containing diet in late finishing. Contrary to their first experiment, they observed no differences in overall growth performance in this study.

Our results show there are no differences amongst treatments throughout the grower period (27 to 77 kg BW) for ADG, ADFI, or BW; however, there was poorer feed efficiency when supplementing ZnAA at 25 or 50 ppm of added Zn which was also observed overall throughout the experiment. There is no available explanation for this difference as historically Zn supplementation has not negatively impacted feed efficiency in swine. In the finishing period, pigs fed either 25 or 50 ppm of Zn from ZnAA had lower feed intake in comparison to pigs fed the control diet or diet with 75 ppm of Zn from ZnAA while those fed increasing levels of ZnO had similar performance. These results are inconsistent with data reported by Patience et al. (2011) who showed that adding 50 ppm of Zn from ZnAA to a ractopamine containing diet increased ($P < 0.05$) feed intake in pigs fed a diet already containing 50 ppm of Zn from $ZnSO_4$

from the trace mineral premix. Overall, we observed a reduction in ADG and final BW for pigs fed 25 or 50 ppm of Zn from ZnAA. This would disagree with previous results from Fry et al. (2013) and Rambo (2013), who found no difference when supplemental Zn was added to a diet, as well as Paulk et al. (2015) who showed supplemental Zn tended ($P < 0.10$) to improve ADG in ractopamine containing diets.

The reduction in HCW observed in this study for diets supplemented with 25 and 50 ppm of Zn from ZnAA can be attributed to the lower final live weights for these treatments. The increase in percentage lean for these treatments was due to the by the increased loin depths and lighter carcass weights compared to the other treatments. Recent work by Paulk et al. (2015) and Rambo (2013) would indicate that Zn does not impact percentage lean or loin depth, respectively.

In conclusion, the supplementation of ZnAA quadratically reduced final BW and ADG while tending to reduce G:F. The reduction in final BW reduced HCW for ZnAA supplemented pigs while increasing loin depth and percentage lean. However, these results are inconsistent with results from previous studies. Therefore, more research is necessary to better understand the effect of supplemental Zn source and level in swine growth performance in a commercial setting.

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FIGURES AND TABLES

Table 3-1. Basal diet composition (as-fed basis)[1]

Item	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Ingredient, %					
Corn	56.04	61.52	65.84	69.51	67.28
Soybean Meal, 46.5% CP	21.65	16.30	12.00	8.35	20.65
DDGS[2]	20.00	20.00	20.00	20.00	10.00
Calcium carbonate	1.25	1.28	1.23	1.20	1.03
Monocalcium P, 21% P	0.15	-	-	-	0.10
Sodium chloride	0.35	0.35	0.35	0.35	0.35
L-Lys HCL	0.36	0.37	0.39	0.39	0.28
DL-Met	0.01	-	-	-	0.03
L-Thr	0.05	0.04	0.05	0.06	0.07
Phytase[3]	0.01	0.01	0.01	0.01	0.01
Trace mineral premix[4]	0.05	0.05	0.05	0.05	0.05
Vitamin premix[5]	0.08	0.08	0.08	0.08	0.05
Ractopamine HCl	-	-	-	-	0.10
Total	100.0	100.0	100.0	100.0	100.0
Calculated analysis					
Standard ileal digestible (SID) amino acids,%					
Lys	1.02	0.91	0.82	0.74	0.90
Ile:Lys	63	62	60	59	64
Leu:Lys	152	159	164	172	150
Met:Lys	29	29	30	31	31
Met+Cys:Lys	55	56	57	60	58
Thr:Lys	61	61	61	63	65
Trp:Lys	18.4	17.6	16.6	15.8	19.0
Val:Lys	70	70	70	70	71
Lys:ME, g/Mcal	3.08	2.72	2.47	2.21	2.71
ME, kcal/kg	3,314	3,322	3,329	3,333	3,320
CP, %	20.0	18.0	16.4	15.0	17.6
Ca, %	0.61	0.57	0.54	0.52	0.50
P, %	0.45	0.40	0.38	0.36	0.40
Available P, %	0.29	0.26	0.25	0.25	0.24
Standard digestible P, %	0.33	0.29	0.28	0.27	0.29

[1] Phase 1, 2, 3, 4, and 5 diets were fed from 27 to 45, 45 to 61, 61 to 77, 77 to 104, and 104 to 127 kg, respectively.

[2] Dried distillers grain with solubles.

[3] Optiphos 2000 (Enzyvia LLC, Sheridan, IN) provided 227 phytase units (FTU)/lb, with an assumed release of 0.07% available P.

[4] Provided per kilogram of premix: 3.402 g Cu from copper sulfate; 0.068 g I from ethylenediamine dihydriodide; 22.680 g Fe from ferrous sulfate; 0.007 g of Mn from manganese oxide; 0.300 g of Se from sodium selenite; 22.680 mg of Zn from zinc sulfate.

[5] Provided per kilogram of premix: 1,451,494 IU vitamin A; 362,874 IU vitamin D; 10,885 IU vitamin E; 726 mg vitamin K; 13,608 mg Niacin, 4,536 mg pantothenic acid; 1,361 mg riboflavin, 6.4 mg vitamin B_{12}.

Table 3-2. Proximate analysis of diets (as-fed basis)[1]

	Phase 1							Phase 2						
		ZnAA[2], ppm			ZnO, ppm				ZnAA, ppm			ZnO, ppm		
Item[3]	Control	25	50	75	25	50	75	Control	25	50	75	25	50	75
DM, %	88.8	88.6	89.0	88.8	89.0	88.9	89.2	88.9	88.9	88.8	88.7	88.9	89.0	88.6
CP, %	19.6	18.6	19.6	20.3	20.1	19.7	20.4	19.0	18.3	18.4	19.4	17.6	18.4	19.1
ADF, %	4.5	4.3	4.8	4.5	5.2	4.6	4.2	4.5	5.2	5.0	5.0	5.3	5.5	5.3
NDF, %	13.4	13.1	12.2	11.9	12.6	11.8	11.0	13.4	13.0	12.3	12.1	12.1	12.3	13.0
Crude Fiber, %	3.1	3.5	3.4	3.3	3.5	3.3	3.2	4.0	3.7	4.0	3.4	3.2	3.6	3.7
NFE,[4] %	58.3	59.0	58.5	57.4	57.4	58.0	57.7	58.0	59.1	58.3	57.7	60.1	59.0	57.6
Fat, %	4.1	3.8	3.8	4.0	4.0	3.9	3.9	4.5	4.3	4.3	4.0	4.1	4.2	4.3
Ash, %	4.02	4.22	4.17	4.14	4.34	4.22	4.37	3.85	3.81	3.94	4.07	3.84	3.86	4.00
Zinc, ppm	114.5	133.7	145.6	164.2	96.2	122.9	124.9	94.9	123.4	135.5	156.9	101.5	110.6	132.6

[1] Phase 1 and 2 diets were fed from 27 to 45 and 45 to 61 kg, respectively.
[2] ZnAA = Zn AA complex (Availa-Zn; Zinpro, Eden Prairie, MN).
[3] Values represent the mean of samples collected from feeders during each replicate, then pooled and subsampled, and one composite sample of each diet was analyzed.
[4] Nitrogen Free Extract

Table 3-3. Proximate analysis of diets (as-fed basis)[1]

	Phase 3							Phase 4						
		ZnAA[2], ppm			ZnO, ppm				ZnAA, ppm			ZnO, ppm		
Item[3]	Control	25	50	75	25	50	75	Control	25	50	75	25	50	75
DM, %	88.6	88.7	88.8	88.8	89.1	88.7	88.9	88.8	88.8	88.7	88.6	88.9	88.7	88.5
CP, %	16.5	16.2	16.4	15.4	16.4	16.3	17.4	14.9	15.4	14.8	14.1	14.7	14.6	14.7
ADF, %	4.7	4.5	4.7	3.9	4.3	3.6	3.8	3.7	3.1	3.3	3.6	4.3	3.8	4.1
NDF, %	13.5	12.1	13.7	12.9	12.8	10.9	11.8	11.7	11.2	10.7	11.0	11.1	11.2	12.1
Crude Fiber, %	3.5	4.0	4.0	3.4	3.9	4.0	3.7	3.2	3.3	3.4	3.4	3.5	3.3	3.4
NFE,[4] %	60.8	60.6	60.9	62.2	61.2	60.6	60.0	62.9	62.9	63.1	64.0	63.3	63.8	63.0
Fat, %	4.1	4.2	4.0	4.1	4.2	4.2	4.3	4.3	4.0	4.0	4.0	4.2	4.0	4.3
Ash, %	3.59	3.69	3.37	3.63	3.62	3.46	3.48	3.56	3.43	3.35	3.34	3.31	3.01	3.30
Zinc, ppm	100.4	101.8	121.9	158.1	108.3	114.1	136.1	120.3	113.9	126.2	150.1	108.3	115.3	122.2

[1] Phase 3 and 4 diets were fed from 61 to 77 and 77 to 104 kg, respectively.
[2] ZnAA = Zn AA complex (Availa-Zn; Zinpro, Eden Prairie, MN).
[3] Values represent the mean of samples collected from feeders during each replicate, then pooled and subsampled, and one composite sample of each diet was analyzed.
[4] Nitrogen Free Extract

Table 3-4. Proximate analysis of diets (as-fed basis)[1]

	Phase 5						
		ZnAA[2], ppm			ZnO, ppm		
Item[3]	Control	25	50	75	25	50	75
DM, %	88.1	88.3	88.2	88.2	87.9	88.7	87.5
CP, %	17.2	16.0	17.8	16.1	16.3	16.1	19.1
ADF, %	3.9	4.3	3.7	3.5	3.3	3.7	3.8
NDF, %	11.3	10.8	10.9	9.9	9.9	12.1	11.2
Crude Fiber, %	3.3	3.4	3.0	3.0	3.2	3.3	3.6
NFE,[4] %	60.6	61.9	60.6	62.1	61.6	62.1	57.5
Fat, %	3.4	3.7	3.3	3.4	3.3	3.7	3.5
Ash, %	3.52	3.39	3.59	3.64	3.62	3.54	3.76
Zinc, ppm	102.5	121.3	136.2	166.1	97.2	108.8	122.2

[1] Phase 5 diet was fed from 104 to 127 kg.
[2] ZnAA = Zn AA complex (Availa-Zn; Zinpro, Eden Prairie, MN).
[3] Values represent the mean of samples collected from feeders during each replicate, then pooled and subsampled, and one composite sample of each diet was analyzed.
[4] Nitrogen Free Extract

Table 3-5. The effects of increasing levels of Zn from organic or inorganic sources on finishing pig growth performance and carcass characteristics[1]

									Probability, $P <$						
		ZnAA[2], ppm			ZnO, ppm				ZnAA vs	Level		ZnAA		ZnO	
Item	Control	25	50	75	25	50	75	SEM	ZnO	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
No. of replicates[3]	14	17	17	17	17	14	14								
BW, kg															
D 0	28.7	28.7	28.7	28.7	28.6	28.7	28.7	0.886	0.777	0.885	0.964	0.906	0.867	0.896	0.930
End of phase 3	76.7	76.8	77.0	77.4	77.4	77.1	77.5	0.923	0.544	0.322	0.976	0.362	0.748	0.427	0.797
Final[4]	130.6	127.4	129.3	130.3	129.7	129.8	128.8	2.069	0.581	0.610	0.193	0.776	0.028	0.265	0.944
Grower[5]															
ADG, kg	0.85	0.84	0.85	0.85	0.85	0.85	0.86	0.009	0.299	0.371	0.804	0.507	0.508	0.385	0.809
ADFI, kg	1.96	1.98	1.99	1.98	1.99	1.97	1.98	0.027	0.934	0.496	0.291	0.431	0.369	0.692	0.426
G:F	0.433	0.427	0.425	0.432	0.429	0.433	0.434	0.006	0.036	0.865	0.023	0.653	0.007	0.479	0.332
Finisher[6]															
ADG,[7] kg	0.93	0.89	0.91	0.93	0.92	0.92	0.91	0.051	0.299	0.530	0.047	0.982	0.004	0.305	0.723
ADFI, kg	2.77	2.68	2.74	2.78	2.72	2.72	2.76	0.117	0.974	0.812	0.017	0.443	0.014	0.743	0.157
G:F[4]	0.337	0.332	0.332	0.333	0.336	0.338	0.331	0.005	0.243	0.242	0.944	0.404	0.272	0.243	0.250
Overall															
ADG,[7] kg	0.89	0.87	0.88	0.89	0.88	0.89	0.88	0.027	0.140	0.987	0.070	0.708	0.006	0.744	0.869
ADFI, kg	2.36	2.32	2.36	2.37	2.35	2.34	2.36	0.056	0.951	0.617	0.222	0.348	0.183	0.958	0.521
G:F[7]	0.377	0.373	0.372	0.375	0.376	0.379	0.375	0.004	0.042	0.456	0.527	0.395	0.066	0.659	0.440
Carcass Characteristics															
HCW,[7] kg	97.4	96.0	96.8	98.2	97.6	97.4	97.0	1.108	0.581	0.732	0.300	0.295	0.038	0.676	0.709
Yield, %	74.89	74.37	74.84	75.38	75.28	75.07	75.32	0.598	0.893	0.350	0.939	0.445	0.896	0.400	0.808
Backfat,[8] mm	17.13	17.13	16.72	16.88	17.09	17.32	16.87	0.755	0.349	0.366	0.742	0.278	0.745	0.630	0.409
Loin depth,[8] cm	6.99	7.12	7.00	6.91	6.97	6.99	6.96	0.138	0.470	0.392	0.242	0.208	0.075	0.816	0.919
Lean,[8] %	56.59	56.95	57.05	56.70	56.8	56.69	56.94	0.628	0.555	0.381	0.276	0.629	0.064	0.315	0.923

[1] A total of 3,390 mixed sex pigs (PIC 337 × 1050; initial BW 28.67 kg) were used in were used in this study housed in 3 replicate barns. Barn 1 utilized 1,122 pigs for 112 d, barn 2 used 1,159 pigs for 114 d, while group 3 included 1,109 pigs fed for 120 d.
[2] ZnAA = Zn AA complex (Availa-Zn; Zinpro, Eden Prairie, MN).
[3] Each replicate had 24-27 pigs per pen.
[4] Zinc source × zinc level interaction (quadratic; $P < 0.10$)
[5] Includes phases 1 to 3.
[6] Includes phases 4 and 5.
[7] Zinc source × zinc level interaction (quadratic; $P < 0.05$)
[8] Adjusted to a common HCW for analysis.