EFFECTS OF PELLETING AND DIETARY FAT AND FIBER LEVELS ON PIG GROWTH AND FAT QUALITY

by

JEREMIAH EUGENE NEMECHEK

B.S., North Carolina State University, 2009
M.S., Kansas State University, 2011

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Animal Sciences and Industry
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2014

Abstract

In 11 experiments, 7,325 pigs were used to determine the effects of: 1) diet type and form on finishing pig growth performance and carcass fat iodine value (IV); 2) pellet quality and feeder adjustment on pig growth performance; 3) corn particle size and diet form on finishing pig growth performance and carcass characteristics; and 4) dietary acidification, diet complexity, and feed-grade antibiotics on nursery pig growth performance. Feeding diets with wheat middlings and dried distillers grains with solubles all the way until marketing decreased G:F and carcass yield, and worsened carcass fat IV. Withdrawing these ingredients 17 d prior to market restored carcass yield, but resulted in small improvements in IV. Pelleting diets improved growth performance; however, a novel finding is that pelleting diets fed to finishing pigs increased belly fat IV. Feeding nursery pigs from a wide feeder gap may improve ADG and ADFI, with no negative effects on G:F. For finishing pigs, reducing feeder gap reduced feed disappearance and improved G:F. In all experiments, feeding pelleted diets improved G:F, but the greatest improvements occurred when the percentage of fines was minimized. Grinding corn finer than 650 microns decreased ADFI and improved G:F for finishing pigs fed meal diets, but not for pigs fed pelleted diets. Pelleting diets improved ADG and G:F, but the greatest magnitude of G:F improvement to pellets occurred when pigs were fed diets containing the largest particle size corn. Thus, grinding corn finer than 650 microns improved feed efficiency for finishing pigs fed meal diets, but provided no additional benefit for pigs fed pelleted diets. When dietary supplementation of benzoic acid was evaluated, added benzoic acid in nursery pig diets did not influence growth performance in university conditions, whereas feeding complex diets or antimicrobials improved growth. In the commercial setting, acidifiers improved growth in one

experiment but not the other. The varying response to acidifiers is likely influenced by health status, age, or starting weight of pigs.

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Dedication

I dedicate my dissertation to my family, both immediate and extended. I am proud to have been a part of our ongoing history at Kansas State University.

Chapter 1 - Effects of diet form and type on growth performance, carcass yield, and iodine value of finishing pigs

ABSTRACT

Two experiments were conducted to determine the effects of pelleting, diet type, and dietary fiber and fat withdrawal prior to marketing on growth performance, carcass yield, and carcass fat iodine value (IV) of finishing pigs. Each experiment used 288 pigs (initially 49.6 and 48.5 kg BW, respectively) with 6 dietary treatments arranged as 2 × 3 factorials. In Exp. 1, main effects were diet form (meal vs pellet) and diet regimen. Diet regimens were: 1) a low-fiber, low-fat (corn-soybean meal) diet from d 0 to 81; 2) a high-fiber, high-fat [30% distillers dried grains with solubles (DDGS) and 19% wheat middlings (midds)] diet from d 0 to 64 followed by the low-fiber, low-fat diet from d 64 to 81 (fiber and fat withdrawal); and 3) the high-fiber, high-fat diet fed from d 0 to 81. Pigs fed pelleted diets had increased ($P < 0.05$) ADG and G:F compared with those fed meal diets. Feeding pigs pelleted diets increased belly fat IV compared with those fed meal diets with a greater increase when feeding high-fiber, high-fat throughout the entire study (interaction, $P < 0.05$). Pigs fed the low-fiber, low-fat diet throughout had increased ($P < 0.05$) G:F compared with pigs fed the other 2 treatments. Pigs fed low-fiber, low-fat throughout the study or pigs withdrawn from high-fiber, high-fat diets had increased ($P < 0.05$) carcass yield compared to pigs fed high-fiber, high-fat throughout. In Exp. 2, treatment main effects were diet form (meal vs pellet) and diet type (corn-soybean meal-based control, the control with 30% DDGS and 19% midds, or the control diet with 3% corn oil). The corn oil containing diet was formulated to provide similar carcass fat IV as pigs fed diets containing DDGS and midds. Overall, feeding pelleted diets increased ($P < 0.05$) ADG and G:F compared with feeding meal diets. Pigs fed pelleted diets had increased ($P < 0.05$) belly fat IV compared to those fed meal

diets, regardless of diet formulation. Pigs fed the diets containing DDGS and midds had decreased ($P < 0.05$) ADG, carcass yield, and HCW compared with pigs fed the control or corn oil diets and decreased ($P < 0.05$) G:F compared to pigs fed added corn oil. Belly IV was greatest ($P < 0.05$) for pigs fed diets with DDGS and midds, lowest for pigs fed the control diet, with pigs fed the corn oil diets intermediate. In conclusion, pelleting diets improves pig growth performance; however a novel finding of this study is that pelleting diets fed to finishing pigs also increases belly fat IV.

Key Words: carcass yield, corn oil, distillers dried grains with solubles, finishing pig, growth, pelleting

INTRODUCTION

Studies have observed that up to 30% dried distillers grains with solubles (**DDGS**) can be fed without negative effects on growth performance (Widmer et al., 2007; Stein and Shurson, 2009; Xu et al., 2010). However, when combined with wheat middlings (**midds**), Salyer et al. (2012) observed linear decreases in ADG and G:F as midds were added at 0, 10, or 20%.

In addition, feeding high levels of DDGS, midds, or the combination of both reduces carcass yield of finishing pigs (Linneen et al., 2008; Salyer et al., 2012). This is due to increased large intestinal weights caused by the high fiber component of the ingredients (Asmus et al, 2014). Along with the dietary fiber component from DDGS and midds, the oil content, particularly C18:2 fatty acids, also increases (NRC, 2012). Iodine value (**IV**), a measure of unsaturated fatty acids (**UFA**), is one method used by packers to assess fat quality in pork. Feeding ingredients high in UFA increases carcass fat IV (Benz et al., 2011) and thus produces

less desirable product for the meat packing industry (McClelland et al. 2012). However reducing or withdrawing added DDGS and midds before marketing can mitigate some of the negative effects on carcass yield and carcass fat IV (Gaines et al., 2007; Asmus et al., 2014; Coble et al., 2014).

The beneficial effects of pelleting swine diets on growth performance of finishing pigs has also been documented, including increased BW gain and improved feed efficiency (Baird, 1973; Wondra et al., 1995). However, most of the previous pelleting research has evaluated corn-soybean meal-based diets with limited inclusion of by-products. In addition, to our knowledge, the effect of pelleting on FA profile and IV of carcass fat has not been reported. Therefore, the objectives of these trials was to determine the effects of diet type and form on growth performance, carcass yield, and carcass fat IV of finishing pigs.

MATERIALS AND METHODS

All experimental procedures and animal care were approved by the Kansas State University Institutional Animal Care and Use Committee.

General

Experiments 1 and 2 each used a total of 288 finishing pigs (327 × 1050, PIC, Hendersonville, TN) initially 49.6 and 48.5 kg BW, respectively. Pigs were housed in a totally enclosed, environmentally regulated, mechanically ventilated barn containing 36 pens (2.44 m × 3.05 m). The pens had adjustable gates facing the alleyway and allowed 0.93 m^2/pig. Each pen was equipped with a cup waterer and a single-sided, dry self-feeder (Farmweld, Teutopolis, IL) with 2 eating spaces located in the fence line. Pens were located over a completely slatted

concrete floor with a 1.20-m pit underneath for manure storage. All pigs were provided *ad libitum* access to feed and water.

Each experiment was arranged as a 2 × 3 factorial. Pens were randomly allotted to 1 of 6 experimental treatments with 6 pens per treatment and 8 pigs per pen (4 barrows and 4 gilts per pen). Pigs and feeders were weighed approximately every 2 wk to calculate ADG, ADFI, and G:F. Caloric efficiency of pigs for all trials were determined using dietary ingredient values for ME and NE from NRC (2012). Caloric efficiency was calculated on a pen basis by multiplying total pen feed intake by dietary energy (Mcal/kg) and dividing by total pen gain. Diets for both experiments were prepared and pelleted at a commercial feed mill in Beloit, KS (Hubbard Feeds, Inc, Mankato, MN). All pelleted diets were processed with a Sprout Waldron Pellet Mill, model Ace 501, equipped with a 4.37-mm diameter die. Prior to pelleting, diets were conditioned with steam at 60°C for approximately 9 sec. A single batch of meal feed was prepared and half fed as such, and half was pelleted. Diets were delivered to feeders using a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that recorded all feed additions. Feed samples were taken at the feeder during each phase. All diets were analyzed for moisture (934.01; AOAC International, 2006), CP (990.03; AOAC International, 2006), ether extract (920.39 A; AOAC International, 2006), crude fiber (978.10; AOAC International, 2006), ADF, and NDF. Pellet durability index (**PDI**) was determined using the standard tumbling-box technique (S269.4; ASAE, 1996) and modified PDI was done by adding 5 hexagonal nuts (1.27 cm) prior to tumbling. Percentage fines (ASAE, 1987) were also measured in duplicate for all pelleted diets, with fines characterized as material that would pass through a #6 sieve (3,360 μm openings). All pellet quality measurements were analyzed at the K-State Grain Sciences and Industry Feed Mill.

At the end of each trial, pigs were individually tattooed in sequential order to allow for carcass data collection at a commercial packing plant and data retrieval by pig. Hot carcass weights (**HCW**) were measured immediately after evisceration and were used to calculate percentage yield by dividing HCW at the plant by live weight at the farm before transport. All carcass fat samples were collected from the pig's left side. For both experiments, belly fat samples were collected from the ventral side of the belly along the navel edge between the 10^{th} and the 12^{th} rib of each pig. In Exp. 2, fat samples were also collected from the shoulder of each pig approximately 5 cm dorsal to the medial ridge of the scapula. All fat samples were immediately frozen after collection and remained frozen until preparation for FA analysis could be conducted. Fat samples were thawed and adipose tissue was isolated by removing the skin and lean tissue. Samples were then analyzed for FA profiles using gas chromatography as described in detail by Asmus et al. (2014). Iodine value was calculated using the equation (AOCS, 1998): IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723.

Experiment 1

An 81-d trial was conducted to determine the effects of diet form and fiber withdrawal on growth performance, carcass yield, and carcass fat IV of finishing pigs. Treatment main effects included diet form (meal or pellet) and diet regimen. The 3 diet regimens were: 1) low-fiber, low-fat (corn-soybean meal) from d 0 to 81, 2) high-fiber, high-fat (30% DDGS and 19% midds) from d 0 to 64 followed by low-fiber, low-fat from d 64 to 81 (fiber and fat withdrawal), and 3) high-fiber, high-fat from d 0 to 81 (Table 1). Diets were fed in 4 phases from d 0 to 14, 14 to 40, 40 to 64, and 64 to 81. Diets within phase were formulated to contain equal amounts of

standardized ileal digestible (**SID**) Lys with 0.93, 0.79, 0.69, and 0.63 SID Lys for phases 1, 2, 3, and 4, respectively.

Experiment 2

An 87-d trial was conducted to determine the effects of diet form and type on growth performance, carcass yield, and carcass fat IV of finishing pigs. Treatments were arranged in a 2 × 3 factorial with the main effects of diet form and type. The 2 diet forms used were meal or pellet. The 3 dietary types were: 1) corn-soybean meal-based control, 2) control with 30% DDGS and 19% midds, and 3) control with 3% corn oil (Tables 2 and 3). The corn-soybean meal-based control provided a baseline, while the diet containing 30% DDGS and 19% midds was the previously established diet from Exp. 1 that allowed for a predictable increase in carcass fat IV. Extracted corn oil was used in the third treatment to compare to the endogenous corn oil present in the DDGS. The level of 3% corn oil was selected based on research conducted by Benz et al. (2011) with soybean oil in an effort to obtain similar carcass fat IV to pigs fed the diet containing DDGS and midds. Diets were fed in 4 phases from d 0 to 21, 21 to 45, 45 to 70, and 70 to 87. Diets within phase were formulated to contain equal amounts of SID Lys with 0.98, 0.86, 0.77, and 0.69 SID Lys for phases 1, 2, 3, and 4, respectively.

Statistical Analysis

Experimental data for both trials were analyzed using analysis of variance as a 2 × 3 factorial using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Pen was the experimental unit for all data analysis. For HCW, carcass yield, and carcass fat IV, measurements were collected for each pig, then pen means were calculated and used in the model. Experiment 1 included main effects of 2 diet forms and 3 diet regimens and their interaction as fixed effects, and Exp. 2 included main effects of 2 diet forms and 3 diet types and

their interactions. Differences between treatments were determined by using least squares means with results considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

RESULTS

Experiment 1

Chemical analysis and pellet quality measurements. Analysis of diets revealed that, as expected, the inclusion of dietary DDGS and midds increased ADF, NDF, crude fiber, and ether extract (Tables 4 and 5). Standard PDI was greater than 90% during all phases for pelleted diets (Table 6). Percentage fines were low for all diets and phases at less than 10% fines.

Growth performance and carcass yield. No diet form × diet regimen interactions ($P > 0.14$) were observed for growth performance during any of the dietary phases or for the overall trial (Table 7). From d 0 to 64, ADG did not differ among pigs fed different diet forms; however pigs fed meal diets had increased ($P < 0.05$) ADFI and poorer ($P < 0.05$) G:F than pigs fed pelleted diets (Table 8). Diet type level did not influence ADG; however, pigs fed low-fiber, low-fat diets from d 0 to 64 had decreased ($P < 0.05$) ADFI and increased ($P < 0.05$) G:F compared with pigs fed high-fiber, high-fat diets during this period.

From d 64 to 81, pigs fed pelleted diets had increased ($P < 0.05$) ADG and tended to have increased ($P < 0.10$) ADFI compared with pigs fed meal diets. Feeding pelleted diets also tended to increase ($P < 0.10$) G:F. Pigs previously fed high-fiber, high-fat diets, then switched to low-fiber, low-fat diets during this phase, had increased ($P < 0.05$) ADG compared with pigs maintained on the high-fiber, high-fat diets. Pigs fed the low-fiber, low-fat diets throughout the trial had intermediate ADG. Pigs previously fed high-fiber, high-fat diets and switched to the

low-fiber, low-fat diet had increased ($P < 0.05$) ADFI compared with pigs fed low-fiber, low-fat or high-fiber, high-fat diets throughout the trial. Pigs fed low-fiber, low-fat diets throughout the trial had increased ($P < 0.05$) G:F compared with pigs fed high-fiber, high-fat diets throughout, and pigs that were withdrawn from the high-fiber, high-fat diet were intermediate.

Overall (d 0 to 81), pigs fed pelleted diets had increased ($P < 0.05$) ADG and improved ($P < 0.05$) G:F, ME caloric efficiency, and NE caloric efficiency compared with pigs fed meal diets. There was no difference in ADFI between pigs fed the different diet forms. Pigs fed pelleted diets tended ($P < 0.10$) to have increased final BW and HCW compared with pigs fed meal diets, but diet form did not influence carcass yield. Diet regimen did not influence ADG or NE caloric efficiency for the overall trial, but pigs fed low-fiber, low-fat throughout the trial had lower ($P < 0.05$) ADFI and improved ($P < 0.05$) G:F and ME caloric efficiency compared with pigs on the high-fiber, high-fat withdrawal or pigs fed high fiber, high-fat throughout. Diet regimen did not affect final BW or HCW, but pigs fed high-fiber, high-fat throughout the trial had decreased ($P < 0.05$) carcass yield compared with pigs fed low-fiber, low-fat diets or those withdrawn from high-fiber, high-fat diets on d 64. Removing high-fiber ingredients (DDGS and midds) from the diet before harvest improved carcass yield and returned carcass weights to values similar to control pigs fed corn-soybean meal–based diets throughout the trial.

Belly fatty acid composition. Interactive effects between diet form and diet regimen were detected ($P < 0.05$) for palmitic (C16:0) and linoleic (C18:2n6c) acid concentrations (Table 9). Pelleting decreased palmitic and increased linoleic acid by a greater magnitude when the diet contained high-fiber, high-fat than when the diet was low in fiber and fat. Pelleting diets appeared to worsen the impact on belly fat IV of the high oil content in DDGS. Palmitic and total C18:2 fatty acids account for the greatest portions of saturated fatty acids (**SFA**) and

polyunsaturated fatty acids (**PUFA**), respectively. As a result, interactions were also detected ($P < 0.05$) for total SFA, total PUFA, UFA:SFA, PUFA:SFA ratios, and belly fat IV.

Feeding pelleted diets reduced ($P < 0.05$) myristic (C14:0), palmitic (C16:0), palmitoleic (C16:1), margaric (C17:0), oleic (C18:1n9c), and vaccenic (C18:1n7) fatty acids; however, it increased ($P < 0.05$) linoleic (C18:2n6c), α-linolenic (C18:3n3), eicosadienoic (C20:2), and total C18:2 fatty acids (Table 10). As a result, total PUFA and belly fat IV increased ($P < 0.05$), whereas total SFA, MUFA, and all other fatty acids decreased ($P < 0.05$) when pigs were fed pelleted diets. There were no differences ($P > 0.10$) in stearic (C18:0), arachidic (20:0), eicosenoic (20:1), or arachidonic (C20:4n6) fatty acids between pigs fed the different diet forms.

Compared with pigs fed high-fat, high-fiber throughout the trial, pigs fed low-fiber, low-fat throughout the trial had increased ($P < 0.05$) C16:0, C18:0, C18:1n9c, C18:1n7, total SFA, and total MUFA concentrations, with those fed the withdrawal regimen intermediate ($P < 0.05$). Pigs fed the low-fiber, low-fat diet had decreased ($P < 0.05$) C18:2n6C, C18:3n3, C20:2, C20:4n6, total C18:2, PUFA, and belly fat IV compared to those fed high-fiber, high-fat, with those on the withdrawal regiment intermediate ($P < 0.05$).

Regardless of withdrawal, pigs fed high-fiber, high-fat diets during any period of the experiment had decreased ($P < 0.05$) C14:0 and C16:1 concentrations and increased ($P < 0.05$) C17:0 concentrations compared with pigs fed low-fiber, low-fat for the entire trial. Feeding high-fiber, high-fat diets throughout the experiment decreased ($P < 0.05$) C20:0 concentrations compared with the other two regimens. No differences were detected in C20:1 among pigs fed the different diet regimens.

Experiment 2

Chemical analysis and pellet quality measurements. Analysis of diets revealed that, as expected, the inclusion of dietary DDGS and midds increased ADF, NDF, crude fiber, and ether extract (Tables 11 and 12). In addition, ether extract increased due to the inclusion of corn oil, which was also expected. Standard PDI was greater than 88% during all phases for pelleted diets with modified PDI ranging from 82.5 to 87.5% (Table 13). Percentage fines were low for all diets and phases ranging between approximately 7 and 14% fines.

Growth performance and carcass yield. No diet form × diet type interactions were observed for growth performance, HCW, or carcass yield for the overall trial (Table 14). Overall (d 0 to 87), pigs fed pelleted diets had increased ($P < 0.05$) ADG, decreased ($P < 0.05$) ADFI, and improved ($P < 0.05$) and G:F, ME caloric efficiency, and NE caloric efficiency compared to pigs fed meal diets (Table 15). Pigs fed pelleted diets tended ($P < 0.10$) to have increased final BW, but diet form did not influence HCW or carcass yield. Pigs fed diets containing DDGS and midds had decreased ($P < 0.05$) ADG compared to pigs fed the control or corn oil diets. Feeding the corn oil diet resulted in decreased ($P < 0.05$) ADFI compared to pigs fed the DDGS and midds diet, with pigs fed the control diet intermediate. Feed efficiency followed dietary energy with pigs fed the corn oil diet having the greatest ($P < 0.05$) G:F, pigs fed the DDGS and midds diet having the poorest ($P < 0.05$), and pigs fed the control intermediate. Pigs fed diets with DDGS and midds had poorer ($P < 0.05$) ME caloric efficiency compared with pigs fed the control or added corn oil diets. Diet type did not influence NE caloric efficiency. Pigs fed the diet with DDGS and midds had decreased ($P < 0.05$) HCW and carcass yield compared to pigs fed the control or corn oil treatments.

Belly fatty acid composition. Diet form × diet type interactions were observed ($P < 0.05$) for oleic acid (C18:1n9c), total C18:1, linoleic acid (C18:2n6c), total C18:2, total MUFA and total PUFA (Table 16). These interactions were a result of by the greatest magnitude of decrease in C18:1 and increase in C18:2 fatty acids when pelleting the control diet than when pelleting the diet containing corn oil with the diet containing DDGS and midds having an intermediate response to pelleting. There was also an interaction ($P < 0.05$) observed for mystiric acid (C14:0) where pelleting the control diet increased C14:0 concentration but pelleting either of the other 2 treatment diets decreased C14:0 concentration, with the greatest decrease observed in pigs fed diets containing DDGS and midds.

Feeding pelleted diets also increased ($P < 0.05$) stearic (C18:0) and eicosenoic (C20:1) acids and decreased ($P < 0.05$) vaccenic acid (C18:1n7) compared to feeding meal diets (Table 17).

For diet types, pigs fed the control diet had increased ($P < 0.05$) palmitic (C16:0) and reduced ($P < 0.05$) eicosenoic (C20:1) acid concentrations compared to pigs fed the DDGS and midds or corn oil diets. Compared with pigs fed the control diet, pigs fed the diet containing DDGS and midds had decreased ($P < 0.05$) stearic acid (C18:0) and total SFA, with those fed the diet containing corn oil intermediate ($P < 0.05$). Pigs fed diets with DDGS and midds had increased ($P < 0.05$) margaric (C17:0) and α-linolenic (C18:3n3) acid concentrations compared to pigs fed either of the other 2 diet types.

There was no interaction between diet form and oil source for belly fat IV. Pigs fed pelleted diets had increased ($P < 0.05$) belly fat IV and there was no evidence that the increase was influenced by diet type. Belly IV was greatest ($P < 0.05$) for pigs fed diets with DDGS and midds, lowest for pigs fed the control, and intermediate for pigs fed the corn oil diets.

Shoulder fatty acid composition. Similar to belly fat, there were diet form × diet type interactions ($P < 0.05$) for several fatty acids (C16:0, C18:1, C18:2, C20:1; Table 18). Pelleting the control diet resulted in a greater increase in unsaturated fatty acids and reduction in saturated fatty acids than pelleting of the diet containing corn oil with the response to pelleting the diet containing wheat middlings and DDGS intermediate. These changes in individual fatty acids led to interactions ($P < 0.05$) between diet form and diet type for total MUFA, PUFA, PUFA:SFA ratio, and IV with tendencies for interactions ($P < 0.10$) for total SFA and UFA:SFA ratio.

For main effects of diet type, pigs fed the control diet had increased ($P < 0.05$) myristic acid compared to pigs fed the diets containing corn oil or DDGS and midds. Feeding corn oil to pigs decreased ($P < 0.05$) vaccenic (C18:1n7) and α-linolenic (C18:3n3) acid concentrations compared to pigs fed the control diet, with pigs fed the diet containing DDGS and midds intermediate (Table 19). Pigs fed corn oil had decreased ($P < 0.05$) stearic acid (C18:0) concentration compared to pigs fed the control diet, with further decrease ($P < 0.05$) when pigs were fed the diet containing DDGS and midds. For main effects of diet form, pigs fed meal diets had increased ($P < 0.05$) myristic acid (C14:0) concentrations compared to pigs fed pelleted diets.

An interactive effect between diet form and oil source was detected ($P < 0.05$) for shoulder fat IV, resulting from pigs fed the control or corn oil diets having higher shoulder fat IV when diets were fed as pellets compared to meal form. However, pigs fed the DDGS and midds diet had a slight numeric decrease in shoulder fat IV when fed pelleted diets compared to meal.

DISCUSSION

In Exp. 1, feeding diets containing 30% DDGS and 19% midds did not influence ADG from d 0 to 64, but when pigs were withdrawn from the high-fiber, high-fat diet and switched to a corn-soybean meal-based diet from d 64 to 81, ADG increased compared to pigs that remained on the high-fiber, high-fat diet throughout. This response was driven primarily by increases in ADFI. The diets fed in Exp. 1 were similar to those used by Asmus et al. (2012) who investigated the effects of reducing or completely removing DDGS and midds from finishing pig diets for multiple durations. The authors reported similar increases in ADG and ADFI when the high fiber components were withdrawn from the diet. They attributed this effect to the bulk density and energy content of the diets, where pigs previously fed high fiber diets continued to consume higher volumetric amounts of feed despite switching to a more energy dense diet. Overall for both experiments, pigs fed the control diets without DDGS or midds had similar ADG and improved G:F compared with those fed 30% DDGS and 19% midds for the entirety of each trial. This is in agreement with Salyer et al. (2012) who reported that pigs fed the combination of DDGS and midds had poorer feed efficiency compared to those fed diets without cereal grain by-products. The response to feed efficiency was most likely a result of the energy content in the diets, which was further demonstrated by pigs fed the diet containing 3% corn oil diet in Exp. 2 having the greatest G:F. In addition, pigs fed diets containing DDGS and midds had poorer caloric efficiencies on a ME basis for both experiments. These results indicate that ME overestimated the energy of high fiber ingredients. However, NE estimates the energy for high fiber ingredients more accurately, as evidenced by caloric efficiency being similar on a NE basis among pigs fed the different diet types.

Feeding pelleted diets improved growth performance compared to feeding meal diets in both experiments. The overall improvements in ADG were 4 and 3% for Exp. 1 and 2, respectively, while the improvements in G:F were approximately 6% for both experiments. These results are in agreement with Wondra et al. (1995) who observed a 4 to 6% increase in ADG and 7% improvement in G:F when feeding pelleted diets compared to meal. De Jong et al. (2012) also reported improvements of approximately 6% for ADG and G:F when diets were fed in pellet instead of meal form. However, the beneficial effects of pelleting are not consistent among all research. Myers et al. (2013) found no benefit in G:F when feeding pelleted diets compared to meal. The authors suggested that the lack of response could be partially due to poor pellet quality and high percentage of fines present in the pelleted diet leading to increased feed wastage. This is in agreement with Stark et al. (1993) and Nemechek et al. (2012) who reported that feed efficiency of finishing pigs worsened as the percentage of fines in pelleted diets increased. Our research further supports this concept, where in the current trials growth benefits were observed when pigs were fed pelleted diets with low percentages of fines. Feeding pelleted diets also improved ME and NE caloric efficiencies in both experiments. This is in agreement with data from De Jong et al. (2013a,b) and was most likely a result of increased energy digestibility of pelleted diets, which has been reported by numerous researchers (Skoch et al. 1983; Wondra et al. 1995)

Similar to previously reported data (Linneen et al., 2008; Salyer et al., 2012), feeding DDGS and midds prior to harvest resulted in reduced carcass yield in both experiments. However, in Exp. 1, withdrawing these ingredients 17 d prior to market improved carcass yield and returned carcass weights to values similar to the control fed pigs. Asmus et al. (2014) also demonstrated that switching pigs from a high fiber diet to a low fiber diet 23 d prior to market

allowed for full recovery of carcass yield. In agreement, Coble et al. (2014) reported that removing DDGS and midds 15 to 20 d before harvest allowed carcass yield to return to levels of those fed corn-soybean meal-based diets throughout the finishing period. Due to the fiber component of the diets being the cause of the reduced carcass yield, it was expected that pigs fed the diet containing 3% corn oil in Exp. 2 had similar carcass yield as the control fed pigs. Diet form did not influence carcass yield in either experiment, which agrees with Wondra et al. (1995) and Myers et al. (2013) who reported no differences in carcass yield when finishing pigs were fed diets in meal or pelleted form.

As expected, feeding ingredients high in UFA increased carcass fat IV, which agrees with numerous other publications (Benz et al., 2010; 2011; Cromwell et al., 2011). In Exp. 1, pigs fed the high-fiber, high-fat diet to market had increased concentrations of total C18:2 and PUFA in belly adipose tissue compared to those fed low-fiber, low-fat throughout the trial, with those on the withdrawal regimen intermediate. These changes in fatty acid profile, specifically decreases in total PUFA and carcass fat IV, suggest that withdrawing the DDGS and midds from the diet before harvest allowed for improved fat quality compared with feeding these ingredients to market; however, this approach did not return fatty acid concentrations to the same levels as pigs fed low-fiber, low-fat throughout the entire study. Withdrawing these ingredients reduced the intake of PUFA provided in the diet; thus, the decrease in belly IV value is most likely related to PUFA intake rather than a direct effect of the fiber on PUFA profile. Similarly, Coble et al. (2014) found that jowl IV decreased linearly with increased withdrawal duration of DDGS and midds, but IV of pigs administered the longest withdrawal treatment of 20 d was still greater than that of pigs fed corn-soybean diets throughout the entire finishing period. Asmus et al. (2014) observed that switching pigs from diets containing DDGS and midds to a corn-soybean meal-

based diet 23 d prior to market reduced jowl fat IV, but further reductions occurred when the withdrawal duration was extended to 47 d prior to harvest. In Exp. 2, when all diets types were fed for the entire duration of the trial, belly fat IV was increased by 8.2 g/g for pigs fed diets with DDGS and wheat middlings and 7.1 g/g for pigs fed the corn oil diets compared with pigs fed the control.

Pelleting the diets increased UFA and carcass fat IV in both experiments; however, the response to pelleting the different diet types was not consistent. In Exp. 1, the increase in PUFA and IV of belly fat in response to pelleting was greater when DDGS and midds were fed compared to when the corn-soybean meal diet was fed. The greater belly fat IV from pigs fed pelleted diets was unexpected, particularly because faster-growing pigs will have a lower IV than slower-growing pigs. Lo Fiego et al. (2005) reported that pigs with heaver BW and HCW had decreased PUFA and IV compared with lighter pigs. The reason for the increase in carcass fat IV is not entirely understood, but one hypothesis is that the pelleting process caused increased exogenous fat digestibility and, in turn, resulted in an increase in the amount of dietary oil that is deposited as carcass fat. Thus, Exp. 2 was designed to test this hypothesis by including a diet with 3% corn oil. Kim et al. (2013) reported that total tract true digestibility of acid-hydrolyzed ether extract is much greater for extracted corn oil than for the oil contained within DDGS (94.3 vs. 51.9%). Because fat from extracted corn oil is already highly digestible, we expected that pelleting would increase the digestibility of the fat from the DDGS and midds to a greater extent than the fat from corn oil. The results from Exp. 2, however, did not confirm this hypothesis. Pelleting the diets increased belly fat IV, regardless of diet type and the interactions that occurred for fatty acid profiles of belly and shoulder fat were a result of pelleting increasing the PUFA levels to a greater extent for pigs fed the control diet than those fed the diet containing corn oil or

the diet with DDGS and midds. Wondra et al. (1995) observed that feeding pelleted diets increased DM, N, and GE digestibility compared to feeding meal diets. The increase in carcass fat IV from pelleting may be related to the increased digestibility of non-fat nutrients in the diets, allowing fat to be deposited in the fatty acid form that it is consumed. To our knowledge, the current trials are the first report of fatty acid change due to diet form.

In summary, pigs fed diets with DDGS and midds had poorer growth performance, decreased HCW, reduced carcass yield, and higher carcass fat IV compared to pigs fed the control diets. In Exp. 1, withdrawing DDGS and midds from the diet 17 d prior to market was able to fully restore carcass yield to similar levels of the control fed pigs, but only an intermediate improvement in belly fat IV was observed. The inclusion of ingredients with greater amounts of UFA increased carcass fat IV, regardless of source. Feeding pelleted diets increased ADG and improved G:F, but diet form did not influence HCW or carcass yield in either trial. Consistent between experiments, feeding pelleted diets increased carcass fat IV. Furthermore, it does not appear that the source of fat (endogenous from the ingredient vs. supplemental) in pelleted diets impacts the carcass fat IV response to pelleting.

LITERATURE CITED

AOAC. 2006. Official Methods of Analysis. 18th ed. Assoc. Off. Anal. Chem., Arlington, VA.

ASAE. 1987. Wafers, pellets, and crumbles – definitions and methods for determining density, durability, and moisture content. ASAE Standard S269.3, Agricultural Engineers Yearbook of Standards. p 318. Am. Soc. Agric. Biol. Eng., St. Joseph, MI.

ASAE. 1996. Cubes, Pellets, and Crumbles: Definitions and Methods for Determining Density, Durability, and Moisture Content. ASAE Standard S269.4. Am. Soc. Agric. Biol. Eng., St. Joseph, MI.

Asmus, M. D., J. M. DeRouchey, M. D. Tokach, S. S. Dritz, T. A. Houser, J. L. Nelssen, and R. D. Goodband. 2014. Effects of lowering dietary fiber before marketing on finishing pig growth performance, carcass characteristics, carcass fat quality, and intestinal weights. J. Anim. Sci. 92:119-128.

Baird, D. M. 1973. Influence of pelleting swine diets on metabolizable energy, growth and carcass characteristics. J. Anim. Sci. 36:516-521.

Benz, J. M. S. K. Linneen, M. D. Tokach, S. S. Dritz, J. L. Nelssen, J. M. DeRouchey, R. D. Goodband, R. C. Sulabo, and K. J. Prusa. 2010. Effects of dried distillers grains with solubles on carcass fat quality of finishing pigs. J. Anim. Sci. 88:3666-3682.

Benz, J. M. M. D. Tokach, S. S. Dritz, J. L. Nelssen, J. M DeRouchey, R. C. Sulabo, and R. D. Goodband. 2011. Effects of choice white grease and soybean oil on growth performance, carcass characteristics, and carcass fat quality of growing-finishing pigs. J. Anim. Sci. 89:404-413.

Coble, K. F., J. M. DeRouchey, M. D. Tokach, R. D. Goodband, S. S. Drit, T. A. Houser, B. Goehring, and M. J. Azain. 2014. Effects of withdrawing high-fiber ingredients before market on finishing pig growth performance, carcass characteristics, intestinal weights, and carcass fat quality. J. Anim. Sci. 92(Suppl. 2):86. (Abstr.)

Cromwell, G. L., M. J. Azain, O. Adeola, S. K. Baidoo, S. D. Carter, T. D. Crenshaw, S. W. Kim, D. C. Mahan, P. S. Miller, and M. C. Shannon. 2011. Corn distillers dried grains with solubles in diets for growing-finishing pigs: A cooperative study. J. Anim. Sci. 89:2801-2811.

De Jong, J. A., J. M. DeRouchey, M. D. Tokach, R. D. Goodband, S. S. Dritz, J. L. Nelssen, and C. Hastad. 2012. Effects of corn particle size, complete diet grinding, and diet form on pig growth performance, caloric efficiency, and carcass characteristics. J. Anim. Sci. 91 (Suppl. 2):216. (Abstr.)

De Jong, J. A., J. M. DeRouchey, M. D. Tokach, R. D. Goodband, S. S. Dritz, J. L. Nelssen, and C. Hastad. 2013a. Effects of corn particle size, complete diet grinding and diet form on pig

growth performance, caloric efficiency, and carcass characteristics. J. Anim. Sci. 91(Suppl. 2):112 (Abstr.).

De Jong, J. A., J. M. DeRouchey, M. D. Tokach, R. D. Goodband, S. S. Dritz, and J. L. Nelssen. 2013b. Effects of varying ingredient particle size and diet form on nursery pig growth performance and caloric efficiency. J. Anim. Sci. 91(Suppl. 2):70 (Abstr.).

Gaines, A. M., J. D. Spencer, G. I Petersen, and N. R. Augspurger. 2007. Effect of corn distiller's dried grains with solubles (DDGS) withdrawal program on growth performance and carcass yield in grow-finish pigs. J. Anim. Sci. 85 (Suppl. 1):438. (Abstr.)

Kim, B. G., D. Y. Kil, and H. H. Stein. 2012. In growing pigs, the true ileal and total tract digestibility of acid hydrolyzed ether extract in extracted corn oil is greater than in intact sources of corn oil or soybean oil. J. Anim. Sci. 91:755-763.

Lo Fiego, D. P., P. Santero, P. macchioni, and E. De Leonibus. 2005. Influence of genetic type, live weight at harvest and carcass fatness on fatty acid composition of subcutaneous adipose tissue of raw ham in the heavy pig. Meat Sci. 59:107-114.

McClelland, K. M., G. Rentfrow, G. L. Cromwell, M. D. Lindemann, and M. J. Azain. 2012. Effects of corn distillers dried grains with solubles on quality traits of pork. J. Anim. Sci. 90:4148-4156.

Nemechek, J., M. Tokach, E. Fruge, E. Hansen, S. Dritz, R. Goodband, J. DeRouchey, and J. Nelssen. 2012. Effects of pellet quality and feeder adjustment on growth performance of finishing pigs. J. Anim. Sci. 91 (Suppl. 2):215. (Abstr.)

NRC. 2012. Nutrient Requirements of Swine. 11th rev. ed. Natl. Acad. Press, Washington, DC.

Salyer, J. A., J. M. DeRouchey, M. D. Tokach, S. S. Dritz, R. D. Goodband, J. L. Nelssen, and D. B. Petry. 2012. Effects of dietary wheat middlings, distillers dried grains with solubles, and choice white grease on growth performance, carcass characteristics, and carcass fat quality of finishing pigs. J. Anim. Sci. 90:2620-2630.

Skoch, E. R., S. F. Binder, C. W. Deyoe, G. L. Alee, and K. C. Behnke. 1983. Effects of pelleting conditions on performance of pigs fed a corn-soybean meal diet. J. Anim. Sci. 57:922.

Stark, C. R., K. C. Behnke, J. D. Hancock, and R. H. Hines. 1993. Pellet quality affects growth performance of nursery and finishing pigs. In: Proc. Swine Day, Stn. Rep. Prog. 695, Manhattan, KS. p. 71-74.

Stein, H. H. and G. C. Shurson. 2009. Board-invited review: The use and application of distillers dried grains with solubles in swine diets. J. Anim. Sci. 87:1292-1303.

Whitney, M. H., G. C. Shurson, L. J. Johnston, D. M. Wulf, and B. C. Shanks. 2006. Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grain with solubles originating from a modern Midwestern ethanol plant. J. Anim. Sci. 84:3356-3363.

Widmer, M. R., L. M. McGinnis, D. M. Wulf, and H. H. Stein. 2007. Effects of co-products from the ethanol industry on pig performance and carcass composition. J. Anim. Sci. 85(Suppl. 1):437. (Abstr.)

Wondra, K. J., J. D. Hancock, K. C. Behnke, R. H. Hines, and C. R. Stark. 1995. Effects of particle size and pelleting on growth performance, nutrient digestibility, and stomach morphology in finishing pigs. J. Anim. Sci. 73:757-763.

TABLES

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

	Phase 1[1]		Phase 2		Phase 3		Phase 4	
Item Fiber and fat level[2]:	Low	High	Low	High	Low	High	Low	High
Ingredient, %								
Corn	73.71	34.88	78.93	39.99	82.65	43.56	84.97	45.79
Soybean meal, 46.5% CP	23.80	13.74	18.84	8.71	15.32	5.20	13.15	3.04
Dried distillers grains with solubles	---	30.00	---	30.00	---	30.00	---	30.00
Wheat middlings	---	19.00	---	19.00	---	19.00	---	19.00
Monocalcium P, 21% P	0.45	---	0.35	---	0.25	---	0.20	---
Limestone	1.05	1.30	1.00	1.28	0.98	1.29	0.93	1.28
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.15	0.15	0.13	0.13	0.10	0.10	0.08	0.08
Trace mineral premix[4]	0.15	0.15	0.13	0.13	0.10	0.10	0.08	0.08
L-Lys·HCl	0.170	0.310	0.150	0.293	0.135	0.278	0.128	0.270
DL-Met	0.020	---	---	---	---	---	---	---
L-Thr	0.025	---	0.010	---	---	---	---	---
Phytase[5]	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis								
Standardized ileal digestible (SID) amino acids, %								
Lys	0.93	0.93	0.79	0.79	0.69	0.69	0.63	0.63
Ile:Lys	69	72	70	74	72	76	73	78
Met:Lys	30	34	30	37	32	40	33	43
Met + Cys:Lys	59	70	62	77	66	83	69	88
Thr:Lys	63	66	63	69	64	72	66	74
Trp:Lys	19	19	19	19	19	19	19	19
Val:Lys	78	88	81	94	85	99	87	103
Total Lys, %	1.04	1.09	0.89	0.94	0.78	0.83	0.72	0.77
ME, kcal/kg	3,296	3,233	3,307	3,240	3,316	3,245	3,324	3,249
NE, kcal/kg	2,474	2,333	2,507	2,365	2,533	2,386	2,549	2,400
CP, %	17.5	20.8	15.6	18.9	14.3	17.6	13.5	16.7
Ca, %	0.59	0.58	0.53	0.56	0.49	0.55	0.46	0.54
P, %	0.47	0.58	0.42	0.56	0.39	0.55	0.37	0.54
Available P, %	0.27	0.39	0.25	0.38	0.22	0.38	0.21	0.37

[1] Phase 1 diets were fed from d 0 to 15, phase 2 from d 15 to 40, phase 3 from d 40 to 64, and phase 4 from d 64 to 81.

[2] Each diet was fed in either meal or pellet form.

[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 sulphate, 11g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[5] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 780 phytase units (FTU)/kg, with a release of 0.11% available P.

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

	Phase 1[1]			Phase 2[2]		
Item	Control	DDGS + Midds	Corn Oil	Control	DDGS + Midds	Corn Oil
Ingredient, %						
Corn	72.01	33.03	68.84	77.57	37.46	74.25
Soybean meal, 46.5% CP	25.56	15.70	25.64	20.17	11.36	20.40
Dried distillers grains with solubles	---	30.00	---	---	30.00	---
Wheat middlings	---	19.00	---	---	19.00	---
Corn oil	---	---	3.00	---	---	3.00
Monocalcium P, 21% P	0.45	---	0.52	0.37	---	0.44
Limestone	1.05	1.30	1.05	1.00	1.28	1.00
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.150	0.150	0.150	0.125	0.125	0.125
Trace mineral premix[4]	0.150	0.150	0.150	0.125	0.125	0.125
L-Lys·HCl	0.220	0.310	0.225	0.235	0.293	0.235
Met hydroxyl analog	0.020	---	0.028	0.013	---	0.015
L-Thr	0.030	---	0.040	0.035	---	0.040
Phytase[5]	0.012	0.012	0.012	0.015	0.015	0.015
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lys	0.98	0.98	0.98	0.86	0.86	0.86
Ile:Lys	67	71	66	65	72	65
Met:Lys	28	33	29	29	35	29
Met + Cys:Lys	55	62	55	56	67	56
Thr:Lys	60	62	61	61	63	61
Trp:Lys	19	19	19	18	18	18
Val:Lys	74	85	73	74	88	73
Total Lys, %	1.11	1.19	1.11	0.98	1.05	0.97
ME, kcal/kg	3,298	3,234	3,452	3,309	3,241	3,463
CP, %	18.4	21.7	18.1	16.3	20.0	16.1
Ca, %	0.55	0.57	0.56	0.50	0.55	0.52
P, %	0.47	0.56	0.47	0.42	0.54	0.43
Available P, %	0.29	0.37	0.30	0.26	0.37	0.28

[1] Phase 1 diets were fed from d 0 to 21.

[2] Phase 2 diets were fed from d 21 to 45.

[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 sulphate, 11g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[5] Natuphos 2500 (BASF Corp., Mt. Olive, NJ) provided 300 phytase units (FTU)/kg, with a release of 0.10% available P.

Table 1-3. Composition of phase 3 and 4 diets, Exp. 2 (as-fed basis)

	Phase 3[1]			Phase 4[2]		
Item	Control	DDGS + Midds	Corn Oil	Control	DDGS + Midds	Corn Oil
Ingredient, %						
Corn	81.04	40.70	77.72	83.98	43.80	80.62
Soybean meal (46.5% CP)	16.81	8.16	17.04	13.86	5.13	14.17
Dried distillers grains with solubles	---	30.00	---	---	30.00	---
Wheat middlings	---	19.00	---	---	19.00	---
Corn oil	---	---	3.00	---	---	3.00
Monocalcium phosphate (21% P)	0.34	---	0.42	0.45	---	0.49
Limestone	0.98	1.29	0.98	0.93	1.28	0.93
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.100	0.100	0.100	0.075	0.075	0.075
Trace mineral premix[4]	0.100	0.100	0.100	0.075	0.075	0.075
L-Lys·HCl	0.225	0.278	0.225	0.215	0.270	0.213
Met hydroxyl analog	0.010	---	0.010	---	---	0.010
L-Thr	0.038	---	0.043	0.050	---	0.055
Phytase[5]	0.018	0.018	0.018	0.021	0.021	0.021
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lys	0.77	0.77	0.77	0.69	0.69	0.69
Ile:Lys	66	74	65	66	75	66
Met:Lys	30	37	29	30	40	31
Met + Cys:Lys	59	71	58	60	75	61
Thr:Lys	62	65	62	65	67	66
Trp:Lys	18	18	18	18	18	18
Val:Lys	75	92	74	77	96	76
Total Lys, %	0.88	0.96	0.88	0.79	0.87	0.79
ME, kcal/kg	3,316	3,245	3,470	3,318	3,250	3,472
CP, %	14.9	18.7	14.8	13.8	17.5	13.6
Ca, %	0.48	0.54	0.49	0.47	0.53	0.48
P, %	0.40	0.53	0.41	0.41	0.52	0.41
Available P, %	0.25	0.36	0.27	0.27	0.36	0.28

[1] Phase 3 diets were fed from d 45 to 70.

[2] Phase 4 diets were fed from d 70 to 87.

[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 sulphate, 11g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[5] Natuphos 2500 (BASF Corp., Mt. Olive, NJ) provided 300 phytase units (FTU)/kg, with a release of 0.10% available P.

Table 1-4. Chemical analysis of diets, Exp. 1[1]

	Phase 1[2]				Phase 2[3]			
Diet form:	Meal		Pellet		Meal		Pellet	
Item / Fiber and fat level:	Low	High	Low	High	Low	High	Low	High
DM, %	89.58	89.96	89.71	89.06	90.58	88.60	90.07	88.54
CP, %	18.1	20.6	18.4	22.1	16.8	21.3	17.0	20.8
ADF, %	3.1	7.1	3.1	5.9	2.5	7.0	1.9	4.9
NDF, %	5.7	14.5	6	14.2	6.0	15.5	5.9	13.9
Crude fiber, %	1.8	4.0	1.9	3.5	1.7	4.3	1.8	3.5
Ether extract, %	1.6	3.7	1.7	4.0	2.3	4.7	2.0	4.5
Ca, %	0.55	0.63	0.56	0.66	0.39	0.60	0.42	0.61
P, %	0.46	0.65	0.47	0.63	0.45	0.69	0.43	0.59

[1] A composite sample consisting of 6 subsamples was used for analysis.
[2] Phase 1 diets were fed from d 0 to 15.
[3] Phase 2 diets were fed from d 15 to 40.

Table 1-5. Chemical analysis of diets, Exp. 1[1]

	Phase 3[2]				Phase 4[3]			
Diet form:	Meal		Pellet		Meal		Pellet	
Item / Fiber and fat level:	Low	High	Low	High	Low	High	Low	High
DM, %	88.54	89.24	88.91	88.42	88.58	89.17	89.14	91.40
CP, %	14.9	19.4	15.0	19.5	14.0	17.8	13.4	17.7
ADF, %	2.3	6.1	2.6	6.2	2.4	6.3	2.2	6.0
NDF, %	6.2	16.9	7.2	16.5	7.1	16.1	6.2	16.0
Crude fiber, %	2.0	4.1	1.8	4.3	1.8	4.5	1.8	4.5
Ether extract, %	1.9	4.5	2.4	3.3	2.3	4.5	2.2	5.1
Ca, %	0.45	0.46	0.43	0.57	0.30	0.47	0.40	0.54
P, %	0.47	0.66	0.43	0.58	0.38	0.65	0.36	0.63

[1] A composite sample consisting of 6 subsamples was used for analysis
[2] Phase 3 diets were fed from d 40 to 64.
[3] Phase 4 diets were fed from d 64 to 81.

Table 1-6. Analysis of pellet quality, Exp. 1[1]

	Fiber and fat level	
Item	Low[2]	High[3]
Standard pellet durability index, %[4]		
Phase 1	91.0	92.7
Phase 2	90.1	96.2
Phase 3	92.9	95.9
Phase 4	94.9	91.4
Modified pellet durability index[5]		
Phase 1	87.9	89.4
Phase 2	86.3	92.7
Phase 3	89.5	93.8
Phase 4	92.4	88.8
Fines, %		
Phase 1	7.6	7.3
Phase 2	9.0	7.4
Phase 3	8.0	8.4
Phase 4	7.9	8.1

[1] A representative feed sample was taken at the feeder during each phase and analyzed in duplicate for each pellet quality measurement.

[2] Refers to diet with 0% dried distillers grains with solubles (DDGS) and 0% wheat middlings (midds).

[3] Refers to diet with 30% DDGS and 19% midds.

[4] Pellet durability index was determined using the standard tumbling-box technique.

[5] Procedure was altered by adding 5 hexagonal nuts prior to tumbling.

Table 1-7. Interactive effects of diet regimen and diet form on finishing pig growth performance, Exp. 1[1]

Fiber and fat level	Diet form							Probability, $P <$		
	Meal			Pellet						
d 0 to 64:	Low[2]	High[3]	High	Low	High	High		Diet form ×	Meal vs.	Diet
d 64 to 81:	Low	Low	High	Low	Low	High	SEM	regimen	pellet	regimen
d 0 to 64										
ADG, kg	0.95	0.97	0.96	0.97	0.98	0.99	0.022	0.925	0.273	0.636
ADFI, kg	2.47	2.63	2.65	2.41	2.49	2.52	0.055	0.758	0.016	0.012
G:F	0.386	0.368	0.362	0.405	0.393	0.391	0.010	0.523	0.001	0.001
d 64 to 81										
ADG, kg	0.93	0.97	0.88	1.02	1.03	0.97	0.032	0.886	0.005	0.026
ADFI, kg	2.93	3.26	3.22	3.15	3.38	3.16	0.069	0.135	0.100	0.001
G:F	0.317	0.296	0.273	0.322	0.303	0.306	0.009	0.246	0.058	0.006
d 0 to 81										
ADG, kg	0.95	0.97	0.94	0.98	0.99	0.98	0.017	0.829	0.029	0.354
ADFI, kg	2.56	2.77	2.77	2.56	2.67	2.66	0.054	0.568	0.116	0.006
G:F	0.369	0.350	0.341	0.384	0.370	0.370	0.005	0.192	0.001	0.001
Caloric efficiency, Mcal/kg										
ME	8.97	9.32	9.53	8.63	8.83	8.76	0.120	0.202	0.001	0.016
NE	6.82	6.89	6.98	6.56	6.54	6.42	0.088	0.218	0.001	0.965
BW, kg										
d 0	49.7	49.4	49.8	49.5	49.9	49.3	1.327	0.913	0.972	0.930
d 64	111.0	111.4	111.2	112.5	112.7	112.4	1.869	0.996	0.371	0.882
d 81	126.7	127.8	126.1	130.4	130.1	128.9	1.885	0.940	0.066	0.436
Carcass yield, %	75.11	74.66	74.11	75.03	74.85	73.35	0.239	0.876	0.277	0.001
HCW, kg	95.3	95.4	93.5	97.9	97.5	94.7	1.314	0.131	0.080	0.105

[1] A total of 288 pigs (PIC 327 × 1050, initially 49.6 kg BW) were used in an 81-d trial with 6 pens per treatment and 8 pigs per pen.

[2] Refers to diet with 0% dried distillers grains with solubles (DDGS) and 0% wheat middlings (midds).

[3] Refers to diet with 30% DDGS and 19% midds.

Table 1-8. Main effects of diet regimen and diet form on fishing pig growth performance, Exp. 1[1]

	Fiber and fat level								
d 0 to 64:	Low[1]	High[2]	High		Diet form			Probability, $P <$	
d 64 to 81:	Low	Low	High	SEM	Meal	Pellet	SEM	Diet regimen	Diet form
d 0 to 64									
ADG, kg	0.96	0.97	0.97	0.015	0.96	0.98	0.012	0.636	0.273
ADFI, kg	2.44[a]	2.56[b]	2.59[b]	0.039	2.59	2.47	0.032	0.012	0.016
G:F	0.395[a]	0.380[b]	0.376[b]	0.005	0.371	0.396	0.006	0.001	0.001
d 64 to 81									
ADG, kg	0.97[ab]	1.00[a]	0.92[b]	0.023	0.92	1.00	0.019	0.026	0.005
ADFI, kg	3.04[b]	3.32[a]	3.19[b]	0.049	3.14	3.23	0.040	0.001	0.101
G:F	0.320[a]	0.300[ab]	0.289[b]	0.006	0.294	0.310	0.007	0.006	0.058
d 0 to 81									
ADG, kg	0.97	0.98	0.96	0.012	0.95	0.99	0.010	0.354	0.029
ADFI, kg	2.56[a]	2.72[b]	2.71[b]	0.038	2.70	2.63	0.031	0.001	0.116
G:F	0.377[a]	0.360[b]	0.356[b]	0.003	0.353	0.375	0.003	0.001	0.001
Caloric efficiency, Mcal/kg									
ME	8.80[a]	9.08[b]	9.15[b]	0.085	9.27	8.74	0.070	0.016	0.001
NE	6.69	6.72	6.70	0.062	6.90	6.51	0.051	0.965	0.001
BW, kg									
d 0	49.6	49.7	49.5	0.938	49.6	49.6	0.766	0.930	0.972
d 64	111.8	112.0	111.8	1.322	111.2	112.6	1.079	0.882	0.371
d 81	128.6	129.0	127.5	1.333	126.9	129.8	1.088	0.436	0.066
Carcass yield, %	75.07[a]	74.75[a]	73.73[b]	0.170	74.63	74.41	0.139	0.001	0.277
HCW, kg	96.6	96.4	94.1	0.934	94.7	96.7	0.767	0.105	0.080

[1] A total of 288 pigs (PIC 327 × 1050, initially 49.6 kg BW) were used in an 81-d trial with 8 pigs per pen. There were 12 pens per diet regimen main effect and 18 pens per diet form main effect.

[2] Refers to diet with 0% dried distillers grains with solubles (DDGS) and 0% wheat middlings (midds).

[3] Refers to diet with 30% DDGS and 19% midds.

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

Table 1-9. Interactive effects of diet regimen and diet form on finishing pig belly fatty acid profile, Exp. 1[1]

	Diet form									
	Fiber and fat level	Meal			Pellet				Probability, $P <$	
Item	d 0 to 64: / d 64 to 81:	Low[2] / Low	High[3] / Low	High / High	Low / Low	High / Low	High / High	SEM	Diet form × regimen	Meal vs. Pellet	Diet regimen
Myristic acid (C14:0), %		1.47	1.39	1.36	1.44	1.31	1.29	0.018	0.59	0.001	0.001
Palmitic acid (C16:0), %		23.91	22.49	21.87	23.68	21.67	21.04	0.130	0.05	0.001	0.001
Palmitoleic acid (C16:1), %		3.30	3.06	2.96	3.03	2.66	2.62	0.061	0.81	0.001	0.001
Margaric acid (C17:0), %		0.35	0.39	0.43	0.33	0.36	0.38	0.014	0.45	0.002	0.001
Stearic acid (C18:0), %		10.61	9.44	8.94	10.79	9.21	8.64	0.114	0.07	0.19	0.001
Oleic acid (C18:1n9c), %		39.45	37.84	36.73	38.71	36.59	35.73	0.214	0.65	0.001	0.001
Vaccenic acid (C18:1n7), %		4.27	3.95	3.76	4.02	3.57	3.47	0.051	0.87	0.001	0.001
Linoleic acid (C18:2n6c), %		12.89	17.22	19.57	14.25	20.38	22.51	0.290	0.01	0.001	0.001
Total C18:2 fatty acids[4], %		13.05	17.41	19.75	14.38	20.52	22.64	0.290	0.01	0.001	0.001
α-Linolenic acid (C18:3n3), %		0.58	0.68	0.74	0.63	0.80	0.84	0.014	0.16	0.001	0.001
Arachidic acid (C20:0), %		0.22	0.22	0.21	0.23	0.22	0.21	0.004	0.53	0.57	0.001
Eicosenoic acid (C20:1), %		0.65	0.67	0.66	0.67	0.66	0.63	0.015	0.33	0.58	0.36
Eicosadienoic acid (C20:2), %		0.59	0.78	0.85	0.65	0.90	0.95	0.012	0.15	0.001	0.001
Arachidonic acid (C20:4n6), %		0.25	0.29	0.30	0.24	0.28	0.29	0.006	0.84	0.15	0.001
Other fatty acids, %		1.30	1.42	1.46	1.22	1.26	1.29	0.018	0.05	0.001	0.001
Total SFA[5], %		36.94	34.29	33.18	36.82	33.12	31.90	0.208	0.01	0.001	0.001
Total MUFA[6], %		48.25	46.16	44.76	46.95	43.99	42.96	0.286	0.56	0.001	0.001
Total PUFA[7], %		14.80	19.55	22.06	16.23	22.89	25.15	0.318	0.02	0.001	0.001
UFA:SFA[8], ratio		1.71	1.92	2.02	1.72	2.03	2.14	0.018	0.01	0.001	0.001
PUFA:SFA[9], ratio		0.40	0.57	0.67	0.44	0.69	0.79	0.012	0.001	0.001	0.001

Iodine value, mg/g[10]	65.7	71.7	74.7	67.0	75.5	78.4	0.378	0.003	0.001	0.001

[1] All items calculated as a percentage of the total fatty acid content. Belly fat samples were collected from the ventral side of the belly along the navel edge between the 10th and the 12th rib

[2] Refers to diet with 0% dried distillers grains with solubles (DDGS) and 0% wheat middlings (midds).

[3] Refers to diet with 30% DDGS and 19% midds.

[4] Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% 18:2, 10t12c] + [% C18:2, 9c11c] + [C18:2, 9t11t].

[5] Total saturated fatty acids = [% C10:0] + [% C11:0] + [% C12:0] + [% C14:0] + [% C15:0] + [% C16:0] + [% C17:0] + [% C18:0] + [% C20:0] + [% C21:0] + [% C22:0] + [% C 24:0].

[6] Total monounsaturated fatty acids = [% C14:1] + [% C15:1] + [% C16:1] + [% C17:1] + [% C18:1n9t] + [% C18:1n9c] + [% C18:1n7] + [% C20:1] + [% C24:1].

[7] Total polyunsaturated fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2 9c,11t] + [% C18:2 10t,12c] + [% C18:2 9c,11c] + [% C18:2 9t,11t] + [% C18:3n6] + [% C18:3n3] + [% C20:2] + [% C20:3n6] + [% C20:4n6] + [% C20:5n3] + [% C22:5n3] + [% C22:5n6].

[8] UFA:SFA ratio = [total MUFA + total PUFA] / total SFA.

[9] PUFA:SFA ratio = total PUFA / total SFA.

[10] Iodine value = [% C16:1] × 0.95 + [% C18:1] × 0.86 + [% C18:2] × 1.732 + [% C18:3] × 2.616 + [% C20:1] × 0.785 + [% C22:1] × 0.723.

Table 1-10. Main effects of diet regimen and diet form on finishing pig belly fatty acid profile, Exp. 1[1]

	Fiber and fat level				Diet form			Probability, *P* <	
d 0 to 64:	Low[2]	High[3]	High						
Item d 64 to 81:	Low	Low	High	SEM	Meal	Pellet	SEM	Diet regimen	Diet form
Myristic acid (C14:0), %	1.44[a]	1.33[b]	1.31[b]	0.018	1.39	1.33	0.016	0.001	0.001
Palmitic acid (C16:0), %	23.67[a]	21.95[b]	21.36[c]	0.127	22.64	22.01	0.112	0.001	0.001
Palmitoleic acid (C16:1), %	3.09[a]	2.78[b]	2.73[b]	0.062	3.03	2.69	0.054	0.001	0.001
Margaric acid (C17:0), %	0.34[a]	0.38[b]	0.40[b]	0.010	0.39	0.36	0.009	0.001	0.001
Stearic acid (C18:0), %	10.70[a]	9.32[b]	8.79[c]	0.078	9.66	9.54	0.065	0.001	0.19
Oleic acid (C18:1n9c), %	38.91[a]	37.03[b]	36.09[c]	0.206	37.84	36.84	0.180	0.001	0.001
Vaccenic acid (C18:1n7), %	4.03[a]	3.64[b]	3.52[c]	0.054	3.88	3.57	0.047	0.001	0.001
Linoleic acid (C18:2n6c), %	14.14[a]	19.40[b]	21.50[c]	0.303	17.09	19.60	0.268	0.001	0.001
Total C18:2 fatty acids[4], %	14.28[a]	19.56[b]	21.65[c]	0.303	17.26	19.73	0.267	0.001	0.001
α-Linolenic acid (C18:3n3), %	0.64[a]	0.77[b]	0.82[c]	0.014	0.70	0.79	0.013	0.001	0.001
Arachidic acid (C20:0), %	0.22[a]	0.22[a]	0.21[b]	0.003	0.22	0.22	0.002	0.001	0.57
Eicosenoic acid (C20:1), %	0.66	0.66	0.64	0.010	0.66	0.65	0.008	0.36	0.58
Eicosadienoic acid (C20:2), %	0.65[a]	0.87[b]	0.93[c]	0.013	0.77	0.86	0.012	0.001	0.001
Arachidonic acid (C20:4n6), %	0.25[a]	0.29[b]	0.30[c]	0.006	0.28	0.27	0.005	0.001	0.15
Other fatty acids, %	1.26[a]	1.34[b]	1.37[b]	0.013	1.39	1.25	0.010	0.001	0.001
Total SFA[5], %	36.79[a]	33.60[b]	32.46[c]	0.185	34.72	33.85	0.160	0.001	0.001
Total MUFA[6], %	47.19[a]	44.64[b]	43.53[c]	0.293	46.00	44.24	0.258	0.001	0.001
Total PUFA[7], %	16.17[a]	21.91[b]	24.13[c]	0.333	19.42	22.05	0.294	0.001	0.001
UFA:SFA[8], ratio	1.73[a]	1.99[b]	2.09[c]	0.017	1.90	1.97	0.014	0.001	0.001
PUFA:SFA[9], ratio	0.45[a]	0.66[b]	0.75[c]	0.012	0.57	0.67	0.011	0.001	0.001
Iodine value, mg/g[10]	67.0[a]	74.3[b]	77.1[c]	0.393	71.3	74.3	0.346	0.001	0.001

[1] All items calculated as a percentage of the total fatty acid content. Belly fat samples were collected from the ventral side of the belly along the navel edge between the 10th and the 12th rib

[2] Refers to diet with 0% dried distillers grains with solubles (DDGS) and 0% wheat middlings (midds).

[3] Refers to diet with 30% DDGS and 19% midds.
[4] Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% 18:2, 10t12c] + [% C18:2, 9c11c] + [C18:2, 9t11t].
[5] Total saturated fatty acids = [% C10:0] + [% C11:0] + [% C12:0] + [% C14:0] + [% C15:0] + [% C16:0] + [% C17:0] + [% C18:0] + [% C20:0] + [% C21:0] + [% C22:0] + [% C 24:0].
[6] Total monounsaturated fatty acids = [% C14:1] + [% C15:1] + [% C16:1] + [% C17:1] + [% C18:1n9t] + [% C18:1n9c] + [% C18:1n7] + [% C20:1] + [% C24:1].
[7] Total polyunsaturated fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2 9c,11t] + [% C18:2 10t,12c] + [% C18:2 9c,11c] + [% C18:2 9t,11t] + [% C18:3n6] + [% C18:3n3] + [% C20:2] + [% C20:3n6] + [% C20:4n6] + [% C20:5n3] + [% C22:5n3] + [% C22:5n6].
[8] UFA:SFA ratio = [Total MUFA + Total PUFA] / Total SFA.
[9] PUFA:SFA ratio = Total PUFA / Total SFA.
[10] Iodine value = [% C16:1] × 0.95 + [% C18:1] × 0.86 + [% C18:2] × 1.732 + [% C18:3] × 2.616 + [% C20:1] × 0.785 + [% C22:1] × 0.723.
[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$)

Table 1-11. Chemical analysis of diets, Exp. 2[1]

		Phase 1[2]						Phase 2[3]					
Diet form:		Meal			Pellet			Meal			Pellet		
Item	Diet type	Control	DDGS + Midds	Corn Oil	Control	DDGS + Midds	Corn Oil	Control	DDGS + Midds	Corn Oil	Control	DDGS + Midds	Corn Oil
DM, %		89.47	90.73	89.62	89.18	88.94	89.33	89.60	90.63	89.47	89.46	88.64	89.13
CP, %		17.7	18.4	18.0	18.8	23.0	18.1	18.1	18.6	17.4	16.9	21.6	17.0
ADF, %		2.7	7.1	2.6	3	7.3	3.1	3.2	7.3	3.3	2.9	6.4	3.2
NDF, %		7.6	17.7	6.6	6.7	16.6	6.6	5.9	18.0	6.7	5.1	14.0	5.3
Crude fiber, %		2.0	4.7	2.0	1.8	4.5	2.0	2.1	4.8	2.1	1.8	4.0	2.0
Ether extract, %		1.6	4.3	3.5	1.4	3.4	3.7	1.5	4.3	3.7	1.5	3.2	3.1
Ca, %		0.98	0.45	0.83	0.58	0.62	0.64	0.62	0.58	0.54	0.65	0.60	0.53
P, %		0.49	0.65	0.51	0.48	0.66	0.49	0.46	0.66	0.44	0.44	0.62	0.42

[1] A composite sample consisting of 6 subsamples was used for analysis

[2] Phase 1 diets were fed from d 0 to 21.

[3] Phase 2 diets were fed from d 21 to 45.

Table 1-12. Chemical analysis of diets, Exp. 2[1]

		Phase 3[2]						Phase 4[3]					
Diet form:		Meal			Pellet			Meal			Pellet		
Item	Diet type	Control	DDGS + Midds	Corn Oil	Control	DDGS + Midds	Corn Oil	Control	DDGS + Midds	Corn Oil	Control	DDGS + Midds	Corn Oil
DM, %		89.09	90.58	89.41	88.77	90.16	88.93	89.85	90.15	89.81	89.74	91.89	90.61
CP, %		17.1	21	15.3	16.3	20.8	15.9	14.2	22.3	14.0	14.5	18.4	14.3
ADF, %		2.8	7.6	3.0	3.4	5.9	2.8	3.4	8.2	2.8	3.3	6.5	2.6
NDF, %		6.4	16	6.4	5.9	14.4	6.6	6.7	16.8	6.3	5.1	16.5	5.1
Crude fiber, %		1.7	4.2	2.0	1.8	3.5	1.9	2.1	4.8	2.1	1.6	4.3	1.5
Ether extract, %		2.0	4.6	4.2	1.6	4.4	3.8	2.0	3.7	3.2	1.9	4.7	3.5
Ca, %		0.38	0.47	0.61	0.45	0.61	0.55	0.90	0.88	1.19	0.98	0.56	0.56
P, %		0.49	0.66	0.49	0.46	0.66	0.44	0.47	0.58	0.51	0.44	0.64	0.40

[1] A composite sample consisting of 6 subsamples was used for analysis

[2] Phase 3 diets were fed from d 45 to 70.

[3] Phase 4 diets were fed from d 70 to 87.

Table 1-13. Analysis of pellet quality, Exp. 2

	Diet Type		
Item	Control[1]	DDGS + Midds[2]	Corn Oil[3]
Standard pellet durability index, %[4]			
Phase 1	93.6	92.0	91.5
Phase 2	94.2	90.4	88.9
Phase 3	94.1	89.9	90.5
Phase 4	90.0	94.3	92.7
Modified pellet durability index[5]			
Phase 1	85.5	84.2	84.8
Phase 2	86.4	84.1	82.5
Phase 3	86.0	84.9	84.0
Phase 4	83.0	87.5	83.0
Fines, %			
Phase 1	10.2	12.4	14.0
Phase 2	11.9	12.7	7.6
Phase 3	7.2	8.8	6.9
Phase 4	7.3	13.6	8.5

[1]Corn-soybean meal-based diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings (midds), and 0% corn oil.

[2]Control diet with 30% DDGS and 19% midds.

[3]Control diet with 3% corn oil.

[4] Pellet durability index was determined using the standard tumbling-box technique.

[5] Procedure was altered by adding 5 hexagonal nuts prior to tumbling.

Table 1-14. Interactive effects of diet form and diet type on growth performance and carcass yield, Exp. 2[1]

Diet form:	Meal			Pellet				Probability, *P* <		
Diet type:	Control[2]	DDGS + Midds[3]	Corn Oil[4]	Control	DDGS + Midds	Corn Oil	SEM	Diet Form × Type	Diet Form	Diet Type
Initial BW, kg	48.5	48.5	48.5	48.5	48.5	48.5	1.041	0.998	0.997	0.996
d 0 to 87										
ADG, kg	0.95	0.91	0.95	0.96	0.94	0.98	0.013	0.706	0.038	0.009
ADFI, kg	2.64	2.66	2.52	2.49	2.63	2.44	0.042	0.372	0.016	0.002
G:F	0.359	0.341	0.378	0.385	0.357	0.401	0.005	0.619	0.001	0.001
Caloric efficiency, Mcal/kg										
ME	9.24	9.53	9.19	8.61	9.09	8.64	0.125	0.744	0.001	0.005
NE	7.00	6.94	7.04	6.53	6.62	6.62	0.094	0.699	0.001	0.784
Final BW, kg	130.8	127.3	131.4	131.7	130.1	134.5	1.521	0.747	0.076	0.028
HCW, kg	98.6	93.9	98.6	98.2	95.9	101.6	1.218	0.366	0.132	0.001
Carcass yield, %	75.37	73.82	75.01	74.53	73.75	75.54	0.309	0.163	0.619	0.001

[1]A total of 288 pigs (PIC 327 × 1050, initially 48.5 kg BW) were used in an 87-d trial with 6 pens per treatment and 8 pigs per pen.
[2]Corn-soybean meal-based diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings (midds), and 0% corn oil.
[3]Control diet with 30% DDGS and 19% midds.
[4]Control diet with 3% corn oil.

Table 1-15. Main effects of diet form and diet type on growth performance and carcass yield, Exp. 2[1]

	Diet form			Diet Type				Probability, *P* <	
	Meal	Pellet	SEM	Control[2]	DDGS + Midds[3]	Corn Oil[4]	SEM	Diet Form	Diet Type
Initial BW, kg	48.5	48.5	0.601	48.5	48.5	48.5	0.736	0.997	0.996
d 0 to 87									
ADG, kg	0.93	0.96	0.008	0.95[ab]	0.92[a]	0.96[b]	0.009	0.038	0.009
ADFI, kg	2.60	2.52	0.024	2.56[b]	2.64[b]	2.48[a]	0.029	0.016	0.002
G:F	0.359	0.381	0.003	0.372[b]	0.349[c]	0.389[a]	0.003	0.001	0.001
Caloric efficiency, Mcal/kg									
ME	9.32	8.78	0.072	8.92[a]	9.31[b]	8.92[a]	0.088	0.001	0.005
NE	6.99	6.59	0.054	6.76	6.78	6.83	0.067	0.001	0.784
Final BW, kg	129.8	132.1	0.876	131.3[ab]	128.7[a]	132.98[b]	1.076	0.076	0.028
HCW, kg	97.0	98.6	0.703	98.4[b]	94.9[a]	100.1[b]	0.861	0.132	0.001
Carcass yield, %	74.73	74.60	0.178	74.95[b]	73.78[a]	75.27[b]	0.218	0.619	0.001

[1]A total of 288 pigs (PIC 327 × 1050, initially 48.5 kg BW) were used in an 87-d trial with 8 pigs per pen. There were 18 pens per diet form main effect and 12 pens per diet type main effect.

[2]Corn-soybean meal-based diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings (midds), and 0% corn oil.

[3]Control diet with 30% DDGS and 19% midds.

[4]Control diet with 3% corn oil.

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

Table 1-16. Interactive effects of diet form and diet type on belly fatty acid profile, Exp. 2[1]

	Diet form							Probability, *P* <		
	Meal			Pellet						
Item Diet type:	Control[2]	DDGS + Midds[3]	Corn Oil[4]	Control	DDGS + Midds	Corn Oil	SEM	Diet form × Type	Meal vs. Pellet	Diet Type
Myristic acid (C14:0), %	1.39	1.39	1.36	1.41	1.30	1.33	0.020	0.028	0.034	0.022
Palmitic acid (C16:0), %	23.62	22.16	22.48	23.20	22.27	22.27	0.152	0.239	0.177	0.001
Palmitoleic acid (C16:1), %	3.29	2.95	2.65	2.76	2.46	2.47	0.076	0.056	0.001	0.001
Margaric acid (C17:0), %	0.24	0.27	0.21	0.22	0.27	0.19	0.016	0.545	0.239	0.001
Stearic acid (C18:0), %	10.44	9.07	9.65	10.91	9.24	9.66	0.116	0.148	0.032	0.001
Oleic acid (C18:1n9c), %	46.66	42.56	42.55	44.99	41.66	42.31	0.239	0.019	0.001	0.001
Vaccenic acid (C18:1n7), %	0.93	0.84	0.63	0.73	0.64	0.61	0.048	0.130	0.001	0.001
Total C18:1 fatty acids[5], %	47.61	43.40	43.11	45.69	42.25	42.88	0.265	0.013	0.001	0.001
Linoleic acid (C18:2n6c), %	11.31	18.30	18.15	13.62	19.64	18.87	0.268	0.020	0.001	0.001
Total C18:2 fatty acids[6], %	11.94	19.13	18.93	14.31	20.53	19.68	0.274	0.021	0.001	0.001
α-Linolenic acid (C18:3n3), %	0.70	0.72	0.65	0.66	0.69	0.64	0.022	0.765	0.171	0.037
Eicosenoic acid (C20:1), %	0.43	0.71	0.69	0.53	0.77	0.73	0.016	0.181	0.001	0.001
Total SFA[7], %	35.69	32.89	33.70	35.74	33.07	33.45	0.202	0.545	0.958	0.001
Total MUFA[8], %	51.33	47.05	46.45	48.99	45.48	46.08	0.318	0.014	0.001	0.001
Total PUFA[9], %	12.60	19.77	19.49	14.92	21.16	20.23	0.263	0.019	0.001	0.001
UFA:SFA[10], ratio	1.79	2.03	1.96	1.79	2.02	1.98	0.017	0.486	0.885	0.001
PUFA:SFA[11], ratio	0.35	0.60	0.58	0.42	0.64	0.61	0.009	0.096	0.001	0.001
Iodine value, mg/g[12]	66.74	75.40	74.31	68.65	76.45	75.26	0.300	0.229	0.001	0.001

[1] All items calculated as a percentage of the total fatty acid content. Belly fat samples were collected from the ventral side of the belly along the navel edge between the 10th and the 12th rib

[2] Corn-soybean meal-based control diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings (midds), and 0% corn oil.

[3] Control diet with 30% DDGS and 19% midds.

[4] Control diet with 3% corn oil.

[5] Total C18:1 fatty acids = [% C18:1n9c] + [% C18:1n7]

[6] Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% 18:2, 10t12c] + [% C18:2, 9c11c] + [C18:2, 9t11t].

[7] Total saturated fatty acids = [% C14:0] + [% C15:0] + [% C16:0] + [% C17:0] + [% C18:0] + [% C20:0] + [% C21:0] + [% C22:0] + [% C 24:0].

[8] Total monounsaturated fatty acids = [% C14:1] + [% C15:1] + [% C16:1] + [% C17:1] + [% C18:1n9t] + [% C18:1n9c] + [% C18:1n7] + [% C20:1] + [% C24:1].

[9] Total polyunsaturated fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2 9c,11t] + [% C18:2 10t,12c] + [% C18:2 9c,11c] + [% C18:2 9t,11t] + [% C18:3n6] + [% C18:3n3].

[10] UFA:SFA ratio = [total MUFA + total PUFA] / total SFA.

[11] PUFA:SFA ratio = total PUFA / total SFA.

[12] Iodine value = [% C16:1] × 0.95 + [% C18:1] × 0.86 + [% C18:2] × 1.732 + [% C18:3] × 2.616 + [% C20:1] × 0.785.

Table 1-17. Main effects of diet form and diet type on belly fatty acid profile, Exp. 2[1]

	Diet form			Diet type				Probability, $P <$	
Item	Meal	Pellet	SEM	Control[2]	DDGS + Midds[3]	Corn Oil[4]	SEM	Meal vs. Pellet	Diet Type
Myristic acid (C14:0), %	1.38	1.35	0.012	1.40[b]	1.35[a]	1.35[a]	0.014	0.034	0.022
Palmitic acid (C16:0), %	22.75	22.58	0.088	23.41[b]	22.21[a]	22.37[a]	0.107	0.177	0.001
Palmitoleic acid (C16:1), %	2.96	2.56	0.044	3.03[b]	2.70[a]	2.56[a]	0.054	0.001	0.001
Margaric acid (C17:0), %	0.24	0.23	0.009	0.23[a]	0.27[b]	0.20[a]	0.011	0.239	0.001
Stearic acid (C18:0), %	9.72	9.94	0.067	10.67[c]	9.16[a]	9.66[b]	0.082	0.032	0.001
Oleic acid (C18:1n9c), %	43.92	42.99	0.138	45.83[b]	42.11[a]	42.43[a]	0.169	0.001	0.001
Vaccenic acid (C18:1n7), %	0.80	0.66	0.028	0.83[b]	0.74[b]	0.62[a]	0.034	0.001	0.001
Total C18:1 fatty acids[5], %	44.71	43.61	0.153	46.65[b]	42.83[a]	42.99[a]	0.188	0.001	0.001
Linoleic acid (C18:2n6c), %	15.92	17.38	0.155	12.47[a]	18.97[b]	18.51[b]	0.190	0.001	0.001
Total C18:2 fatty acids[6], %	16.67	18.17	0.158	13.12[a]	19.83[b]	19.30[b]	0.194	0.001	0.001
α-Linolenic acid (C18:3n3), %	0.69	0.67	0.013	0.68[a]	0.71[b]	0.65[a]	0.016	0.171	0.037
Eicosenoic acid (C20:1), %	0.61	0.68	0.009	0.48[b]	0.74[a]	0.71[a]	0.011	0.001	0.001
Total SFA[7], %	34.10	34.09	0.116	35.71[c]	32.98[a]	33.58[b]	0.142	0.958	0.001
Total MUFA[8], %	48.28	46.85	0.184	50.16[b]	46.27[a]	46.27[a]	0.225	0.001	0.001
Total PUFA[9], %	17.29	18.77	0.152	13.76[a]	20.46[c]	19.86[b]	0.186	0.001	0.001
UFA:SFA[10], ratio	1.93	1.93	0.010	1.79[a]	2.02[c]	1.97[b]	0.012	0.885	0.001
PUFA:SFA[11], ratio	0.51	0.55	0.005	0.39[a]	0.62[c]	0.59[b]	0.006	0.001	0.001
Iodine value, mg/g[12]	72.15	73.45	0.173	67.70[a]	75.93[c]	74.79[b]	0.212	0.001	0.001

[1] All items calculated as a percentage of the total fatty acid content. Belly fat samples were collected from the ventral side of the belly along the navel edge between the 10th and the 12th rib

[2] Corn-soybean meal-based control diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings (midds), and 0% corn oil.

[3] Control diet with 30% DDGS and 19% midds.

[4] Control diet with 3% corn oil.

[5] Total C18:1 fatty acids = [% C18:1n9c] + [% C18:1n7]

[6] Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% 18:2, 10t12c] + [% C18:2, 9c11c] + [C18:2, 9t11t].

[7] Total saturated fatty acids = [% C14:0] + [% C15:0] + [% C16:0] + [% C17:0] + [% C18:0] + [% C20:0] + [% C21:0] + [% C22:0] + [% C 24:0].

[8] Total monounsaturated fatty acids = [% C14:1] + [% C15:1] + [% C16:1] + [% C17:1] + [% C18:1n9t] + [% C18:1n9c] + [% C18:1n7] + [% C20:1] + [% C24:1].

[9] Total polyunsaturated fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2 9c,11t] + [% C18:2 10t,12c] + [% C18:2 9c,11c] + [% C18:2 9t,11t] + [% C18:3n6] + [% C18:3n3].

[10] UFA:SFA ratio = [total MUFA + total PUFA] / total SFA.

[11] PUFA:SFA ratio = total PUFA / total SFA.

[12] Iodine value = [% C16:1] × 0.95 + [% C18:1] × 0.86 + [% C18:2] × 1.732 + [% C18:3] × 2.616 + [% C20:1] × 0.785.

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

Table 1-18. Interactive effects of diet form and diet type on shoulder fatty acid profile, Exp. 2[1]

	Diet form									
	Meal			Pellet				Probability, $P <$		
Item Diet type:	Control[2]	DDGS + Midds[3]	Corn Oil[4]	Control	DDGS + Midds	Corn Oil	SEM	Diet form × Type	Meal vs. Pellet	Diet Type
Myristic acid (C14:0), %	1.35	1.28	1.25	1.29	1.22	1.19	0.021	0.956	0.002	0.001
Palmitic acid (C16:0), %	23.82	22.46	22.54	22.96	23.23	22.64	0.244	0.008	0.974	0.008
Palmitoleic acid (C16:1), %	2.58	2.21	2.04	2.13	1.96	1.84	0.058	0.100	0.001	0.001
Margaric acid (C17:0), %	0.28	0.33	0.27	0.30	0.27	0.24	0.013	0.028	0.064	0.004
Stearic acid (C18:0), %	11.64	10.04	10.45	11.81	10.10	10.49	0.196	0.940	0.579	0.001
Oleic acid (C18:1n9c), %	44.45	40.69	40.74	42.36	39.96	40.20	0.307	0.035	0.001	0.001
Vaccenic acid (C18:1n7), %	0.55	0.51	0.42	0.65	0.47	0.37	0.070	0.469	0.891	0.020
Total C18:1 fatty acids[5], %	44.87	41.05	40.93	42.76	40.25	40.37	0.301	0.033	0.001	0.001
Linoleic acid (C18:2n6c), %	12.96	19.65	19.71	16.08	20.01	20.38	0.246	0.001	0.001	0.001
Total C18:2 fatty acids[6], %	13.68	20.55	20.55	16.89	20.96	21.32	0.245	0.001	0.001	0.001
α-Linolenic acid (C18:3n3), %	0.74	0.73	0.69	0.75	0.70	0.67	0.018	0.461	0.366	0.005
Eicosenoic acid (C20:1), %	0.51	0.81	0.81	0.68	0.86	0.85	0.018	0.002	0.001	0.001
Total SFA[7], %	37.09	34.10	34.51	36.37	34.82	34.56	0.282	0.052	0.946	0.001
Total MUFA[8], %	47.96	44.07	43.78	45.57	43.07	43.06	0.329	0.038	0.001	0.001
Total PUFA[9], %	14.55	21.46	21.40	17.73	21.72	22.12	0.244	0.001	0.001	0.001
UFA:SFA[10], ratio	1.69	1.92	1.89	1.74	1.86	1.89	0.023	0.060	0.910	0.001
PUFA:SFA[11], ratio	0.39	0.63	0.62	0.49	0.62	0.64	0.010	0.001	0.001	0.001
Iodine value, mg/g)[12]	67.39	75.96	75.53	70.73	75.42	76.14	0.355	0.001	0.001	0.001

[1] All items calculated as a percentage of the total fatty acid content. Fat samples were collected from the shoulder of each pig approximately 5 cm dorsal to the medial ridge of the scapula

[2] Corn-soybean meal-based control diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings (midds), and 0% corn oil.

[3] Control diet with 30% DDGS and 19% midds.

[4] Control diet with 3% corn oil.

[5] Total C18:1 fatty acids = [% C18:1n9c] + [% C18:1n7]

[6] Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% 18:2, 10t12c] + [% C18:2, 9c11c] + [C18:2, 9t11t].

[7] Total saturated fatty acids = [% C14:0] + [% C15:0] + [% C16:0] + [% C17:0] + [% C18:0] + [% C20:0] + [% C21:0] + [% C22:0] + [% C 24:0].

[8] Total monounsaturated fatty acids = [% C14:1] + [% C15:1] + [% C16:1] + [% C17:1] + [% C18:1n9t] + [% C18:1n9c] + [% C18:1n7] + [% C20:1] + [% C24:1].

[9] Total polyunsaturated fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2 9c,11t] + [% C18:2 10t,12c] + [% C18:2 9c,11c] + [% C18:2 9t,11t] + [% C18:3n6] + [% C18:3n3].

[10] UFA:SFA ratio = [total MUFA + total PUFA] / total SFA.

[11] PUFA:SFA ratio = total PUFA / total SFA.

[12] Iodine value = [% C16:1] × 0.95 + [% C18:1] × 0.86 + [% C18:2] × 1.732 + [% C18:3] × 2.616 + [% C20:1] × 0.785.

Table 1-19. Main effects of diet form and diet type on shoulder fatty acid profile, Exp. 2[1]

	Diet form			Diet type				Probability, $P <$	
Item	Meal	Pellet	SEM	Control[2]	DDGS + Midds[3]	Corn Oil[4]	SEM	Meal vs. Pellet	Diet Type
Myristic acid (C14:0), %	1.29	1.23	0.012	1.32[b]	1.25[a]	1.22[a]	0.015	0.002	0.001
Palmitic acid (C16:0), %	22.94	22.95	0.141	23.39[b]	22.85[a]	22.59[a]	0.172	0.974	0.008
Palmitoleic acid (C16:1), %	2.27	1.98	0.033	2.36[c]	2.08[b]	1.94[a]	0.041	0.001	0.001
Margaric acid (C17:0), %	0.29	0.27	0.008	0.29[b]	0.30[b]	0.25[a]	0.010	0.064	0.004
Stearic acid (C18:0), %	10.71	10.80	0.113	11.72[c]	10.07[a]	10.47[b]	0.138	0.579	0.001
Oleic acid (C18:1n9c), %	41.96	40.84	0.177	43.41[b]	40.32[a]	40.47[a]	0.217	0.001	0.001
Vaccenic acid (C18:1n7), %	0.49	0.50	0.040	0.60[b]	0.49[ab]	0.39[a]	0.049	0.891	0.020
Total C18:1 fatty acids[5], %	42.28	41.13	0.174	43.81[a]	40.65[b]	40.65[b]	0.213	0.001	0.001
Linoleic acid (C18:2n6c), %	17.44	18.82	0.142	14.52[a]	19.83[b]	20.04[b]	0.174	0.001	0.001
Total C18:2 fatty acids[6], %	18.26	19.72	0.142	15.28[a]	20.75[b]	20.93[b]	0.174	0.001	0.001
α-Linolenic acid (C18:3n3), %	0.72	0.71	0.010	0.75[b]	0.72[ab]	0.68[a]	0.013	0.366	0.005
Eicosenoic acid (C20:1), %	0.71	0.80	0.011	0.60[a]	0.83[b]	0.83[b]	0.013	0.001	0.001
Total SFA[7], %	35.23	35.25	0.163	36.73[b]	34.46[a]	34.53[a]	0.200	0.946	0.001
Total MUFA[8], %	45.27	43.90	0.190	46.77[b]	43.57[a]	43.42[a]	0.233	0.001	0.001
Total PUFA[9], %	19.13	20.52	0.141	16.14[a]	21.59[b]	21.76[b]	0.172	0.001	0.001
UFA:SFA[10], ratio	1.83	1.83	0.013	1.71[a]	1.89[b]	1.89[b]	0.016	0.91	0.001
PUFA:SFA[11], ratio	0.55	0.58	0.006	0.44[a]	0.63[b]	0.63[b]	0.007	0.001	0.001
Iodine value, mg/g[12]	72.96	74.10	0.205	69.06[a]	75.69[b]	75.83[b]	0.251	0.001	0.001

[1] All items calculated as a percentage of the total fatty acid content. Fat samples were collected from the shoulder of each pig approximately 5 cm dorsal to the medial ridge of the scapula

[2] Corn-soybean meal-based control diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings (midds), and 0% corn oil.

[3] Control diet with 30% DDGS and 19% midds.

[4] Control diet with 3% corn oil.

[5] Total C18:1 fatty acids = [% C18:1n9c] + [% C18:1n7]

[6] Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% 18:2, 10t12c] + [% C18:2, 9c11c] + [C18:2, 9t11t].

[7] Total saturated fatty acids = [% C14:0] + [% C15:0] + [% C16:0] + [% C17:0] + [% C18:0] + [% C20:0] + [% C21:0] + [% C22:0] + [% C 24:0].

[8] Total monounsaturated fatty acids = [% C14:1] + [% C15:1] + [% C16:1] + [% C17:1] + [% C18:1n9t] + [% C18:1n9c] + [% C18:1n7] + [% C20:1] + [% C24:1].

[9] Total polyunsaturated fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2 9c,11t] + [% C18:2 10t,12c] + [% C18:2 9c,11c] + [% C18:2 9t,11t] + [% C18:3n6]

+ [% C18:3n3].

[10] UFA:SFA ratio = [total MUFA + total PUFA] / total SFA.

[11] PUFA:SFA ratio = total PUFA / total SFA.

[12] Iodine value = [% C16:1] × 0.95 + [% C18:1] × 0.86 + [% C18:2] × 1.732 + [% C18:3] × 2.616 + [% C20:1] × 0.785.

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

Chapter 2 - Effects of diet form and feeder adjustment on growth performance of nursery and finishing pigs

ABSTRACT

Three experiments were conducted to determine the effect of feeder adjustment and diet form on growth performance of nursery (Exp. 1 and 2) and finishing (Exp. 3) pigs. Treatments were arranged as 2 × 3 factorials with main effects of feeder adjustment and diet form. The 2 feeder adjustments were a narrow and wide feeder adjustment (minimum gap opening of 1.27 and 2.54 cm, respectively). The 3 diet forms were meal, poor-quality pellets (70% pellets and 30% fines for Exp. 1 and 2 and 50% pellets and 50% fines for Exp. 3), and screened pellets with minimal fines. There were no feeder adjustment × diet form interactions in any experiment. In Exp. 1, 210 pigs (initially 11.9 kg BW) were used in a 21-d trial with 7 pigs per pen and 5 pens per treatment. There were no differences in ADG, ADFI, or G:F due to feeder adjustment. Pigs fed the meal diet had increased ($P < 0.05$) ADG and ADFI compared with pigs fed the poor-quality or screened pellets. Pigs fed meal or poor-quality pellets had decreased ($P < 0.05$) G:F compared with pigs fed screened pellets. In Exp. 2, 1,005 nursery pigs (initially 14.1 kg BW) were used in a 28-d trial with 25 pigs per pen and 7 pens per treatment. Pigs fed from the narrow feeder adjustment had decreased ($P < 0.05$) ADG and ADFI compared to pigs fed from the wide adjustment, with no differences in G:F. Pigs fed the meal diet had decreased ($P < 0.05$) ADG compared with pigs fed poor-quality or screened pellets. Pigs fed meal or poor-quality pellets had decreased ($P < 0.05$) G:F compared to pigs fed screened pellets. In Exp. 3, 246 pigs (initially 56.8 kg BW) were used in a 69-d trial with 5 pens per treatment with 6 or 7 pigs per pen. Overall, ADFI decreased ($P < 0.05$) and G:F increased ($P < 0.05$) for pigs fed from the narrow adjusted feeders compared to the wide adjustment, with no differences in ADG due to feeder

adjustment. Overall, pigs fed meal diets tended to have decreased ($P < 0.10$) ADG and had decreased ($P < 0.05$) G:F compared to pigs fed screened pellets, with those fed poor-quality pellets intermediate. Feeding meal or poor-quality pellets increased ($P < 0.05$) ADFI compared to pigs fed screened pellets. In conclusion, feeding nursery pigs from a wide feeder gap may increase ADG and ADFI with no negative effects on G:F. For finishing pigs, reducing feeder gap reduced feed disappearance and improved G:F. In all experiments, the greatest G:F improvements from pelleting were observed when percentage of fines was minimized.

Key Words: feeder adjustment, growth, pellet quality, pig

INTRODUCTION

The importance of minimizing feed wastage has increased interest in feeder adjustment and the ideal feeder pan coverage. In finishing pigs, Myers et al. (2012) reported that wider feeder gap adjustments decreased G:F, attributed to increased feed wastage. Their percentage pan coverage recommendations for optimal growth performance decreased as BW range increased. Despite improvements in G:F with narrow feeder adjustments, providing too little pan coverage restricts access to feed and reduces weight gain of pigs (Smith et al., 2004; Duttlinger et al., 2009). The research on feeder gap management has been conducted using meal or crumbled diets, providing no information regarding feeder management of pelleted diets.

The growth performance benefits of feeding pelleted diets to swine have been known for decades (Baird, 1973). Wondra et al. (1995) reported a 4 to 6% increase in ADG and 7% improvement in G:F when pelleted diets were fed to finishing pigs compared to meal diets. However, the quality of the pellets has been shown to be an important aspect of the overall

response. Stark et al. (1993) observed that the feed efficiency benefit from pellets is related to the percentage fines in the diets. Compared to meal diets, feeding screened pellets with minimal fines to nursery pigs provided an 11% improvement in feed efficiency, while feeding pellets with 25% fines provided an 8% improvement. Similarly, they reported that finishing pig feed efficiency linearly worsened as percentage fines increased in the diet.

While feeder gap adjustment and pellet quality have been researched independently, no research has been conducted to investigate their relationship. We hypothesized that diets containing a high level of fines may require a narrower feeder gap adjustment to decrease wastage. Therefore, 3 experiments were conducted to determine the effects of feeder adjustment and diet form (meal vs poor or high quality pellets) on growth performance of nursery and finishing pigs.

MATERIALS AND METHODS

All experimental procedures and animal care were approved by the Kansas State University Institutional Animal Care and Use Committee.

Animals and housing

In Exp. 1, 210 nursery pigs (327 × 1050, PIC [Hendersonville, TN]; initially 11.9 kg BW) were used in a 21-d trial with 7 pigs were pen and 5 pens per treatment. The experiment was conducted in the nursery facility at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. All pens (1.52 m × 1.83 m) were equipped with a nipple waterer, wire-mesh floors, and a 3-hole, dry self-feeder (Smidley Mfg., Inc., Britt, IA). Each feeder hole was 13.6 cm in length with a 14.0 cm horizontal depth (measured from the front lip

to the back of the pan) and 6.4 cm vertical depth (measured from the bottom of the pan to the height of the feeder lip). Diets were manufactured and delivered in 22.7 kg bags. Feed was weighed and hand added to each pen as needed to provide *ad libitum* access.

In Exp. 2, a total of 1,005 nursery pigs (TR4 × Fast Genetics [Saskatoon, SK] × PIC L02, initially 14.1 kg BW) were used in a 28-d trial, with 25 pigs per pen and 7 pens per treatment. The trial was conducted at New Fashion Pork's nursery research facility in Buffalo Center, IA. All pens (1.83 m × 3.96 m) contained a nipple waterer and a 5-hole dry self-feeder. Each feeder hole was 15.2 cm in length with a 12.7 cm horizontal depth (measured from the front lip to the back of the pan) and 7.6 cm vertical depth (measured from the bottom of the pan to the height of the feeder lip). Diets were delivered in bulk and fed through bulk bins using a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded diets as specified.

In Exp. 3, 252 finishing pigs (327 × 1050, PIC; 56.8 kg BW) were used in a 69-d trial. There were 5 pens per treatment with 7 pigs and 1 replicate with 6 pigs per pen. The trial was conducted in the finishing pig facility at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. The facility was a totally enclosed, environmentally regulated, mechanically ventilated barn containing 36 pens (2.44 m × 3.05 m). The pens had adjustable gates facing the alleyway and allowed 0.93 m^2/pig. Each pen was equipped with a cup waterer and a single-sided, dry self-feeder (Farmweld, Teutopolis, IL) with 2 eating spaces located in the fence line. Each feeder hole was 35.6 cm in length with a 27.9 cm horizontal depth (measured from the front lip to the back of the pan) and 12.7 cm vertical depth (measured from the bottom of the pan to the height of the feeder lip). Pens were located over a completely slatted concrete floor with a 1.20-m pit underneath for manure storage. Similar to Exp. 2, diets were

delivered in bulk and fed through bulk bins using a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded diets as specified.

All pigs were provided with ad libitum access to feed and water. Pigs and feeders were weighed weekly for Exp. 1 and 2 and approximately every 2 weeks for Exp. 3 to calculate ADG, ADFI, and G:F. Caloric efficiency of pigs for all trials were determined using dietary ingredient values for ME and NE from NRC (2012). Caloric efficiency was calculated on a pen basis by multiplying total pen feed intake by dietary energy (Mcal/kg) and dividing by total pen gain.

Treatments and Diet Manufacturing

Similar treatments and procedures were used in all experiments. Pens were randomly allotted to 1 of 6 experimental treatments in a completely randomized design. Treatments were arranged in a 2 × 3 factorial with the main effects of feeder adjustment and diet form. The 2 feeder adjustment treatments consisted of a narrow adjustment (minimum gap opening of 1.27 cm) and a wide adjustment (minimum gap opening of 2.54 cm). The feeders were adjusted to the minimum gap setting, but the agitation plate could be moved upward to a maximum gap opening of 1.91 or 3.18 cm, respectively. The 3 diet form treatments consisted of meal, poor-quality pellets, and screened pellets with minimal fines. In the nursery trials (Exp. 1 and 2), the poor-quality pellets consisted of approximately 70% pellets and 30% fines. For the finishing trial (Exp. 3), the poor-quality pellets consisted of approximately 50% pellets and 50% fines.

Diets for Exp. 1 were prepared and pelleted at the K-State Grain Sciences and Industry Feed Mill in Manhattan, KS. Pelleted diets were manufactured using a 30 HP California Pellet Mill (Crawfordsville, IN) 1000 series “Master HD” model pellet mill. The pellet mill was equipped with a 31.75 mm thick die with 3.97 mm hole diameters. Prior to pelleting, feed was conditioned with steam at approximately 69.5°C. Diets for Exp. 2 and 3 were manufactured at

Hubbard Feeds in Atlantic, IA. All pelleted diets were processed with a Sprout Waldron Pellet Mill, model 300HP. The pellet mill was equipped with a 29.48 mm thick die with 4.5-mm hole diameters. Prior to pelleting, diets were conditioned with steam at 54.4°C for approximately 30 sec. In accordance with the capabilities of each feed mill, the desired level of fines in the poor-quality pellets were created by 2 different methods. For Exp. 1, pellets were manufactured and screened to remove and collect fines. After the screened pelleted diet was bagged, the fines were added back to the remaining pellets. The mixture of pellets and fines was then added to the mixer, and additional fines were created in the mixer by mechanical breakdown. For Exp. 2 and 3, the pellets were passed through the roller mill, rather than the mixer, to create the additional fines. The roller mill was a 2-high, single speed drive Roscamp Champion Roller Mill equipped with 20.32 cm rolls. To ensure the desired level of fines was achieved, feed samples were taken at the feeder during each experiment. Percentage fines (ASAE, 1987) were measured for all pelleted diets, with fines characterized as material that would pass through a #6 sieve (3,360 μm openings). All pellet quality measurements were analyzed at the K-State Grain Sciences and Industry Feed Mill.

Dietary ingredients were similar among all experiments and diets were formulated to contain identical ingredient compositions within each experiment (Table 1). In Exp. 1 and 2, diets were fed in 1 phase and were corn-soybean meal–based with 20% DDGS. Diets for Exp. 3 were corn-soybean meal–based and fed in 3 phases with decreasing nutrient concentrations in each phase. Phases 1 and 2 contained 20% DDGS and phase 3 contained 10% DDGS.

Feeder pan coverage scoring

For Exp. 1 and 2, a digital photo of each feeder pan was take on the last day (d 21 and 28, respectively) of each trial prior to weighing the pigs and feeders. For Exp. 3, photos were taken

at the conclusion of phases 1, 2, and 3 (d 22, 48, and 69, respectively). Each feeder pan picture was then scored by 5 individual evaluators and the mean for each feeder was calculated for percentage of pan coverage.

Statistical Analysis

Experimental data for both trials were analyzed using analysis of variance as a 2 × 3 factorial using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Pen was the experimental unit for all data analysis. Data analysis for all trials included main effects of 2 feeder adjustments, 3 diet forms, and their interaction as fixed effects. When a significant difference was found between diet forms, differences between treatments were determined using the PDIFF statement in SAS. Significant differences were declared at $P < 0.05$ and trends at $P < 0.10$.

RESULTS

Experiment 1

Percentage fine determination revealed that the poor-quality pellets contained 67% pellets and 33% fines; whereas the screened pelleted diet contained 97% pellets and 3% fines (Table 2). Representative pictures of mean pan coverage scores are provided in Figure 1. The narrow feeder adjustment pan coverage scores for the meal, poor-quality pellets, and screened pellets diets were 42, 46, and 37%, respectively (Table 3). The wide feeder adjustment pan coverage scores averaged 92, 98, and 93% for the meal, poor-quality pellets, and screened pellets diets, respectively.

No feeder gap adjustment × diet form interactions were observed for pig performance (Table 4). Overall (d 0 to 21), no differences were observed in ADG, ADFI, G:F, or caloric efficiency between pigs fed from feeders with the different adjustment settings (Table 5). Pigs fed the meal diet had increased ($P < 0.05$) ADG and ADFI compared with pigs fed the poor quality or screened pellets. Pigs fed screened pellets had improved ($P < 0.05$) G:F and caloric efficiency compared with pigs fed meal or poor-quality pellets.

Experiment 2

The poor-quality pellets contained 63% pellets and 37% fines; whereas the screened pelleted diet contained 95% pellets and 5% fines. The narrow feeder adjustment pan coverage scores for the meal, poor-quality pellets, and screened pellets diets were 52, 61, and 57%, respectively (Figure 2). The wide feeder adjustment pan coverage scores were 98, 99, and 97% for the meal, poor-quality pellets, and screened pellet diets, respectively.

No feeder gap adjustment × diet form interactions were observed for pig performance (Table 6). Overall (d 0 to 28), pigs fed from feeders with the wide feeder adjustment had increased ($P < 0.05$) ADG, ADFI, and poorer ($P < 0.05$) caloric efficiency (Table 7). Feed efficiency did not differ among pigs fed from the different feeder gap adjustments. Pigs fed screened pellets or poor-quality pellets had increased ($P < 0.05$) ADG compared with pigs fed the meal diet. No difference in ADFI was observed among pigs fed different diet forms. Similar to Exp. 1, pigs fed screened pellets had improved ($P < 0.05$) G:F and caloric efficiency compared with pigs fed meal or poor-quality pellets.

Experiment 3

For phase 1 (d 0 to 22), the phase 1 poor-quality pellets that were originally intended to contain 50% pellets and 50% fines actually contained 56% pellets and 44% fines. The screened pelleted diet was 92% pellets and 8% fines. The narrow feeder adjustment pan coverage scores for the meal, poor-quality pellets, and screened pellets diets were 31, 49, and 44%, respectively (Figure 3). The wide feeder adjustment pan coverage scores were 83, 96, and 86% for the meal, poor-quality pellets, and screened pellets diets, respectively.

No feeder adjustment × diet form interactions were observed during any of the dietary phases or for the overall study (Table 8). During phase 1, there was no difference in ADG among pigs fed from feeders with the different adjustment settings (Table 9). Pigs fed from feeders with the wide adjustment tended to have increased ($P < 0.10$) ADFI, which resulted in poorer ($P < 0.05$) G:F compared with pigs fed from feeders with the narrow adjustment. For diet form, ADG did not differ among treatments. Pigs fed the meal diet had increased ($P < 0.05$) ADFI compared with pigs fed the poor quality pellets or screened pellets. Diet form decreased G:F during phase 1, with pigs fed the meal diet having poorer ($P < 0.05$) G:F than pigs fed screened pellets, with those fed poor-quality pellets intermediate.

During phase 2 (d 22 to 48), the narrow feeder adjustment pan coverage scores for the meal, poor-quality pellets, and screened pellets diets were 62, 77, and 69%, respectively (Figure 4). The wide feeder adjustment pan coverage scores were 90, 99, and 92% for the meal, poor-quality pellets, and screened pellets diets, respectively. The phase 2 poor-quality pelleted diet contained 48% pellets and 52% fines; whereas the screened pelleted diet contained 92% pellets and 8% fines. There was no difference in ADG among pigs fed from feeders with the different adjustment settings. Pigs fed from feeders with the wide adjustment had increased ($P < 0.05$)

ADFI and decreased ($P < 0.05$) G:F compared with pigs fed from feeders with the narrow adjustment. For diet form, the pigs fed poor quality pellets unexpectedly tended to have increased ($P < 0.10$) ADG compared with pigs fed either of the other 2 diet form treatments. Pigs fed the meal or poor-quality pelleted diets had increased ($P < 0.05$) ADFI compared with pigs fed the screened pellets. The response to diet form on feed efficiency was identical to phase 1, in which pigs fed the screened pellets had the best ($P < 0.05$) G:F, pigs fed the meal diet had the poorest G:F, and pigs fed poor-quality pellets were intermediate.

The phase 3 (d 48 to 69) narrow feeder adjustment pan coverage scores for the meal, poor-quality pellets, and screened pellets diets were 89, 93, and 92%, respectively (Figure 5). The wide feeder adjustment pan coverage scores were 95, 99, and 96% for the meal, poor-quality pellets, and screened pellet diets, respectively. The phase 3 poor-quality pellets contained 45% pellets and 55% fines, whereas the screened pelleted diet was 90% pellets and 10% fines. There was no difference in ADG, ADFI, or G:F between pigs fed from feeders with the different adjustment settings during the final phase, although the numerical trends for ADFI and G:F were similar to previous phases. For diet form, pigs fed the meal diet had decreased ($P < 0.05$) ADG compared with pigs fed either of the pelleted diets, and pigs fed the high quality pellets diet had decreased ($P < 0.05$) ADFI compared with pigs fed the meal or poor-quality pellets. Similar to the previous 2 periods, pigs fed the screened, high quality pellets had the best ($P < 0.05$) G:F, pigs fed the meal diet had the poorest G:F, and pigs fed poor-quality pellets were intermediate.

Overall (d 0 to 69), feeder adjustment had no effect on ADG. Responses from phases 1 and 2 carried over into the overall data, resulting in decreased ($P < 0.05$) ADFI and improved ($P < 0.05$) G:F and caloric efficiency in pigs fed from the narrow adjusted feeders. Pigs fed meal diets had decreased ($P < 0.05$) ADG compared with pigs fed the screened pelleted diets, with

pigs fed poor-quality pellets intermediate. Feeding screened pellets resulted in decreased ($P < 0.05$) ADFI compared with pigs fed poor-quality pellets or meal diets. Consistent with all 3 phases, pigs fed screened pellets had improved ($P < 0.05$) G:F and caloric efficiency compared with pigs fed the meal diet, and those fed poor-quality pellets were intermediate.

DISCUSSION

Unexpectedly, there were no feeder adjustment × diet form interactions observed in any of the experiments. We expected that a narrow feeder adjustment would be more beneficial for feeders with poor-quality pellets by providing better management of the fines. As evidenced by the photographs, the feeders containing poor-quality pellets had a large build-up of fines in the edges of the pans. Despite our hypothesis, we found that the responses to feeder adjustment and diet form were independent. Other studies have observed that the response to pelleting varies among trials. Hedemann et al. (2005) found that no differences were observed in ADG or ADFI when feeding meal or pelleted diets to growing pigs; however, Wondra et al. (1995) reported that feeding pelleted diets resulted in a 4 to 6% improvement in ADG compared to feeding meal. Myers et al. (2013) also observed discrepancies in growth performance response to diet form and attributed the differences to pellet quality. The authors concluded that feeding high-quality pellets improved growth performance compared to meal, but when pellet quality was poor there were no benefits in feed efficiency from pelleting.

Despite variation in ADG and ADFI, our experiments agree that the greatest improvements in feed efficiency were observed from pigs fed screened pellets with minimal fines. Stark et al. (1993) found that feeding screened pellets to nursery pigs provided an 11% improvement in feed efficiency compared to feeding meal, whereas feeding pellets with 25%

fines provided an 8% improvement. We observed that feeding screened pellets improved G:F by approximately 5% in Exp. 1 and 2. For Exp. 3, pigs fed the meal diet had the poorest G:F, pigs fed screened pellets had the best G:F, and pigs fed poor-quality pellets were intermediate. Feeding the poor-quality pelleted diet provided approximately 6% improvement in G:F compared to feeding the meal diet. Wondra et al. (1995) and De Jong et al. (2013) reported similar improvements of 7 and 6%, respectively, when finishing pigs were fed pelleted diets compared to meal. However, in Exp. 3, finishing pigs fed screened pellets had a much greater improvement of 14% in G:F when compared to pigs fed meal.

The poor-quality pelleted diet contained approximately 50% pellets and 50% fines, but when the photographs of feeders with poor-quality pellets were evaluated, there appeared to be much greater than 50% fines in the pan. We believe that pigs sorted through the feed with a preference for the pelleted portion rather than the fines leading to the visual increase in fines in the feeder relative to pellets. This may have led to increased wastage of fines, contributing to poorer feed efficiency compared to feeding screened pellets with minimal fines. Furthermore, data from Jensen and Becker (1965) supports the theory that the improvement in feed efficiency from pelleting is highly related to providing the diet in a pelleted physical form and not necessarily from processes occurring during pellet manufacturing. In a series of 3 experiments, the authors reported that pigs fed diets in pellet form averaged an 8% improvement in G:F compared to pigs fed diets that were pelleted, reground, and then fed in meal form. The combination of data confirms previous research from Stark et al. (1993) that feeding pelleted diets improves feed efficiency, but the magnitude of improvement was greatest when the percentage of fines in the diet was minimized. Although the magnitude of response may vary,

our 3 experiments agree that the percentage of fines in the diets must be minimized to obtain maximum benefits to feed efficiency from pelleting.

Smith et al. (2004) reported that during a 42-d nursery experiment, feeding pigs from a wider feeder adjustment resulted in increased BW gain at the conclusion of the trial, but differences in ADG only occurred in the last 21 d of their trial. The varying response between the current experiments may be related to experiment duration or differences in university (Exp. 1) versus field (Exp. 2) research conditions. The feeders in the university setting allowed for approximately 2.33 pigs per feeder hole, while the feeders in the commercial setting allowed for 5 pigs per feeder hole. In addition, the length of the feeder pans allowed for 5.81 and 3.05 cm of eating space per pig in the university and commercial settings, respectively. Therefore, there was more competition for eating space in the commercial pens. This increase in competition may have been mitigated by the increased feeder pan coverage from the wide adjusted feeders. Feeding pigs from a wide feeder adjustment most likely made feed more accessible and allowed for pigs to spend less time at the feeder, thus, contributing to the increased ADG and ADFI observed in the commercial setting. For G:F, both experiments agree that feeder adjustment did not significantly influence feed efficiency. This is in agreement with Smith et al., (2004) who found that there were no differences in G:F when nursery pigs were fed from feeders with pan coverage ranging from 6 to 93%. The combined results suggest that feeding nursery pigs from a wide feeder gap may provide benefits in ADG and ADFI with no negative effects on feed efficiency. These results were unexpected, because the feeder pan was almost completely covered with the wide feeder adjustment and feed wastage was expected. We recognize that different feeder designs may influence this response; however, with feeders used in the current

experiment and by Smith et al. (2004), excessive feed in the pan did not appear to result in additional feed wastage.

The present data in finishing pigs showed that feeder adjustment did not influence gain. Conversely, Myers et al. (2012) reported that from 41 to 68 kg BW, providing 28% pan coverage limited access to feed and decreased ADG compared to pigs fed from feeders with 58 or 75% pan coverage. Similarly, Duttlinger et al. (2009) found that 24% pan coverage restricted feed intake and limited growth of finishing pigs. The lack of ADG response in the current trial may be due to the relatively high feeder pan coverage on the narrow feeder adjustment, which averaged a minimum of 41% coverage during phase 1. At the same feeder setting, feeder pan coverage scores increased over time for the narrow feeder setting. Increasing pan coverage further with the wide adjustment increased feed wastage and resulted in poorer feed efficiency during phase 1, 2, and for the overall trial. Thus, monitoring feeder gap opening to properly manage feeder pan coverage can help minimize feed wastage and improve feed efficiency in finishing pigs. This result is in agreement with Myers et al. (2012), suggesting that decreased feeder gap opening should be used for feeding heavier weight pigs.

Caloric efficiencies were also determined for all experiments, which is a commonly used calculation for estimating the utilization of dietary energy fed to pigs. Caloric efficiency was calculated on a pen basis by multiplying total pen feed intake by dietary energy (Mcal/kg) and dividing by total pen gain. Improvements in caloric efficiency for pigs fed from the narrow feeder adjustment were observed in Exp. 2 and 3, but not Exp. 1. In Exp. 1, pigs fed from different feeder adjustments had similar growth performance and all diets equal in energy, thus, explaining why no differences in caloric efficiency were observed. However, in Exp. 2, the increased BW gain and feed intake in pigs fed from the wide adjusted feeders resulted in poorer

caloric efficiency. Although caloric efficiency is most commonly used as a method to estimate the energy digestibility of diets, the observed differences in Exp. 3 between pigs fed from different feeder adjustments is most likely not due to improved energy digestibility. Rather, these differences were a result of increased feed wastage from pigs fed from the wide adjusted feeders, thus, the dietary energy within the feed was also wasted and not consumed by the pigs. In addition, pigs fed screened pelleted diets had the greatest improvements in caloric efficiency in all of the current experiments. Feeding pelleted diets has been shown to decrease feed wastage (Hanrahan, 1984) and increased nutrient digestibility (Wondra et al., 1995). The caloric efficiency responses from feeding pelleted diets observed in the current experiments support the previous findings, and were likely caused by the combination of decreased feed wastage and improved nutrient digestibility from feeding pelleted diets.

In summary, there were no feeder adjustment × diet form interactions. Results from Exp. 1 and 2 suggest that feeding nursery pigs from a wide feeder gap may provide benefits in ADG and ADFI; however, feeder adjustment appeared to have little influence on feed wastage for nursery pigs. In contrast, reducing feeder gap width and leading to less feeder pan coverage for finishing pigs allowed for decreased feed wastage and improved feed efficiency, with no effect on ADG. In all experiments, feeding pelleted diets improved G:F and caloric efficiency, but the improvement was greatest when percentage of fines was minimized.

LITERATURE CITED

ASAE. 1987. Wafers, pellets, and crumbles – definitions and methods for determining density, durability, and moisture content. ASAE Standard S269.3, Agricultural Engineers Yearbook of Standards. p 318. Am. Soc. Agric. Biol. Eng., St. Joseph, MI.

Baird, D. M. 1973. Influence of pelleting swine diets on metabolizable energy, growth and carcass characteristics. J. Anim. Sci. 36:516-521.

De Jong, J. A., J. M. DeRouchey, M. D. Tokach, R. D. Goodband, S. S. Dritz, J. L. Nelssen, and C. Hastad. 2013. Effects of corn particle size, complete diet grinding, and diet form on pig growth performance, caloric efficiency, and carcass characteristics. J. Anim. Sci. 91 (Suppl. 2):216. (Abstr.)

De Jong, J. A., J. M. DeRouchey, M. D. Tokach, R. D. Goodband, S. S. Dritz, and C. W. Hastad. 2014a. Effects of corn particle size, complete diet grinding, and diet form on 11- to 20-kg nursery pig growth performance and caloric efficiency. J. Anim. Sci. 92 (Suppl. 2):133. (Abstr.)

De Jong, J. A., J. M. DeRouchey, M. D. Tokach, R. D. Goodband, and S. S. Dritz. 2014b. Effects of fine grinding corn or dried distillers grains with solubles (DDGS) and diet form on growth performance and caloric efficiency of 11- 22-kg nursery pigs. J. Anim. Sci. 92 (Suppl. 2):355. (Abstr.)

Duttlinger, A. W., S. S. Dritz, M. D. Tokach, J. M. DeRouchey, J. L. Nelssen, and R. D. Goodband. 2009. Effects of feeder adjustment on growth performance of finishing pigs. J. Anim. Sci. 87 (Suppl. 3):184. (Abstr.)

Hedemann, M. S., L. L. Mikkelsen, P. J. Naughton, and B. B. Jensen. 2005. Effect of feed particle size and feed processing on morphological characteristics in the small and large intestine of pigs and on adhesion of Salmonella enterica serovar Typhimurium DT12 in the ileum in vitro. J. Anim. Sci. 83:1554-1562.

Jensen, A. H., and D. E. Becker. 1965. Effect of pelleting diets and dietary components on the performance of young pigs. J. Anim. Sci. 24:392-397.

Myers, A. J., R. D. Goodband, M. D. Tokach, S. S. Dritz, J. M. DeRouchey, and J. L. Nelssen. 2012. The effects of feeder adjustment and trough space on growth performance of finishing pigs. J. Anim. Sci. 90:4576-4582.

Myers, A. J., R. D. Goodband, M. D. Tokach, S. S. Dritz, J. M. DeRouchey, and J. L. Nelssen. 2013. The effects of diet form and feeder design on growth performance of finishing pigs. J. Anim. Sci. 91:3420-3428.

NRC. 2012. Nutrient Requirements of Swine. 11th rev. ed. Natl. Acad. Press, Washington, DC.

Smith, L. F., A. D. Beaulieu, J. F. Patience, H. W. Gonyou, and R. D. Boyd. 2004. The impact of feeder adjustment and group size-floor space allowance on the performance of nursery pigs. J. Swine Health Prod. 12:111-118.

Stark, C. R., K. C. Behnke, J. D. Hancock, and R. H. Hines. 1993. Pellet quality affects growth performance of nursery and finishing pigs. In: Proc. Swine Day, Stn. Rep. Prog. 695, Manhattan, KS. p. 71-74.

Wondra, K. J., J. D. Hancock, K. C. Behnke, R. H. Hines, and C. R. Stark. 1995. Effects of particle size and pelleting on growth performance, nutrient digestibility, and stomach morphology in finishing pigs. J. Anim. Sci. 73:757-763.

TABLES

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

			Exp. 3		
Item	Exp. 1	Exp. 2	Phase 1	Phase 2	Phase 3
Ingredient, %					
Corn	42.78	48.30	59.75	62.87	75.41
Soybean meal, 46.5% CP	30.95	27.10	17.05	14.00	11.65
Dried distillers grains with solubles	20.00	20.00	20.00	20.00	10.00
Soybean oil	3.00	---	---	---	---
Choice white grease	---	1.30	1.35	1.35	1.35
Monocalcium P, 21% P	0.60	0.60	---	---	---
Limestone	1.25	0.87	1.01	0.99	0.85
Salt	0.35	0.50	0.35	0.35	0.35
Trace mineral premix[1]	0.150	0.075	0.100	0.100	0.100
Vitamin premix[2]	0.250	0.030	0.030	0.030	0.030
Copper sulfate	---	0.066	---	---	---
Selenium, 0.2% Se	---	---	0.015	0.015	0.015
L-Lys·HCl	0.375	0.402	0.300	0.250	0.200
DL-Met	0.060	---	---	---	---
Met hydroxyl analog	---	0.120	---	---	---
L-Thr	0.070	0.092	---	---	---
Phytase[3]	0.165	0.040	0.041	0.041	0.041
Antibiotic[4]	---	0.400	---	---	---
AMMO Curb[5]	---	0.100	---	---	---
Total	100.0	100.0	100.0	100.0	100.0
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lys	1.30	1.20	0.90	0.79	0.67
Ile:Lys	64	62	68	71	71
Met:Lys	33	34	32	35	35
Met + Cys:Lys	58	58	62	68	69
Thr:Lys	62	62	55	64	64
Trp:Lys	17.6	18	18	19	19
Val:Lys	73	73	83	88	88
Total Lys, %	1.50	1.35	1.04	0.92	0.77
ME, kcal/kg	3,468	3,309	3,351	3,352	3,358
NE, kcal/kg	2,306	2,229	2,477	2,053	2,556
CP, %	23.9	21.9	17.7	16.5	13.7
Ca, %	0.71	0.68	0.48	0.47	0.40
P, %	0.60	0.59	0.42	0.40	0.35
Available P, %	0.43	0.31	0.26	0.25	0.25

[1]For Exp. 1, 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. For Exp. 2 and 3, provided per kilogram of premix: 53.3 g Mn from manganese sulfate and manganous oxide, 134 g Fe from iron sulfate, 160 g Zn from zinc sulfate, 13.3 g Cu from copper sulfate, and 1,370 mg I from calcium iodate.

[2]For Exp. 1, 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}. For Exp. 2 and 3, provided per kilogram of premix: 22,046,244 IU vitamin A; 3,968,324 IU vitamin D_3; 97,003 IU vitamin E; 10,288 mg vitamin K; 13,228 mg riboflavin; 61,729 mg pantothenic acid; 79,366 mg niacin; and 88 mg vitamin B_{12}.

[3]For Exp. 1, Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 992 phytase units (FTU)/kg, with a release of 0.13% available P. For Exp. 2 and 3, Natuphos 2500 (BASF Corporation, Florham Park, NJ), provided 992 FTU/kg, with a release of 0.12% available P.

[4]Chlortetracycline (CTC-50).

[5]Propionic acid-based mold inhibitor (Kemin Industries Inc., Des Moines, IA).

Table 2-2. Percentage fines of pelleted diets[1]

Item	Poor-quality pellet	Screened pellet
Percentage fines[2]		
Experiment 1	33	3
Experiment 2	37	5
Experiment 3		
Phase 1	44	8
Phase 2	52	8
Phase 3	55	10

[1] Feed samples were taken at the feeder for all trials. For Exp. 1 and 2, samples were pooled throughout the entire trial. For Exp. 3, samples were taken and pooled within each phase. All samples were run in duplicate for percentage fines determination.
[2] Fines were characterized as material that would pass through a #6 sieve (3,360 μm openings).

Table 2-3. **Influence of feeder adjustment and diet form on pan coverage**

	Minimum feeder gap opening					
	1.27 cm			2.54 cm		
Item	Meal	Poor-quality pellet[1]	Screened pellet	Meal	Poor-quality pellet	Screened pellet
Pan coverage[2], %						
Experiment 1	42	46	37	92	98	93
Experiment 2	52	61	57	98	99	97
Experiment 3						
Phase 1	31	49	44	83	96	86
Phase 2	62	77	69	90	99	92
Phase 3	89	93	92	95	99	96

[1] The poor quality pelleted diet consisted of approximately 70% pellets and 30% fines for Exp. 1 and 2 and 50% pellets and 50% fines for Exp. 3.
[2] Pictures were taken of feeder pan coverage on d 21 and 28 for Exp. 1 and 2, respectively. For Exp. 3, pictures were taken of pan coverage at the conclusion of each phase (d 22, 48, and 69). The feeder pan pictures were then scored by a panel of 5 for percentage of pan coverage.

Table 2-4. Interactive effects of diet form and feeder adjustment on nursery pig growth performance, Exp. 1[1]

	Minimum feeder gap opening									
	1.27 cm			2.54 cm				Probability, *P* <		
	Meal	Poor-quality pellet	Screened pellet	Meal	Poor-quality pellet	Screened pellet	SEM	Diet form × feeder adjustment	Feeder adjustment	Diet form
d 0 to 21										
ADG, g	611	593	591	646	592	594	9.614	0.138	0.134	0.001
ADFI, g	909	873	843	967	877	847	19.66	0.300	0.177	0.001
G:F	0.673	0.680	0.702	0.670	0.675	0.702	0.010	0.967	0.727	0.010
Caloric efficiency, Mcal/kg										
ME	5.16	5.10	4.94	5.19	5.14	4.94	0.071	0.966	0.733	0.010
NE	3.43	3.39	3.29	3.45	3.42	3.29	0.048	0.965	0.733	0.010
BW, kg										
d 0	11.9	11.9	11.9	11.9	11.9	11.9	0.205	0.793	0.648	0.800
d 21	24.7	24.3	24.3	25.5	24.3	24.4	0.316	0.242	0.222	0.611

[1] A total of 210 nursery pigs (PIC 1050 × 327) were used with 7 pigs per pen and 5 pens per treatment.

Table 2-5. Main effects of feeder adjustment and diet form on growth performance of nursery pigs, Exp. 1[1]

	Feeder adjustment			Diet form				Probability, $P <$	
	1.27 cm	2.54 cm	SEM	Meal	Poor-quality pellet	Pellet	SEM	Feeder adjustment	Diet form
d 0 to 21									
ADG, g	599	611	5.55	629[a]	593[b]	593[b]	9.35	0.134	0.001
ADFI, g	875	897	11.35	938[a]	875[b]	845[b]	13.90	0.177	0.001
G:F	0.685	0.682	0.006	0.672[b]	0.678[b]	0.702[a]	0.007	0.727	0.010
Caloric efficiency, Mcal/kg									
ME	5.07	5.09	0.041	5.17[b]	5.12[b]	4.94[a]	0.051	0.733	0.010
NE	3.37	3.38	0.027	3.44[b]	3.40[b]	3.29[a]	0.034	0.733	0.010
BW, kg									
d 0	11.9	11.9	0.163	11.9	11.9	11.9	0.199	0.648	0.800
d 21	24.5	24.7	0.274	25.1	24.9	24.4	0.299	0.222	0.611

[a,b] Means for diet form with different superscripts within row significantly differ, $P < 0.05$.

[1] A total of 210 nursery pigs (PIC 1050 × 327) were used with 7 pigs per pen. For the main effect of feeder adjustment, there were 15 pens (replications) per treatment. For the main effect of diet form there were 10 (replications) pens per treatment.

Table 2-6. Interactive effects of diet form and feeder adjustment on nursery pig growth performance, Exp. 2[1]

	Minimum feeder gap opening									
	1.27 cm			2.54 cm				Probability, *P* <		
	Meal	Poor-quality pellet	Screened pellet	Meal	Poor-quality pellet	Screened pellet	SEM	Diet form × feeder adjustment	Feeder adjustment	Diet form
d 0 to 28										
ADG, g	689	712	721	717	735	739	9.35	0.883	0.020	0.026
ADFI, g	1,093	1,116	1,089	1,139	1,157	1,116	20.13	0.889	0.025	0.252
G:F	0.631	0.638	0.663	0.629	0.635	0.663	0.010	0.944	0.703	0.007
Caloric efficiency, Mcal/kg										
ME	5.28	5.20	5.05	5.47	5.29	5.05	0.052	0.210	0.043	0.001
NE	3.56	3.50	3.40	3.68	3.56	3.40	0.035	0.209	0.043	0.001
BW, kg										
d 0	14.2	14.1	142	14.2	14.1	14.1	0.104	0.996	0.929	0.984
d 28	33.4	34.1	34.3	34.2	34.7	34.8	0.224	0.867	0.024	0.048

[1] A total of 1,005 nursery pigs (Fast × PIC sows × TR4 boars) were used, with 25 pigs per pen and 7 pens per treatment.

Table 2-7. Main effects of feeder adjustment and diet form on growth performance of nursery pigs, Exp. 2[1]

	Feeder adjustment			Diet form				Probability, *P* <	
	1.27 cm	2.54 cm	SEM	Meal	Poor-quality pellet	Pellet	SEM	Feeder adjustment	Diet form
d 0 to 28									
ADG, g	708	730	8.65	703[a]	726[b]	730[b]	8.02	0.020	0.026
ADFI, g	1,098	1,139	18.55	1,116	1,134	1,102	16.24	0.025	0.252
G:F	0.645	0.641	0.008	0.630[b]	0.640[b]	0.663[a]	0.007	0.703	0.007
Caloric efficiency, Mcal/kg									
ME	5.18	5.27	0.030	5.37[c]	5.24[b]	5.05[a]	0.037	0.043	0.001
NE	3.49	3.55	0.020	3.62[c]	3.53[b]	3.40[a]	0.025	0.043	0.001

Table 2-8. Interactive effects of diet form and feeder adjustment on finishing pig growth performance, Exp. 3[1]

	Minimum feeder adjustment										
	1.27 cm			2.54 cm				Probability, *P* <			
BW, kg	Meal	Poor-quality pellet	Screened pellet	Meal	Poor-quality pellet	Screened pellet	SEM	Diet form × feeder adjustment	Feeder adjustment	Diet form
d 0	14.2	14.1	0.088	14.2	14.1	14.1	0.081	0.929	0.984	
d 28	34.0	34.6	0.157	33.8	34.4	34.6	0.147	0.024	0.048	
d 0 to 22										
ADG, kg	0.97	0.94	1.00	0.98	0.96	0.99	0.029	0.880	0.611	0.319
ADFI, kg	2.30	2.13	2.16	2.40	2.29	2.20	0.069	0.662	0.069	0.039

[a,b] Means for diet form with different superscripts within row significantly differ, $P < 0.05$.

[1] A total of 1,005 nursery pigs (Fast × PIC sows × TR4 boars) were used with 25 pigs per pen. For the main effect of feeder adjustment, there were 21 pens (replications) per treatment. For the main effect of diet form, there were 14 pens (replications) per treatment.

G:F	0.422	0.441	0.462	0.408	0.420	0.451	0.007	0.765	0.016	0.001
d 22 to 48										
ADG, kg	0.98	1.05	1.01	1.02	1.05	1.02	0.021	0.525	0.280	0.056
ADFI, kg	2.69	2.62	2.48	2.89	2.85	2.53	0.076	0.490	0.017	0.002
G:F	0.364	0.402	0.407	0.357	0.369	0.403	0.008	0.130	0.030	0.001
d 48 to 69										
ADG, kg	0.91	1.00	1.01	0.94	0.98	1.00	0.032	0.742	0.934	0.041
ADFI, kg	3.26	3.32	3.10	3.56	3.40	3.09	0.109	0.340	0.173	0.016
G:F	0.279	0.300	0.324	0.266	0.288	0.323	0.009	0.756	0.219	0.001
d 0 to 69										
ADG, kg	0.95	0.99	1.00	0.98	1.00	1.00	0.019	0.722	0.463	0.162
ADFI, kg	2.74	2.67	2.56	2.93	2.84	2.59	0.072	0.515	0.033	0.004
G:F	0.349	0.374	0.392	0.337	0.353	0.387	0.006	0.450	0.020	0.001
Caloric efficiency, Mcal/kg										
ME	9.64	8.98	8.56	10.00	9.50	8.66	0.178	0.514	0.030	0.001
NE	6.75	6.29	6.00	7.01	6.64	6.07	0.125	0.534	0.034	0.001
BW, kg										
d 0	56.8	56.8	56.8	56.8	56.7	56.8	1.188	0.999	0.994	0.999
d 22	78.1	78.2	78.7	78.6	77.9	78.7	1.510	0.965	0.932	0.914
d 48	103.5	105.6	105.4	105.0	105.8	105.3	1.860	0.893	0.735	0.736
d 69	122.6	127.2	126.5	124.7	126.3	126.2	2.119	0.753	0.845	0.289

[1] A total of 246 finishing pigs (PIC 327 × 1050) were used. There were 5 pens per treatment with 7 pigs and 1 replicate with 6 pigs per pen.

Table 2-9. Main effects of feeder adjustment and diet form on growth performance of finishing pigs, Exp. 3[1]

	Feeder adjustment			Diet form				Probability, $P <$	
	1.27 cm	2.54 cm	SEM	Meal	Poor-quality pellet	Pellet	SEM	Feeder adjustment	Diet form
d 0 to 22									
ADG, kg	0.97	0.98	0.017	0.97	0.95	0.99	0.021	0.611	0.319
ADFI, kg	2.19	2.30	0.040	2.35[a]	2.21[b]	2.18[b]	0.049	0.069	0.039
G:F	0.442	0.427	0.004	0.415[a]	0.431[b]	0.457[c]	0.005	0.016	0.001
d 22 to 48									
ADG, kg	1.01	1.03	0.012	1.00[a]	1.05[b]	1.01[a]	0.015	0.280	0.056
ADFI, kg	2.60	2.76	0.044	2.79[a]	2.74[a]	2.51[b]	0.054	0.017	0.002
G:F	0.391	0.376	0.004	0.360[a]	0.385[b]	0.405[c]	0.005	0.030	0.001
d 48 to 69									
ADG, kg	0.97	0.97	0.018	0.92[a]	0.99[b]	1.00[b]	0.022	0.934	0.041
ADFI, kg	3.23	3.35	0.063	3.41[a]	3.36[a]	3.10[b]	0.077	0.173	0.016
G:F	0.301	0.292	0.005	0.273[a]	0.294[b]	0.323[c]	0.006	0.219	0.001
d 0 to 69									
ADG, kg	0.98	1.00	0.011	0.97[a]	0.99[ab]	1.00[b]	0.014	0.463	0.162
ADFI, kg	2.66	2.79	0.042	2.84[a]	2.75[a]	2.58[b]	0.051	0.033	0.004
G:F	0.371	0.359	0.003	0.343[a]	0.363[b]	0.390[c]	0.004	0.020	0.001
Caloric efficiency, Mcal/kg									
ME	9.06	9.36	0.103	9.82[a]	9.24[b]	8.61[c]	0.126	0.030	0.001
NE	6.35	6.57	0.072	6.88[a]	6.47[b]	6.03[c]	0.088	0.034	0.001
BW, kg									
d 0	56.8	56.8	0.686	56.8	56.8	56.8	0.840	0.994	0.999
d 22	78.3	78.4	0.872	78.3	78.1	78.7	1.068	0.932	0.914
d 48	104.8	105.4	1.074	104.3	105.7	105.4	1.316	0.735	0.736
d 69	125.4	125.8	1.223	123.6	126.8	126.4	1.498	0.845	0.289

[a,b] Means for diet form with different superscripts within row significantly differ, $P < 0.05$.

[1] A total of 246 finishing pigs (PIC 327 × 1050) were used. For the main effect of feeder adjustment, there were 15 pens per treatment with 7 pigs and 3 replicates with 6 pigs per pen. For the main effect of diet form, there were 10 pens per treatment with 7 pigs and 2 replicates with 6 pigs per pen.

FIGURES

Figure 2-1.

Experiment 1 narrow (top row) and wide feeder (bottom row) adjustments. The narrow adjustment feeders (minimum feeder gap of 1.27 cm with a maximum gap of 1.91 cm) averaged 42, 46, and 37% feeder pan coverage for meal, poor-quality pellets, and screened pellets, respectively. The wide adjustment feeders (minimum feeder gap of 2.54 cm with a maximum gap of 3.18 cm) averaged 92, 98, and 93% feeder pan coverage for meal, poor-quality pellets, and screened pellets, respectively.

Figure 2-2.

Experiment 2 narrow (top row) and wide feeder (bottom row) adjustments. The narrow adjustment feeders (minimum feeder gap of 1.27 cm with a maximum gap of 1.91 cm) averaged 52, 61, and 57% feeder pan coverage for meal, poor-quality pellets, and screened pellets, respectively. The wide adjustment feeders (minimum feeder gap of 2.54 cm with a maximum gap of 3.18 cm) averaged 98, 99, and 97% feeder pan coverage for meal, poor-quality pellets, and screened pellets, respectively.

Figure 2-3.

Experiment 3, phase 1 narrow (top row) and wide feeder (bottom row) adjustments. The narrow adjustment feeders (minimum feeder gap of 1.27 cm with a maximum gap of 1.91 cm) averaged 31, 49, and 44% feeder pan coverage for meal, poor-quality pellets, and screened pellets, respectively. The wide adjustment feeders (minimum feeder gap of 2.54 cm with a maximum gap of 3.18 cm) averaged 83, 96, and 86% feeder pan coverage for meal, poor-quality pellets, and screened pellets, respectively.

Figure 2-4.

Experiment 3, phase 2 narrow (top row) and wide feeder (bottom row) adjustments. The narrow adjustment feeders (minimum feeder gap of 1.27 cm with a maximum gap of 1.91 cm) averaged 62, 77, and 69% feeder pan coverage for meal, poor-quality pellets, and screened pellets, respectively. The wide adjustment feeders (minimum feeder gap of 2.54 cm with a maximum gap of 3.18 cm) averaged 90, 99, and 92% feeder pan coverage for meal, poor-quality pellets, and screened pellets, respectively.

Figure 2-5.

Experiment 3, phase 3 narrow (top row) and wide feeder (bottom row) adjustments. The narrow adjustment feeders (minimum feeder gap of 1.27 cm with a maximum gap of 1.91 cm) averaged 89, 93, and 92% feeder pan coverage for meal, poor-quality pellets, and screened pellets, respectively. The wide adjustment feeders (minimum feeder gap of 2.54 cm with a maximum gap of 3.18 cm) averaged 95, 99, and 96% feeder pan coverage for meal, poor-quality pellets, and screened pellets, respectively.

Chapter 3 - Effects of diet form and corn particle size on growth performance and carcass characteristics of finishing pigs

ABSTRACT

A total of 960 pigs (PIC TR4 × Fast Genetics × PIC Line 02, initially 34.3 kg BW) were used in a 101-d trial to determine the effects of corn particle size and diet form on growth performance and carcass characteristics of finishing pigs. Pens were randomly allotted by initial BW to 1 of 6 experimental treatments with 8 pens per treatment and 20 pigs per pen. The 6 experimental treatments were arranged in a 2 × 3 factorial with main effects of final feed form (meal vs. pellet) and corn particle size (650 µm, 350 µm, or an equal blend of the 650 µm and 350 µm ground corn). The 650 µm corn was ground using a two-high roller mill, and the 350 µm corn was ground using a full circle hammer-mill equipped with a 1.59 mm screen. After all corn was ground, the diet containing the blend of particle sizes was manufactured by adding equal portions of the 2 at the mixer. Overall (d 0 to 101), linear particle size × diet form interactions were observed ($P < 0.05$) for ADFI and G:F, because ADFI decreased and G:F increased as particle size was reduced for pigs fed meal diets but not for pigs fed pelleted diets. Pigs fed pelleted diets had increased ($P < 0.05$) ADG and G:F compared with pigs fed meal diets. As corn particle size decreased, ADG and ADFI decreased (linear; $P < 0.05$) linearly. Pigs fed pelleted diets had increased ($P < 0.05$) HCW compared with pigs fed meal diets, but no other effects on carcass characteristics were observed. In summary, grinding corn finer than 650 µm decreased feed intake and improved feed efficiency for pigs fed meal diets, but not for pigs fed pelleted diets. Pigs fed pelleted diets had improved growth performance, but the greatest magnitude of G:F improvement to pellets occurred when pigs were fed diets containing the largest particle size

corn (650 µm). Thus, grinding corn finer than 650 µm improved feed efficiency for pigs fed meal diets, but provided no benefit in pelleted diets.

Key Words: diet form, growth, particle size, pig

INTRODUCTION

Feed processing techniques such as fine grinding or pelleting have been shown to be effective methods for improving growth performance of pigs. The most notable and consistent response observed is an improvement in feed efficiency.

Consistent improvements in feed efficiency when feeding pelleted diets have been reported (Hanke et al., 1972; Medel et al. 2004; Nemechek et al., 2013) and are often accompanied by increased ADG (Wondra et al., 1995a; Paulk et al. 2011). These improvements in growth performance may result from multiple factors including decreased feed wastage (Hanrahan, 1984), increased nutrient digestibility (Wondra et al., 1995), and improved palatability (Skoch et al., 1983).

Reducing cereal grain particle size has also improved feed efficiency in finishing pigs (Hedde et al., 1985; Mavromichalis et al., 2000). Wondra et al. (1995a) found that G:F improved linearly as corn particle size decreased from 1000 to 400 µm, and the improvements were attributed to increased digestibility of GE, DM, and N. Other research was conducted with cereal grain particle sizes ranging from 1,200 to 600 µm but was limited primarily to diets fed in meal form (Ohh et al., 1983; Seerly et al. 1988). Little information is available on the impact of feeding pelleted diets containing corn ground finer than 700 µm in finishing pigs.

Therefore, the objective of the experiment was to determine the effect of corn particle size (650 µm, 350 µm, or an equal blend of the 650 µm and 350 µm ground corn) and diet form (meal vs. pellet) on finishing pig growth performance and carcass characteristics.

MATERIALS AND METHODS

All experimental procedures and animal care were approved by the Kansas State University Institutional Animal Care and Use Committee.

General

A total of 960 pigs (PIC [Hendersonville, TN] TR4 × Fast Genetics [Saskatoon, SK] × PIC Line 02, initially 34.3 kg BW) were used in a 101-d trial. The study was conducted at the New Fashion Pork Research Facility (Round Lake, MN) in a commercial research-finishing barn located in northwestern IA. The double-curtain-sided barn was tunnel-ventilated with completely slatted flooring and deep pits for manure storage. Each pen (2.4 m × 17.8 m) was equipped with a 5-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. Daily feed additions to each pen were made by a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed deliveries for individual pens.

Pens were randomly allotted by initial BW to 1 of 6 experimental treatments with 8 pens per treatment and 20 pigs per pen. The 6 experimental treatments were arranged in a 2 × 3 factorial with main effects of final feed form (meal vs. pellet) and corn particle size (650 µm, 350 µm, or an equal blend of the 650 µm and 350 µm ground corn). Diets were fed in 4 phases, with Phase 1 through 4 fed from d 0 to 26, 26 to 46, 46 to 73, and 73 to 101, respectively (Table

1). Within each phase, the same corn-soybean meal–based diet containing 30% DDGS (Phases 1 through 3) or 15% DDGS (Phase 4) was used for all 6 experimental treatments.

All diets were prepared at New Fashion Pork's commercial feed mill in Estherville, IA. The 650 µm corn was ground using a two-high roller mill (RMS Roller Grinder, Tea, SD), and the 350 µm corn was ground using a full circle hammer-mill (Jacobsen Machine Works, Minneapolis, MN) equipped with a 1.59 mm screen. After all corn was ground, the diet containing the blend of the 650 µm and 350 µm ground corn was manufactured by adding equal portions of the 2 at the mixer. For all pelleted diets, the complete feed was pelleted with a CPM pellet mill (California Pellet Mill, San Francisco, CA) equipped with a 4.3 mm die.

Pigs were weighed and feed disappearance measured approximately every 2 wk to calculate ADG, ADFI, and G:F. Caloric efficiencies were determined using dietary ingredient values for ME and NE from NRC (2012). Caloric efficiency was calculated on a pen basis by multiplying total pen feed intake by dietary energy (Mcal/kg) and dividing by total pen gain. On d 87 of the trials, pens were weighed and the 6 heaviest pigs (selected by the marketing serviceman) were removed and transported 350 miles to Triumph Foods (St. Joseph, MO) for harvest. The remaining pigs were transported to Triumph Foods on d 101 for harvest. Yield was calculated using live weight at the farm and HCW at the plant. At the plant, backfat and loin depth were measured, and percentage lean was calculated using NPPC (1991) guidelines for lean containing 5% fat: Lean % = (2.83 + (0.469 × (HCW, lb)) – (18.47 × (fat depth, in.)) + (9.824 × loin depth, in.))/(HCW, lb).

Samples of corn and complete diets were collected at the feeder during each phase. Corn particle size of the diets containing a 50:50 mixture of 650 and 350 µm ground corns could not be determined; therefore, whole diet particle size was measured. Particle size of corn samples

and diets in meal form was determined at the K-State Swine Laboratory using the ASAE (1995) standard method for determining particle size. Tyler sieves (numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, 270, and a pan) and a Ro-Tap shaker (W.S. Tyler, Mentor, OH) were used. The Ro-Tap was equipped with a hammer used to tap the sieve stack approximately 150 times per minute during the shaking process. One hundred-gram samples were sifted for 10 min without a flow agent, and the weight on each screen was used to calculate the mean particle size and standard deviation (Table 2). Pellet durability index (PDI) was determined using the standard tumbling-box technique (S269.4; ASAE, 1996), and modified PDI was done by adding 5 hexagonal nuts (1.27 cm) prior to tumbling. Percentage fines (ASAE, 1987) were also determined for all pelleted diets, with fines characterized as material that would pass through a #6 sieve (3,360 μm openings). All pellet quality measurements were analyzed at the K-State Grain Sciences and Industry Feed Mill.

Statistical Analysis

Experimental data were analyzed using analysis of variance as a 2 × 3 factorial using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Pen was the experimental unit for all data analysis. Data analysis included main effects of 2 diet forms and 3 corn particle sizes. Linear and quadratic effects of decreasing particle size were determined as well as interactive effects of corn particle size and diet form. Significant differences were declared at $P < 0.05$ and trends at $P < 0.10$.

RESULTS

Particle size and pellet quality measurements

Particle size of corn was similar to expectations with corn targeted at 650 µm ranging from 616 to 681 µm and corn targeted at 350 µm ranging from 336 to 359 µm across the different dietary phases (Table 2). The complete feed particle size of diets containing the 50:50 blend of 650 and 350 µm corn were intermediate between high– and low–particle size corn diets, which was expected. High-quality pellets were produced as reflected by the PDI being greater than 90% and the percentage fines being 20% or less for all diets and phases.

Growth performance and carcass measurements

Overall (d 0 to 101), linear particle size × diet form interactions were observed ($P < 0.05$) for ADFI, G:F, and caloric efficiency (Table 3). This was a result of decreased ADFI and increased G:F as particle size was reduced for pigs fed meal diets but not for pigs fed pelleted diets. Despite these interactions, in general, pigs fed pelleted diets had increased ($P < 0.05$) ADG, G:F, and improved caloric efficiency. As corn particle size decreased, ADG and ADFI decreased (linear; $P < 0.05$).

For carcass characteristics, pigs fed pelleted diets had increased ($P < 0.05$) HCW compared with pigs fed meal diets. However, there were no other effects on carcass traits observed.

DISCUSSION

Reducing cereal grain particle size in livestock diets has been widely implemented for many years. Early particle size reduction research was conducted with cereal grain particle sizes

ranging from 1200 to 600 µm and was limited primarily in diets fed in meal form (Ohh et al., 1983; Seerly et al. 1988). With advancements in particle size reduction technology, current feed manufacturers can more efficiently reduce grain to much finer particle sizes (300 to 400 µm).

Previous research has shown that reducing cereal grain particle size in meal diets has resulted in improve feed efficiency of finishing pigs (Ohh et al., 1983; Hedde et al., 1985; Mavromichalis et al., 2000). These results agree with the current trial for pigs fed meal diets. However, grinding corn finer than 650 µm for pelleted diets provided no additional benefit to G:F. Although pelleting diets did improve feed efficiency in pigs fed all 3 particle sized diets, the greatest magnitude of G:F improvement to feeding pelleted diets occurred when pigs were fed 650 µm corn. Thus, the improvements in feed efficiency from particle size reduction and pelleting were not additive.

The same interaction was observed for caloric efficiency. The calculation of caloric efficiency is consistently reported by ruminant nutritionists and is one method to estimate the energy digestibility of a diet. Caloric efficiency for each treatment was calculated on a pen basis by multiplying total pen feed intake by dietary energy (Mcal/kg) and dividing by total pen gain; therefore, pigs with a lower caloric efficiency were more efficiently able to utilize the energy in the diets. Similar to feed efficiency, we observed that feeding diets containing fine ground corn in meal form or feeding pelleted diets improved caloric efficiency. All treatment diets contained identical ingredient compositions and equal energy content, but fine grinding the corn in meal diets or pelleting was able to make the calories in the diet more available to the pig.

One possible explanation for the interaction is that the improvements in G:F and caloric efficiency from feeding pellets or fine-ground corn in meal diets are caused by the same biological mechanism. Hedemann et al. (2005) found that pigs fed pelleted diets had an increase

in the amount of acidic mucins on the distal small intestine villi compared to pigs fed meal diets. Although not significant, the authors also found that feeding finer particle size grain resulted in numerical increases in acidic mucins in the same location of the small intestine. Thus, if feeding pellets or fine-ground grain illicit a similar biological response, this may explain why one feed processing technique or the other improved feed efficiency, but not the combination of both.

Another possible explanation for the feed efficiency interaction found in the current experiment may be that additional particle size reduction occurs during the pelleting process. Diets are subjected to extreme force and pressure as the feed is driven through the pellet mill die, which may cause the particle size of larger material to be reduced further. Similar to our findings, De Jong et al. (2013a) reported that reducing particle size of corn from 650 to 320 µm in meal diets improved G:F of finishing pigs, and pelleting the fine-ground corn-diet provided further improvements in G:F. The authors did not feed the 650 µm diet in pelleted form; therefore, the magnitude of G:F improvement from pelleting was not determined between pigs fed coarse- or fine-ground corn. Furthermore, De Jong et al. (unpublished data) found that reducing particle size of wheat from 730 to 300 µm for diets fed in meal form improved feed efficiency of finishing pigs. However, in a separate trial, the authors reported no differences in G:F when finishing pigs were fed pelleted diets containing 600, 400, or 200 µm wheat. Conversely, Wondra et al. (1995a) reported that feed efficiency improved linearly for pigs fed pelleted diets as corn particle size was reduced (1,000, 800, 600, and 400 µm). In their research, pellet quality was much poorer than in the current experiment. The authors reported that PDI improved from 78.8 to 86.4% as corn particle size decreased from 1000 to 400 µm, respectively. Stark et al. (1993) and Nemechek et al. (2012) found that pellet quality affected the feed efficiency response to pelleting. This suggests that the improvements in feed efficiency found by

Wondra et al. (1995) may be due to improved pellet quality and not a direct effect of particle size.

The benefit in feed efficiency from reducing corn particle size below 600 microns in meal diets is different for finishing pigs than nursery pigs. De Jong et al. (2013b) reported that reducing corn particle size from 620 to 350 µm in meal diets did not increase G:F of nursery pigs. Furthermore, De Jong et al. (2014b) found that feed efficiency did not differ between nursery pigs fed diets with 737 or 324 µm corn, regardless of diet form; although feed efficiency was improved by pellets compared to feeding meal. The varying response to corn particle size and pelleting between nursery and finishing pigs could be related to passage rate through the digestive tract. Decreased retention time in young pigs may not allow for nursery pigs to fully benefit from the reduced particle size grain. Although the pelleting response appears to vary among particle sizes, these experiments agree that pelleting the complete diet appears to be an effective method for improving feed efficiency regardless of growth stage.

Due to the limitations of the commercial feed mill used in the current trial, 2 different types of particle size reduction machinery were used to grind the 650 and 350 µm corn (roller mill and hammermill, respectively). We do recognize the possibility for confounding results between particle size and mill type; however, we believe that it is unlikely. Wondra et al. (1995b) conducted a series of trials to evaluate the effect of mill type and particle size on growth, digestibility, and stomach morphology of finishing pigs. The authors found variable results, where mill type did not influence growth performance in 2 of the 3 trials. Therefore, no consistent evidence was reported to suggest that mill type affects the growth performance response to particle size.

Improvements observed in ADG from pigs fed pelleted diets in the current experiment are similar to those reported in previous research (Hanke et al., 1972; Paulk et al. 2011; Nemechek et al., 2013). Due to increased ADG, pigs fed pelleted diets also had increased final BW and HCW compared to pigs fed meal diets. Wondra et al. (1995a) found that pigs fed pelleted diets had increased ADG compared to those fed meal diets, but improvements from pelleting tended to be greater when pigs were fed diets containing 800 or 600 µm corn compared to 1,000 or 400 µm. Other research has reported no difference (Nielsen and Ingvartsen, 2000; Hedemann et al. 2005) or decreases (Bokelman et al., 2014; De Jong et al., 2014a) in ADG when pigs were pelleted diets compared to meal diets.

The effect of particle size on daily weight gain of pigs has also varied among experiments. Hedde et al. (1985) reported that feeding fine-ground corn increased ADG of finishing pigs, while others have found that grain particle size did not influence ADG (Ohh et al., 1983; Wu and Allee, 1984; Bokelman et al. 2014). We found that ADG decreased as corn particle size decreased, which is in agreement with De Jong et al. (2014a). The decreased gain can be explained by the reduced feed intake in pigs fed diets with finer corn particle sizes.

A particle size linear × diet form interaction for ADFI occurred due to pigs fed meal diets having decreased feed intake as corn particle size decreased; however, pigs fed pelleted diets had similar ADFI, regardless of corn particle size. We believe that this response is likely due to decreased palatability of the meal diets containing finer particle size corn. Wondra et al (1995b) also found that finishing pigs fed meal diets with 400 µm corn had decreased ADFI compared to pigs fed diets with 800 µm corn. Similarly, De Jong et al. (2013a) reported that reducing complete diet particle size from 596 to 360 µm resulted in a decrease in ADFI when diets were fed in meal form, but pelleting the 360 µm diet restored the losses in feed intake.

In summary, pigs fed pelleted diets had improved growth performance compared with those fed meal diets, with the greatest magnitude of G:F improvement to pellets occurring when pigs were fed 650 µm corn. Feed efficiency improved as corn particle size decreased for pigs fed meal diets but not for those fed pelleted diets, suggesting that grinding corn finer than 650 µm for pelleted diets conferred no benefit.

LITERATURE CITED

ASAE. 1987. Wafers, pellets, and crumbles – definitions and methods for determining density, durability, and moisture content. ASAE Standard S269.3, Agricultural Engineers Yearbook of Standards. p 318. Am. Soc. Agric. Biol. Eng., St. Joseph, MI.

ASAE. 1996. Cubes, Pellets, and Crumbles: Definitions and Methods for Determining Density, Durability, and Moisture Content. ASAE Standard S269.4. Am. Soc. Agric. Biol. Eng., St. Joseph, MI.

Bokelman, G. E., C. K. Jones, J. R. Kalivoda, M. D. Tokach, J. M. DeRouchey, and C. R. Stark. 2014. Effects of corn particle size and diet form on growth performance of 6-22 kg nursery pigs. J. Anim. Sci. 92 (Suppl. 2):158 (Abstr.).

De Jong, J. A., J. M. DeRouchey, M. D. Tokach, R. D. Goodband, S. S. Dritz, J. L. Nelssen, and C. Hastad. 2013a. Effects of corn particle size, complete diet grinding and diet form on pig growth performance, caloric efficiency, and carcass characteristics. J. Anim. Sci. 91(Suppl. 2):112 (Abstr.).

De Jong, J. A., J. M. DeRouchey, M. D. Tokach, R. D. Goodband, S. S. Dritz, and J. L. Nelssen. 2013b. Effects of varying ingredient particle size and diet form on nursery pig growth performance and caloric efficiency. J. Anim. Sci. 91(Suppl. 2):70 (Abstr.).

De Jong, J. A., J. M. DeRouchey, M. D. Tokach, R. D. Goodband, and S. S. Dritz. 2014a. Effects of fine grinding corn or dried distillers grains with solubles (DDGS) and diet form on growth performance and caloric efficiency of 11- 22-kg nursery pigs. J. Anim. Sci. 92 (Suppl. 2):157 (Abstr.)

De Jong, J. A., J. M. DeRouchey, M. D. Tokach, R. D. Goodband, S. S. Dritz, C. W. Hastad. 2014b. Effects of corn particle size, complete diet grinding, and diet form on 11- to 20-kg nursery pig growth performance and caloric efficiency. J. Anim. Sci. 92 (Suppl. 2):59 (Abstr.)

Hanke, H. E., J. W. Rust, R. J. Meade, and L. E. Hanson. 1972. Influence of source of soybean protein, and of pelleting, on rate of gain and gain/feed of growing swine. J. Anim. Sci. 35:958-962.

Hanrahan, T. J. 1984. Effect of pellet size and pellet quality on pig performance. Anim. Feed Sci. Tech. 10:277-283.

Hedde, R. D., T. O. Lindsey, R. C. Parish, H. D. Daniels, E. A. Morgenthien, and H. B. Lewis. 1985. Effects of diet particle size and feeding of H2-receptor antagonists on gastric ulcers in swine. J. Anim. Sci. 61:179-186.

Hedemann, M. S., L. L. Mikkelsen, P. J. Naughton, and B. B. Jensen. 2005. Effect of feed particle size and feed processing on morphological characteristics in the small and large intestine of pigs and on adhesion of *Salmonella enterica* serovar Typhimurium DT12 in the ileum in vitro. J. Anim. Sci. 83:1554-1562.

Nielsen, E.K., and K. L. Ingvartsen. 2000. Effect of cereal type, disintegration method and pelleting on stomach content, weight and ulcers and performance in growing pigs. Livest. Prod. Sci. 66:271-282.

Nemechek, J., M. Tokach, E. Fruge, E. Hansen, S. Dritz, R. Goodband, J. DeRouchey, and J. Nelssen. 2012. Effects of pellet quality and feeder adjustment on growth performance of finishing pigs. J. Anim. Sci. 91 (Suppl. 2):215. (Abstr.)

Nemechek, J., M. Tokach, J. DeRouchey, S. Dritz, R. Goodband, and J. Nelssen. 2013. Effects of diet form and fiber level before marketing on growth performance, carcass yield, and iodine value of finishing pigs. J. Anim. Sci. 91(Suppl. 2):O074 (Abstr.).

NPPC. 1991. Procedures to evaluate market hogs. 3rd ed. Natl. Pork Prod. Counc., Des Moines, IA.

NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington, DC.

Ohh, S. J. G. L. Alee, K. C. Behnke, and C. W. Deyoe. 1983. Effect of particle size of corn and sorghum grain on performance and digestibility for weaned pigs. In: Proc. Swine Day, Stn. Rep. Prog. 442, Manhattan, KS. p. 60-63.

Paulk, C. B., J. D. Hancock, J. C. Ebert, and J. J. Ohlde. 2011. Effects of an abrupt change from mash to pellets and vice-versa on growth performance in finishing pigs. J. Anim. Sci. 89 (Suppl. 1): 261 (Abstr.).

Seerley, R. W., W. L. Vandergrift, and O. M. Hale. 1988. Effect of particle size of wheat on performance of nursery, growing, and finishing pigs. J. Anim. Sci. 66:2484-2489.

Skoch, E. R., S. F. Binder, C. W. Deyoe, G. L. Allee, and K. C. Behnke. 1983. Effects of pelleting conditions on performance of pigs fed a corn-soybean meal diet. J. Anim. Sci. 57:922-928.

Stark, C. R., K. C. Behnke, J. D. Hancock, and R. H. Hines. 1993. Pellet quality affects growth performance of nursery and finishing pigs. In: Proc. Swine Day, Stn. Rep. Prog. 695, Manhattan, KS. p. 71-74.

Wondra, K. J., J. D. Hancock, K. C. Behnke, R. H. Hines, and C. R. Stark. 1995a. Effects of particle size and pelleting on growth performance, nutrient digestibility, and stomach morphology in finishing pigs. J. Anim. Sci. 73:757-763.

Wondra, K. J., J. D. Hancock, K. C. Behnke, and C. R. Stark. 1995b. Effects of mill type and particle size uniformity on growth performance, nutrient digestibility, and stomach morphology of finishing pigs. J. Anim. Sci. 73:2564-2573.

Wu, J. F., and G. L. Allee. 1984. Effect of particle size and surface area of corn on pig performance and nutrient digestibility. In: Proc. Swine Day. Stn. Rep. Prog. 461, Manhattan, KS. p. 83-88.

TABLES

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

Item	Phase 1	Phase 2	Phase 3	Phase 4
Ingredient, %				
Corn	48.45	53.13	56.33	63.28
Soybean meal, 46.5% CP	17.88	13.36	10.39	18.42
Dried distillers grains with solubles	30.00	30.00	30.00	15.00
Beef tallow	1.50	1.50	1.50	1.50
Limestone	1.36	1.22	1.06	1.05
Salt	0.35	0.35	0.35	0.35
Vitamin-trace mineral premix[2]	0.100	0.100	0.075	0.050
L-Lys·HCl	0.365	0.340	0.305	0.275
L-Thr	---	---	---	0.050
Ractopamine HCl[3], 19.8 g/kg	---	---	---	0.025
Total	100.0	100.0	100.0	100.0
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lys	1.01	0.88	0.78	0.90
Ile:Lys	68	70	72	68
Met:Lys	30	33	35	30
Met + Cys:Lys	58	62	67	58
Thr:Lys	60	62	65	65
Trp:Lys	17	17	17	18
Val:Lys	80	83	87	79
Total Lys, %	1.20	1.06	0.95	1.05
ME, kcal/kg	3,437	3,446	3,455	3,419
NE, kcal/kg	2,522	2,553	2,575	2,560
CP, %	21.3	19.5	18.3	18.5
Ca, %	0.58	0.52	0.45	0.46
P, %	0.43	0.41	0.40	0.39
Available P, %	0.32	0.31	0.30	0.32

[1] Phase 1 diets were fed from d 0 to 26, phase 2 from d 26 to 46, phase 3 from d 46 to 73, and phase 4 from d 73 to 101.

[2] Provided per kilogram of premix: 3,968,324 IU vitamin A; 440,925 IU vitamin D_3; 22,046 IU vitamin E; 1,874 mg vitamin K; 5,512 mg riboflavin; 11,023 mg pantothenic acid; 16, 535 mg niacin; 16.5 mg vitamin B_{12}, 65 g Fe from iron sulfate, 75 g Zn from zinc sulfate and zinc oxide, 160 g Cu from tri-basic copper chloride, 4.5 g Mn from manganese sulfate, 200 mg I from calcium iodate, and 180 mg Se from sodium selenite.

[3] Paylean; Elanco Animal Health (Greenfield, IN).

Table 3-2. Analysis of pellet quality and particle size[1]

Corn particle size:	650 µm		50:50 blend		350 µm	
Item	Meal	Pellet	Meal	Pellet	Meal	Pellet
Corn particle size						
Phase 1						
Mean, µm	675		---	---	350	
Standard deviation, µm	1.91		---	---	1.77	
Phase 2						
Mean, µm	616		---	---	336	
Standard deviation, µm	2.08		---	---	1.89	
Phase 3						
Mean, µm	681		---	---	359	
Standard deviation, µm	1.90		---	---	1.70	
Phase 4						
Mean, µm	656		---	---	355	
Standard deviation, µm	2.12		---	---	1.76	
Diet particle size, µm						
Phase 1						
Mean, µm	610	---	541	---	480	---
Standard deviation, µm	2.18	---	2.21	---	2.31	---
Phase 2						
Mean, µm	595	---	483	---	425	---
Standard deviation, µm	2.12	---	2.26	---	2.31	---
Phase 3						
Mean, µm	611	---	483	---	455	---
Standard deviation, µm	2.20	---	2.29	---	2.33	---
Phase 4						
Mean, µm	622	---	500	---	496	---
Standard deviation, µm	2.17	---	2.25	---	2.35	---
Standard pellet durability index, %[2]						
Phase 1	---	92.8	---	94.1	---	96.0
Phase 2	---	97.6	---	93.2	---	94.5
Phase 3	---	94.1	---	91.7	---	95.8
Phase 4	---	96.8	---	92.4	---	97.8
Modified pellet durability index, %[3]						
Phase 1	---	89.5	---	87.4	---	86.5
Phase 2	---	91.4	---	91.6	---	89.0
Phase 3	---	90.2	---	92.0	---	89.3
Phase 4	---	90.1	---	90.2	---	91.4
Fines, %						
Phase 1	---	9.2	---	11.7	---	11.3
Phase 2	---	9.7	---	10.5	---	8.8
Phase 3	---	18.2	---	11.9	---	10.7
Phase 4	---	20.0	---	8.6	---	11.2

[1] A composite sample of 3 subsamples was used for analysis.
[2] Pellet durability index was determined using the standard tumbling-box technique.
[3] Procedure was altered by adding 5 hexagonal nuts prior to tumbling.

Table 3-3. The effect of corn particle size and diet form on finishing pig performance[1]

								Probability, P <				
Corn particle size:	650 µm		50:50 blend[2]		350 µm			Diet form × particle size		Particle size		
Diet form:	Meal	Pellet	Meal	Pellet	Meal	Pellet	SEM	Linear	Quadratic	Linear	Quadratic	Diet form
d 0 to 101												
ADG, kg	0.90	0.94	0.89	0.93	0.86	0.92	0.010	0.578	0.722	0.013	0.582	0.001
ADFI, kg[3]	2.41	2.35	2.37	2.37	2.26	2.35	0.065	0.021	0.823	0.018	0.283	0.601
G:F[4]	0.372	0.399	0.375	0.392	0.382	0.391	0.020	0.004	0.889	0.766	0.326	0.001
BW, kg												
d 0	34.4	34.4	34.3	34.3	34.4	34.4	0.449	0.995	0.997	0.995	0.985	0.996
d 101	120.7	125.0	120.1	124.4	118.2	122.6	2.860	0.496	0.960	0.166	0.328	0.002
Caloric efficiency, Mcal/kg												
ME	9.25	8.62	9.18	8.77	9.01	8.80	0.069	0.005	0.952	0.639	0.344	0.001
NE	6.87	6.41	6.82	6.52	6.69	6.54	0.052	0.005	0.942	0.645	0.340	0.001
Carcass characteristics[5]												
HCW, kg	88.6	93.1	89.5	92.3	87.7	90.4	0.915	0.339	0.630	0.058	0.235	0.001
Yield, %	74.1	74.5	74.3	74.4	74.6	74.3	0.402	0.676	0.408	0.942	0.771	0.802
Backfat, mm	18.3	18.8	18.3	18.4	18.3	18.9	0.386	0.208	0.746	0.165	0.351	0.116
Loin depth, cm	6.65	6.63	6.55	6.70	6.60	6.53	1.035	0.624	0.292	0.338	0.827	0.131
Lean, %[6]	55.6	55.2	55.2	55.9	55.3	55.1	0.295	0.197	0.429	0.629	0.371	0.435

[1] A total of 960 pigs (PIC TR4 × Fast Genetics York-AND × PIC Line 02, initially 75.7 lb BW) were used in a 101-d trial with 8 pens per treatment and 20 pigs per pen.
[2] Equal blend of the 650 and 350 µm ground corn.
[3] Linear effect of particle size within meal diets, $P < 0.001$. Linear effect of particle size within pelleted diets, $P > 0.960$.
[4] Linear effect of particle size within meal diets, $P < 0.022$. Linear effect of particle size within pelleted diets, $P < 0.058$.
[5] The 6 largest pigs were marketed from each pen on d 87. All remaining pigs were marketed from each pen on d 101. Means represent data collected from all pigs marketed on d 87 and 101. Carcass characteristics other than yield were adjusted by using HCW as a covariate.
[6] Calculated using NPPC (1991) guidelines for lean containing 5% fat. Lean % = (2.83) + (0.469 × (HCW)) – (18.47 × (fat depth)) + (9.824 × loin depth)) / (HCW).

Chapter 4 - Effects of commercial acidifiers, diet complexity, and antimicrobials, on nursery pig performance

ABSTRACT

Five 28-d experiments were conducted to evaluate the effect of dietary acidification on growth performance of nursery pigs in university (Exp. 1, 2, and 3) and commercial (Exp. 4 and 5) settings. In Exp. 1, 2, and 3, there were 6 or 7 pigs per pen and 10 pens per treatment with 280, 240, and 280 pigs (initially 7.0, 7.3, and 6.9 kg BW, respectively). In Exp. 4 and 5, there were 1,728 and 1,800 pigs (initially 5.4 and 7.4 kg BW) with 48 and 50 pigs per double sided fence line feeder (observational unit), respectively, with 9 feeders per treatment. Experiment 1 was arranged as a 2 × 2 factorial with main effects of diet complexity (simple vs. complex) and diet acidification (benzoic acid; Vevovitall; DSM Nutritional Products, Parsippany, NJ; 0 vs. 0.5%). Pigs fed simple diets (no lactose, ZnO, or animal protein) had decreased ($P < 0.05$) ADG and ADFI compared with pigs fed complex diets (whey, fish meal, blood cells and ZnO). Benzoic acid addition did not affect growth performance. In Exp. 2, treatments were arranged as a 2 × 2 factorial with main effects of benzoic acid (0 vs. 0.5%) and without or with carbadox (Mecadox; Philbro Animal Health Corp., Ridgefield Park, NJ). Like Exp. 1, no treatment interactions were observed. From d 0 to 28, pigs fed carbadox had increased ($P < 0.05$) ADG and ADFI. There was no growth response to added benzoic acid. In Exp. 3, 4, and 5, treatments were: 1) no acidifier, 2) 0.5% benzoic acid, 3) 0.2% acid blend (Kem-Gest; Kemin Americas, Des Moines, IA), or 4) 0.05% encapsulated butyric acid (ButiPearl; Kemin Americas). In Exp. 3, from d 0 to 14, pigs fed the acid blend tended to have increased ($P < 0.10$) ADG; however, there were no differences from d 14 to 28 or 0 to 28. In Exp. 4, from d 0 to 14, all acidifiers increased ($P < 0.05$) ADG and G:F compared to pigs fed the control diet; however, like Exp. 3, there were

no differences observed from d 14 to 28 or 0 to 28. In Exp. 5, there were no differences in ADG, ADFI, or G:F observed during the study. In summary, feeding complex diets or a feed-grade antimicrobial improved growth performance of weanling pigs. Benzoic or other commercial acidifiers did not influence growth performance of nursery pigs in university conditions, whereas in the commercial setting, the response to diet acidification was variable.

Key Words: acidifiers, benzoic acid, growth, pig

INTRODUCTION

Weaning is typically associated with higher stress, particularly with regards to intestinal health and development (Funderburke and Seerley, 1990; Smith et al., 2010). Acidifiers have been investigated as beneficial feed additives during this time period (Stein, 2002; Che et al. 2012) due to the potential for antibiotic-like effects. Many different sources of acidifiers are currently available and often vary in pH and potency depending on the form of acid.

Benzoic acid (Vevovitall; DSM Nutritional Products, Parsippany, NJ) is new to the North American swine industry. European nutritionists have used it for a number of years. Data from European trials indicate that adding benzoic acid to the nursery pig diets may improve growth performance (Guggenbuhl et al., 2007; Torrallardona et al., 2007), but little research has been conducted with the product in typical U.S. diet formulations, which are corn and soybean meal–based and often contain pharmacological levels of zinc oxide (Hahn and Baker, 1993; Shelton et al., 2011). Antimicrobials are also often fed during early nursery periods in an attempt to lessen any negative effects on growth caused by weaning-related stressors (Hill et al., 2001). Data is

lacking on the efficacy of benzoic acid in diets containing antimicrobials or in the comparison of benzoic acid to other acidifiers.

Therefore, the objective of the following series of experiments was to determine the effect of dietary acidification on growth performance of nursery pigs. To accomplish the overall objective, the sub-objectives were to determine the effects of: 1) diet complexity and benzoic acid, 2) antimicrobials and benzoic acid, and 3) different commercially available acidifiers on growth performance of nursery pigs housed in both university and field conditions.

MATERIALS AND METHODS

All experimental procedures and animal care were approved by the Kansas State University Institutional Animal Care and Use Committee.

Experiment 1

A total of 280 weanling pigs (PIC 327 × 1050, initially 7.0 kg, 3 d postweaning) were used in a 28-d trial. The experiment was conducted in the nursery facility at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. All pens (1.52 m × 1.83 m) were equipped with a 4-hole, dry self-feeder, a nipple waterer, and wire-mesh floors. Pigs were weaned at approximately 21 d of age and allotted to pens by initial BW to achieve the same average pen weight for all pens. Pigs were fed a common pelleted transition diet for 3 d after weaning before the beginning of the study. On d 3 postweaning, pens were allotted to 1 of 4 dietary treatments with 7 pigs per pen and 10 pens per treatment. Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and G:F.

Diets were formulated and fed in 2 phases with decreasing nutrient concentrations in the second phase (Table 1). The first phase was fed from d 0 to 14, and the experimental treatments were organized in a 2 × 2 factorial with main effects of diet complexity (simple vs. complex) and benzoic acid (Vevovitall; DSM Nutritional Products, Parsippany, NJ; 0 vs. 0.5%). All diets were corn-soybean meal–based, with the simple diets containing no lactose, zinc oxide, or specialty protein sources. The complex diets contained 10% dried whey, 1.25% select menhaden fish meal, 1.25% spray-dried blood cells, and 0.25% zinc oxide. Phase 2 was fed from d 14 to 28, and the 2 treatment diets were corn-soybean meal–based with no specialty protein sources, either with or without 0.5% benzoic acid. All pigs fed benzoic acid from d 0 to 14 were also fed benzoic acid from d 14 to 28, regardless of diet complexity during phase 1. Similarly, pigs fed diets without benzoic acid during phase 1 were fed diets without benzoic acid during phase 2. Benzoic acid was added at the expense of corn when included in the diet. All experimental diets were in meal form and were prepared at the K-State Animal Sciences and Industry Feed Mill.

Experiment 2

A total of 240 weanling pigs (PIC 327 × 1050, initially 7.3 kg, 3 d postweaning) were used in a 28-d trial to determine the effects of feed-grade antibiotics and benzoic acid on growth performance of nursery pigs. There were 6 pigs per pen and 10 pens per treatment. Experiment 2 was conducted in the same housing facility, and similar procedures were used as described in Exp. 1.

A 2-phase diet series was used. The complex diet from the previous experiment was used as the basal diet for phase 1 (d 0 to 14), and the phase 2 diet from Exp. 1 was fed as the basal diet from d 14 to 28. There were 4 dietary treatments arranged as a 2 × 2 factorial with main effects of benzoic acid (Vevovitall; DSM Nutritional Products, Parsippany, NJ; 0 vs. 0.5%) and without

or with carbadox (Mecadox; Philbro Animal Health Corp., Ridgefield Park, NJ). For diets containing carbadox, the inclusion 50 g/ton from d 0 to 14 and 25 g/ton from d 14 to 28 was used. Benzoic acid was included in treatments 2 and 4 at 0.5%. Benzoic acid, carbadox, or the combination was added at the expense of corn when included in the diet.

Experiments 3, 4, and 5

Experiments 3, 4, and 5 were conducted to evaluate the effects of 3 commercial acidifiers on growth performance of nursery pigs in university (Exp. 3) and field (Exp. 4 and 5) conditions. There were 4 dietary treatments used in all 3 experiments which consisted of a control with 1) no acidifier, 2) 0.5% benzoic acid (Vevovitall; DSM Nutritional Products, Parsippany, NJ), 3) 0.2% blend of phosphoric, fumaric, lactic, and citric acid (Kem-Gest; Kemin Americas, Des Moines, IA), or 4) 0.05% encapsulated butyric acid (ButiPearl; Kemin Americas, Des Moines, IA). A 2-phase diet series was used in each trial. For all experiments, each acidifier was added at the expense of corn when included in the diet.

In Exp. 3 a total of 280 weanling pigs (PIC 327 × 1050, initially 6.9 kg, 3 d postweaning) were used in a 28-d trial at a university research nursery. There were 7 pigs per pen and 10 pens per treatment. Experiment 3 was conducted at the same research facility and with similar procedures as Exp. 1 and 2. The control diets for both phases were identical to the control diets fed in Exp. 2.

In Exp. 4 and 5, a total of 1,728 and 1,800 nursery pigs (PIC 327 × 1050) were used, respectively, in 28-d trials conducted at a commercial research nursery facility. All pens (2.13 m × 2.44 m) were equipped with a 6-hole, dry self-feeder (Hog Slat Inc.; Newton Grove, NC) and a cup waterer, Each feeder was available to 2 adjacent pens (1 barrow and 1 gilt pen per feeder), resulting in 48 pigs per feeder (24 pigs per pen) for Exp. 4 and 50 pigs per feeder (25 pigs per

pen) in Exp. 5. There were 9 replicate feeders per treatment. Treatment diets were fed starting on d 10 (Exp. 4) or d 13 (Exp. 5) after weaning, and these days were considered d 0 of the experiments. Treatment diets were identical from d 0 to 14 in both experiments and were formulated to 1.35% standardized ileal digestible (SID) Lys (Table 3). In Exp. 4, a common diet with no acidifiers was fed from d 14 to 28 to monitor subsequent performance and was formulated to 1.30% SID Lys. In Exp. 5, instead of a common diet, a second phase of treatment diets (Control, 0.5% benzoic acid, 0.2% blend of phosphoric, fumaric, lactic, and citric acid, or 0.05% encapsulated butyric acid) was fed from d 14 to 28 and was formulated to 1.30% SID Lys. Pen weights and feed disappearance were measured on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and G:F. All experimental diets were in meal form and were manufactured at a commercial feed mill.

Combined Analysis

In addition to analyzing each experiment individually, data from all trials were combined to evaluate the overall effects of benzoic acid on growth performance. For Exp. 1 and 2, data from all treatments were included in the analysis. For Exp. 3, 4, and 5, only data from the control (no acidifier) and benzoic acid treatment were included in the model. All experiments were included in the d 0 to 14 analysis. Data from Exp. 4 was excluded from the d 14 to 28 analysis because a common diet containing no acidifier was fed from d 14 to 28.

Statistical Analysis

At the conclusion of each experiment, data were analyzed as a completely randomized design with pen (Exp. 1, 2 and 3) or feeder (Exp. 4 and 5) as the experimental unit. Experimental data were analyzed using analysis of variance in the MIXED procedure of SAS (SAS Inst. Inc.,

Cary, NC). For Exp. 1 and 2, treatments were arranged as 2 × 2 factorials with 2 benzoic acid levels and 2 diet complexities (Exp. 1) or 2 antimicrobial levels (Exp. 2). Main effects and interactions as fixed effects were analyzed. For Exp. 3, 4, and 5, analysis of variance was performed using the MIXED procedure of SAS.

When data from all experiments were combined, analysis of variance was conducted using the MIXED procedure of SAS. For Exp. 1 and 2, blocks were assigned to pens based on diet complexity (simple vs. complex) and antimicrobial inclusion (without vs. with). For Exp. 3, 4, and 5, all observations were assigned to 1 block. Block within experiment was included as a random effect.

For all data analysis, when a significant overall treatment difference was found, differences among treatments were determined using the PDIFF statement in SAS. Significant differences were declared at $P < 0.05$ and trends at $P < 0.10$.

RESULTS AND DISCUSSION

Experiment 1

No interactions were observed between diet complexity and benzoic acid on growth performance (Table 3). This is contrary to other research that has reported supplementation of acidifiers is more effective in simple diets without milk products (Giesting et al., 1991).

When different diet complexities were fed (d 0 to 14), pigs fed simple diets had decreased ($P < 0.05$) ADG, ADFI, and G:F compared with pigs fed complex diets (Table 4). This response was expected because the simple diet did not contain any lactose, animal protein, or zinc oxide. Our results agree with those of Mahan et al. (2004) who found that nursery pigs fed complex

diets with increased levels of animal protein (blood plasma and fish meal) and dried whey had increased ADG, ADFI, and G:F compared to pigs fed diets without animal protein and dried whey. In addition to protein sources and lactose levels, pharmacological levels of zinc oxide have also been shown to improve growth of early nursery pigs (Shelton et al., 2011). We found that pigs fed complex diets containing 2,000 mg/kg Zn from ZnO had improved growth, which is in agreement with Hill et al. (2001) who reported that supplementing ZnO at 1,500 to 2,000 mg/kg Zn improved early nursery pig performance.

From d 14 to 28, pigs previously fed simple diets tended to have increased ($P < 0.10$) ADG and improved ($P < 0.05$) G:F compared with pigs previously fed the complex diets. These differences appear to be a compensatory growth response from the pigs previously fed simple diets. Similar compensatory growth responses after feeding simple vs. complex diets have been observed by other researchers (Whang et al., 2000). Wolter et al. (2003) also found that pigs fed complex diets for 8 wk postweaning had improved nursery growth performance compared to pigs fed simple diets, but when pigs were followed through the finishing period, previous diet complexity did not influence final BW at market. Although the duration of feeding and dietary ingredients vary among experiments, multiple researchers have reported compensatory growth following the feeding of simple-postweaning diets (Zimmerman and Khajarern, 1973; Skinner et al., 2014).

Overall (d 0 to 28), the decreased growth during the first phase in pigs fed simple diets carried over into the overall data, causing decreased ($P < 0.05$) ADG and ADFI compared with pigs fed complex diets. Because of the differences in overall ADG, feeding complex diets from d 0 to 14 resulted in an approximately 1-kg heavier ($P < 0.05$) nursery pig at the end of the trial. Overall, G:F did not differ between pigs fed different diet complexities because of the

compensatory feed efficiency exhibited by pigs from d 14 to 28 after they were fed the simple diet from d 0 to 14.

Feeding diets with benzoic acid from d 0 to 14 did not affect ADG, ADFI, or G:F. Similar to d 0 to 14, when benzoic acid was added to the diet from d 14 to 28, there were no differences in ADG or G:F. Pigs fed diets containing benzoic acid from d 14 to 28 had a tendency for increased ($P < 0.10$) ADFI. Overall (d 0 to 28), there were no differences in ADG, ADFI, or G:F when benzoic acid was added to the diet. Conversely, Kluge et al. (2006) found that supplementing benzoic acid in wheat and barley-based nursery pig diets increased ADG and improved feed efficiency of pigs from 7 to 21 kg BW. Other European data agrees with Kluge et al. (2006), reporting that supplementation of benzoic acid improves growth performance of nursery pigs (Guggenbuhl et al., 2007; Torrallardona et al., 2007). The reason for varying responses to benzoic acid among our trials and European trials is unclear; however, the most evident difference among our experiment and European trials is the variation in dietary ingredients with corn-soybean meal diets used in our experiment.

The current experiment confirmed that feeding simple, corn-soybean meal–based diets did not allow for optimal growth of early nursery pigs. Although compensatory growth did occur from d 14 to 28, it was inadequate to compensate for the poorer ADG and ADFI exhibited from d 0 to 14. Thus, the complex diet served as the basal diet for subsequent experiments. Contrary to previous European data, our study suggests that there were no improvements in growth or efficiency when benzoic acid was included in the diet, regardless of diet complexity.

Experiment 2

To further explore the lack of response to benzoic acid in Exp. 1, the influence of dietary antimicrobials (carbadox) on the response to benzoic acid was tested in Exp. 2. No interactions

were observed among pigs fed carbadox and benzoic acid on growth performance during either phase or for the overall period (Table 5).

From d 0 to 14, there were no differences in ADG and ADFI between pigs fed diets with or without carbadox, but pigs fed carbadox tended to have poorer ($P < 0.10$) G:F than those fed diets without carbadox (Table 6). Although the addition of carbadox in phase 1 had little effect on growth, from d 14 to 28, pigs fed carbadox had increased ($P < 0.05$) ADG, ADFI, and G:F compared with pigs fed diets without carbadox. Similar results were reported by Yen and Pond (1987), where feeding 55 ppm carbadox to early nursery pigs improved BW gain and feed efficiency. For the overall trial (d 0 to 28), pigs fed added carbadox had increased ($P < 0.05$) ADG and ADFI but did not influence G:F. Improvements in nursery growth performance when feeding feed-grade antibiotics has been reported by numerous researchers (Coffey and Cromwell, 1995; Keegan et al. 2005). Dritz et al. (2002) found similar results to the present study where feeding antimicrobials to nursery pigs increased ADG but did not improve feed efficiency.

The inclusion of benzoic acid had no effect on ADG, ADFI, or G:F from d 0 to 14, d 14 to 28, or for the overall experiment. Although other research has reported improvements in growth performance when diets containing benzoic acid were fed (Kluge et al., 2006; Guggenbuhl et al., 2007; Torrallardona et al., 2007), our results agree with Exp. 1 where no differences in growth were found with supplementation of benzoic acid.

The lack of interaction between carbadox and benzoic acid for nursery pigs agrees with data from Che et al. (2012) who evaluated the effects of acidifiers (phosphoric, citric, and fumaric acids) and antimicrobials (carbadox) on nursery pig growth performance. The authors determined that the inclusion of acidifiers did not influence growth performance, but pigs fed carbadox had increased ADG compared to those fed diets without. Similarly, Walsh et al. (2007)

reported that nursery pigs fed a diet with carbadox and without acidifiers had improved growth performance compared to pigs fed a diet supplemented with an organic acid-blend and without antimicrobials.

Experiments 3, 4, and 5

Because of the lack of response to benzoic acid in Exp. 1 and 2, additional acidifiers were tested in Exp. 3, 4, and 5 and testing was done in both university (Exp. 3) and commercial (Exp. 4 and 5) environments. In Exp. 3, from d 0 to 14, pigs fed the blend of phosphoric, fumaric, lactic, and citric acid (Kem-Gest) had a tendency for increased ($P < 0.10$) ADG compared with pigs fed the other 3 treatments (Table 7). No differences were observed in ADFI or G:F among pigs fed any of the treatment diets. From d 14 to 28 and for the overall period (d 0 to 28), no differences were observed in ADG, ADFI, or G:F among treatments; therefore, feeding acidifiers did not influence growth performance in a university research setting. These results agree with Exp. 1 and 2 which were conducted at the same university research nursery.

For Exp. 4 (commercial research environment), when the treatment diets were fed from d 0 to 14, pigs fed the control diet had decreased ($P < 0.05$) ADG and G:F compared with pigs fed all diets with acidifiers (Table 8), but ADFI did not differ among treatments. When a common diet was fed from d 14 to 28, there were no differences in ADG, ADFI, or G:F among treatments. These results indicate that no compensatory growth occurred when pigs were removed from diets containing acidifiers. The improved growth performance from d 0 to 14 was not great enough to influence the overall growth data, resulting in no differences in ADG, ADFI, or G:F from d 0 to 28. Although no differences were found in growth for the overall data, pigs fed diets containing any of the 3 acidifiers were approximately 1 kg heavier in BW on d 14 compared with pigs fed

the control diet. This difference was maintained to d 28, resulting in a 1-kg heaver nursery pig at the end of the trial for pigs fed acidifiers.

Due to the improved growth response to acidifiers in Exp. 4, Exp. 5 was conducted at the same facility to further investigate the effect of acidifiers on nursery pig growth performance under the commercial research setting. No differences were observed in ADG, ADFI, or G:F in Exp. 5 among pigs fed the different dietary treatments from d 0 to 14, d 14 to 28, or for the overall trial (Table 9). Pigs housed in commercial research facilities are often considered to have a poorer health status than those in a university facility, which may allow for potential antimicrobial benefits to be observed from the acids. This does not, however, fully explain the varying responses between Exp. 4 and Exp. 5, which were conducted in the same facility. Ravindran and Kornegay (1993) and Tung and Pettigrew (2006) suggested that pig growth response to acidifiers is related to age. In our experiments, the greatest growth performance response to acidifiers was observed in pigs housed in a commercial environment with the lowest starting weight (5.8 kg BW, 10-d postweaning).

Note that the control fed pigs in Exp. 4 had a markedly reduced ADG compared to the control fed pigs in Exp. 5 and in accordance with the expected growth rate target for this age and weight of pig. Thus, an alternative explanation for the response in Exp. 4 is that there was some negative factor associated with the control diet reducing ADG. One would suspect a mixing error as a likely cause. However, a review of the batch production records and chemical analysis of the diets did not reveal any abnormalities detected.

Combined Analysis

When all trials were combined to evaluate the overall effect of benzoic acid, pigs fed diets with added benzoic acid had increased ($P < 0.05$) ADG and G:F from d 0 to 14. This was

partly due to numeric increases in ADG and G:F observed in Exp. 1, 2, and 5; however the response was primarily driven by the response observed in Exp. 4. There were no differences in ADFI when pigs were fed diets without or with benzoic acid. From d 14 to 28, the inclusion of benzoic acid had no effect on ADG, ADFI, or G:F.

Overall Conclusions

Supplementation of benzoic acid did not influence growth performance of nursery pigs housed in university research conditions (Exp. 1, 2, and 3). Additionally, the response to benzoic acid was not influenced by diet complexity (Exp. 1) or antimicrobial inclusion (Exp. 2). Nursery pigs fed complex diets or diets with antimicrobials had improved growth performance compared to pigs fed simple diets or diets without antimicrobials, respectively. When acidifiers were fed in a commercial setting, beneficial effects on growth performance were observed in one experiment (Exp. 4) but not the other (Exp. 5). The variation in response to acidifiers is likely influenced by health status, age, or starting weight of pigs. Due to the inconsistent responses among trials, further investigation is needed to effectively incorporate acidifiers in diets for nursery pigs.

LITERATURE CITED

Che, T. M., O. Adeola, M. J. Azain, S. D. Carter, G. L. Cromwell, G. M. Hill, D. C. Mahan, P. S. Miller, and J. E. Pettigrew. 2012. Effect of dietary acids on growth performance of nursery pigs: a cooperative study. J. Anim. Sci. 90:4408-4413.

Coffey, R. D., and G. L. Cromwell. 1995. The impact of environment and antimicrobial agents on the growth response of early-weaned pigs to spray-dried porcine plasma. J. Anim. Sci. 73:2532-2539.

Dritz, S. S., M. D. Tokach, R. D. Goodband, and J. L Nelssen. 2002. Effects of administration of antimicrobials in feed on growth rate and feed efficiency of pigs in multisite production systems. J. Am. Vet. Med. Assoc. 220:1690-1695.

Funderburke, D. W., and R. W. Seerley. 1990. The effects of postweaning stressors on pig weight change, blood, liver and digestive tract characteristics. J. Anim. Sci. 68:155-162.

Giesting, D. W., M. A. Roos, and R. A. Easter. 1991. Evaluation of the effect of fumaric acid and sodium bicarbonate addition on performance of start pigs fed diets of different types. J. Anim. Sci. 69:2489-2496.

Guggenbuhl, P., A. Seon, A. Pinon Quintana, and C. Simoes Nunes. 2007. Effects of dietary supplementation with benzoic acid (VevoVitall) on the zootechnical performance, the gastrointestinal microflora, and the ileal digestibility of the young pig. Livest. Sci. 108:218-221.

Hahn, J. D., and D. H. Baker. 1993. Growth and plasma zinc responses of young pigs fed pharmacological levels of zinc. J. Anim. Sci. 71:3020:3024.

Hill, G. M., D. C. Mahan, S. D. Carter, G. L. Cromwell, R. C. Ewan, R. L. Harrold, A. J. Lewis, P. S. Miller, G. C. Shurson, and T. L. Veum. 2001. Effect of pharmacological concentrations of zinc oxide with or without the inclusion of an antibacterial agent on nursery pig performance. J. Anim. Sci. 79:934-941.

Keegan, T. P., S. S. Dritz, J. L. Nelssen, J. M. DeRouchey, M. D. Tokach, and R. D. Goodband. 2005. Effects of in-feed antimicrobial alternatives and antimicrobials on nursery pig performance and weight variation. J. Swine Health Prod. 13(1):12-18.

Mahan, D. C., N. D. Fastinger, and J. C. Peters. 2004. Effects of diet complexity and dietary lactose levels during three starter phases on postweaning pig performance. J. Anim. Sci. 82:2790-2797.

Radecki, S. V., M. R. Juhl, and E. R. Miller. 1988. Fumaric and citric acids as feed additives in starter pig diets: effect on performance and nutrient balance. J. Anim. Sci. 1988 66:2598-2605.

Ravindran, V., and E. T. Kornegay. 1993. Acidification of weaner pig diets: a review. J. Sci. Food Agric. 62:313-322.

Shelton, N. W., M. D. Tokach, J. L. Nelssen, R. D. Goodband, S. S. Dritz, J. M. DeRouchey, and G. M. Hill. 2011. Effects of copper sulfate, tri-basic copper chloride, and zinc oxide on weanling pig performance. J. Anim. Sci. 89:2440-2451.

Skinner, L. D., C. L. Levesque, D. Wey, M. Rudar, J. Zhu, S. Hooda, and C. F. M. de Lange. 2014. Impact of nursery feeding program on subsequent growth performance, carcass quality, meat quality, and physical and chemical body composition of growing-finishing pigs. J. Anim. Sci. 92:1044:1054.

Smith, F., J. E. Clark, B. L. Overman, C. C. Tozel, J. H. Huang, J. E. F. Rivier, A. T. Blisklager, and A. J. Moeser. 2010. Early weaning stress impairs development of mucosal barrier function in the porcine intestine. Am. J. Physiol. Gastrointest. Liver Physiol. 298:G352-G363.

Stein, H. H. 2002. Experience of feeding pigs without antibiotics: a European perspective. Anim. Biotechnol. 13:85-95.

Torrallardona, D., I. Badiola, and J. Broz. 2007. Effects of benzoic acid on performance and ecology of gastrointestinal microbiota in weanling piglets. Livest. Sci. 108:210-213.

Tung, C. M., and J. E. Pettigrew. 2006. Critical review of acidifiers. http://www.pork.org/filelibrary/animalscience/reviewofacidifiers.pdf Accessed Aug. 1, 2014.

Whang, K. Y., F. K. McKeith, S. W. Kim, and R. A. Easter. 2000. Effect of starter feeding program on growth performance and gains of body components from weaning to market weight in swine. J. Anim. Sci. 78:2885-2895.

Wolter, B. F., M. Ellis, B. P. Corrigan, J. M. DeDecker, S. E. Curtis, E. N. Parr, and D. M. Webel. 2003. Impact of early postweaning growth rate as affected by diet complexity and space allocation on subsequent growth performance of pigs in a wean-to-finish production system. J. Anim. Sci. 81:353-359.

Yen, J. T., and W. G. Pond. 1987. Effect of dietary supplementation with vitamin C or carbadox on weanling pigs subjected to crowding stress. J. Anim. Sci. 64:1672-1681.

Zimmerman, D. R., and S. Khajarern. 1973. Starter protein nutrition and compensatory responses in swine. J. Anim. Sci. 36:189-194.

TABLES

Table 4-1. Diet composition (as-fed basis), Exp. 1, 2, and 3[1]

	d 0 to 14[2]		
Item	Simple	Complex	d 14 to 28
Ingredient, %			
Corn	63.17	56.93	64.50
Soybean meal, 46.5% CP	32.27	26.39	32.15
Select menhaden fish meal	---	1.25	---
Spray-dried blood cells	---	1.25	---
Spray-dried whey	---	10.0	---
Monocalcium P, 21% P	1.30	0.85	1.05
Limestone	0.90	0.80	1.00
Salt	0.30	0.30	0.35
Zinc oxide	---	0.25	---
Trace mineral premix[3]	0.15	0.15	0.15
Vitamin premix[4]	0.25	0.25	0.25
L-Lys·HCl	0.375	0.295	0.325
DL-Met	0.125	0.140	0.100
L-Thr	0.140	0.125	0.110
Phytase[5]	0.019	0.019	0.019
Diatomacious earth	1.00	1.00	---
Total	100.0	100.0	100.0
Calculated analysis			
Standardized ileal digestible amino acids (SID), %			
Lys	1.30	1.30	1.26
Ile:Lys	60	56	62
Leu:Lys	125	129	130
Met:Lys	32	33	31
Met + Cys:Lys	56	56	56
Thr:Lys	62	62	62
Trp:Lys	17.0	17.0	18
Val:Lys	66	69	68
Total Lys, %	1.43	1.43	1.39
ME, kcal/kg	3,280	3,263	3,316
CP, %	20.9	20.7	20.9
Ca, %	0.71	0.71	0.70
P, %	0.67	0.63	0.62
Available P, %	0.46	0.47	0.41

[1]A total of 280 (Exp. 1), 240 (Exp. 2), and 280 (Exp. 3) weanling pigs (PIC 327 × 1050) were used in 28-d trials.

[2]In Exp. 1, simple or complex diets with or without 0.5% benzoic acid were fed from d 0 to 14. The complex diet was used as the basal diet from d 0 to 14 for Exp. 2 and 3. In Exp. 2, diets contained 0 or 0.5% benzoic acid and 0 or 50 g/ton of carbadox from d 0 to 14 and diets contained 0 or 0.5% benzoic acid and 0 or 25 g/ton of carbadox from d 14 to 28. In Exp. 3, diets contained no acidifier, 0.5% benzoic acid (Vevovitall; DSM Nutritional Products, Parsippany, NJ), 0.2% of a blend of phosphoric, fumaric, lactic, and citric acid (Kem-Gest; Kemin Americas, Des Moines, IA), or 0.05%

encapsulated butyric acid (ButiPearl; Kemin Americas) for both phases.

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

[4]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}.

[5]Ronozyme CT (10,000) (International Nutrition, Omaha, NE), providing 840 phytase units (FTU)/lb and an estimated release of 0.10% available P.

Table 4-2. Diet composition, Exp. 4 and 5 (as-fed basis)[1,2]

	d 0 to 14	d 14 to 28[3]
Item	Control	Control
Ingredient[4], %		
Corn	42.29	51.34
Soybean meal, 46.5% CP	27.55	29.54
Dried distillers grains with solubles	15.00	15.00
Spray-dried blood cells	1.00	---
Spray-dried whey	10.0	---
Dicalcium P, 18.5% P	0.75	1.13
Limestone	1.45	1.50
Salt	0.35	0.50
Zinc oxide	0.25	---
Vitamin-trace mineral premix[4]	0.30	0.30
L-Lys·HCl	0.400	0.450
DL-Met	0.160	0.135
L-Thr	0.125	0.115
Denagard 10	0.175	---
CTC-100	0.200	---
Total	100.0	100.0
Calculated analysis		
Standardized ileal digestible (SID) amino acids, %		
Lys	1.35	1.30
Ile:Lys	59	61
Leu:Lys	137	136
Met:Lys	35	35
Met + Cys:Lys	58	58
Thr:Lys	63	61
Trp:Lys	17.4	17.2
Val:Lys	70	68
Total Lys, %	1.53	1.48
ME, kcal/kg	3,223	3,250
Ca, %	0.90	0.93
P, %	0.60	0.64
Available P, %	0.46	0.46

[1]A total of 1,728 (Exp. 4) and 1,800 (Exp. 5) nursery pigs (PIC 327 × 1050) were used in 28-d trials conducted at a commercial research nursery facility to evaluate the effect of 3 commercial acidifiers on growth performance.

[2]In addition to the control diet, pigs were fed 0.5% benzoic acid (Vevovitall; DSM Nutritional Products, Parsippany, NJ), 0.2% of a blend of phosphoric, fumaric, lactic, and citric acid (Kem-Gest; Kemin Americas, Des Moines, IA), or 0.05% encapsulated butyric acid (ButiPearl; Kemin Americas)

[3]From d 14 to 28, only the control diet was fed in Exp. 1, and all 4 treatment diets were fed in Exp. 2.

[4]Provided per kilogram of premix: 4,003,598 IU vitamin A; 727,526 IU vitamin D_3; 20,040 IU vitamin E; 1,470 mg vitamin K; 2,776 mg riboflavin; 9,520 mg pantothenic acid; 16,535 mg niacin; 11 mg vitamin B_{12}, 35.3 g Fe from ferrous sulfate, 35.3 g Zn from zinc sulfate, 160 g Cu from copper sulfate,

8.8 g Mn from manganese sulfate, 220.5 mg I from calcium iodate, and 100.3 mg Se from sodium selenite.

Table 4-3. Effect of diet complexity and benzoic acid on growth performance of nursery pigs, Exp. 1[1]

Complexity:[2]	Simple	Simple	Complex	Complex		Probability, *P* <		
Benzoic acid:[3]	0	0.5%	0	0.5%	SEM	Complexity × benzoic acid	Complexity	Benzoic acid
d 0 to 14								
ADG, g	186	191	272	281	10.01	0.784	0.001	0.552
ADFI, g	304	299	381	381	13.30	0.820	0.001	0.965
G:F	0.612	0.636	0.714	0.738	0.020	0.968	0.001	0.230
d 14 to 28								
ADG, g	576	594	567	567	15.56	0.334	0.057	0.368
ADFI, g	844	875	853	885	17.88	0.883	0.570	0.096
G:F	0.683	0.679	0.665	0.641	0.019	0.408	0.003	0.165
d 0 to 28								
ADG, g	381	390	417	422	12.90	0.716	0.001	0.396
ADFI, g	572	590	617	630	15.61	0.996	0.003	0.277
G:F	0.667	0.662	0.676	0.669	0.019	0.556	0.305	0.634
BW, kg								
d 0	7.0	7.0	7.0	7.0	0.081	0.954	0.969	0.986
d 14	9.6	9.6	10.8	10.9	0.171	0.721	0.001	0.536
d 28	17.6	17.9	18.7	18.8	0.269	0.800	0.001	0.401

[1]A total of 280 weanling pigs (PIC 327 × 1050) were used with 7 pigs per pen and 10 pens per treatment.

[2]Pigs were fed complex or simple diets from d 0 to 14. From d 14 to 28, pigs were fed the same basal diet formulation with or without benzoic acid.

[3]Pigs were fed diets without or with benzoic acid from d 0 to 28. Vevovitall (DSM Nutritional Products; Parsippany, NJ) was used as the source of benzoic acid.

Table 4-4. Main effects of diet complexity and benzoic acid on growth performance of nursery pigs, Exp. 1[1]

	Complexity[2]			Benzoic acid[3]			Probability, $P <$	
	Simple	Complex	SEM	0	0.5%	SEM	Complexity	Benzoic acid
d 0 to 14								
ADG, g	188	275	7.45	228	235	7.45	0.001	0.552
ADFI, g	303	380	8.85	342	341	8.85	0.001	0.965
G:F	0.618	0.724	0.010	0.662	0.680	0.010	0.001	0.230
d 14 to 28								
ADG, g	584	565	6.72	570	579	6.72	0.057	0.368
ADFI, g	859	869	13.05	848	880	13.05	0.570	0.096
G:F	0.681	0.651	0.007	0.673	0.660	0.007	0.003	0.165
d 0 to 28								
ADG, g	386	420	6.17	399	407	6.17	0.001	0.396
ADFI, g	581	625	9.92	595	611	9.92	0.003	0.277
G:F	0.665	0.673	0.006	0.671	0.667	0.006	0.305	0.634
BW, kg								
d 0	7.0	7.0	0.035	7.0	7.0	0.035	0.969	0.986
d 14	9.6	10.8	0.121	10.2	10.3	0.121	0.001	0.536
d 28	17.8	18.8	0.190	18.2	18.4	0.190	0.001	0.401

[1]A total of 280 weanling pigs (PIC 327 × 1050) were used with 7 pigs per pen and 20 pens per main effect treatment.

[2]Pigs were fed complex or simple diets from d 0 to 14. From d 14 to 28, a common diet was fed that did not differ in complexity.

[3]Pigs were fed diets without or with 0.5% Vevovitall (DSM Nutritional Products; Parsippany, NJ) from d 0 to 28.

Table 4-5. Effect of benzoic acid and antimicrobials on growth performance of nursery pigs, Exp. 2[1]

Antimicrobial:[2]	---	---	Carbadox	Carbadox		Probability, *P* <		
Benzoic acid, %:[3]	---	0.5	---	0.5	SEM	Benzoic acid × antimicrobial	Benzoic acid	Antimicrobial
d 0 to 14								
ADG, g	290	295	290	304	10.98	0.609	0.333	0.565
ADFI, g	395	399	413	431	14.15	0.598	0.509	0.118
G:F	0.736	0.739	0.703	0.705	0.020	0.965	0.466	0.058
d 14 to 28								
ADG, g	544	562	594	617	16.06	0.794	0.108	0.001
ADFI, g	848	866	894	912	19.11	0.994	0.234	0.009
G:F	0.642	0.649	0.665	0.677	0.018	0.767	0.341	0.002
d 0 to 28								
ADG, g	417	426	440	458	13.58	0.722	0.143	0.007
ADFI, g	621	630	653	671	16.70	0.861	0.323	0.023
G:F	0.672	0.676	0.674	0.682	0.019	0.794	0.273	0.214
BW, kg								
d 0	7.3	7.3	7.3	7.3	0.070	0.961	0.979	0.962
d 14	11.3	11.4	11.3	11.6	0.203	0.671	0.433	0.634
d 28	19.0	19.3	19.6	20.3	0.339	0.569	0.200	0.019

[1]A total of 240 weanling pigs (PIC 327 × 1050) were used in a 28-d trial to evaluate the effects of benzoic acid and antimicrobials on growth performance. There were 6 pigs per pen and 10 pens per treatment.

[2]Mecadox (Philbro Animal Health Corp., Ridgefield Park, NJ) was added as a source of carbadox at 50 g/ton from d 0 to 14 and 25 g/ton from d 14 to 28.

[3]Vevovitall (DSM Nutritional Products; Parsippany, NJ) was included in from d 0 to 14 and d 14 to 28 at 0.5% of the diet.

Table 4-6. Main effect of benzoic acid and antimicrobials on growth performance of nursery pigs, Exp. 2[1]

	Benzoic acid, %[2]			Antimicrobial[3]			Probability, *P* <	
	---	0.5	SEM	None	Carbadox	SEM	Benzoic acid	Antimicrobial
d 0 to 14								
ADG, g	288	300	8.20	291	297	8.20	0.333	0.565
ADFI, g	403	413	10.70	396	420	10.70	0.509	0.118
G:F	0.716	0.726	0.009	0.734	0.708	0.009	0.466	0.058
d 14 to 28								
ADG, g	568	588	8.46	552	604	8.46	0.108	0.001
ADFI, g	870	890	11.78	857	903	11.78	0.234	0.009
G:F	0.653	0.660	0.005	0.644	0.669	0.005	0.341	0.002
d 0 to 28								
ADG, g	428	443	7.13	421	450	7.13	0.143	0.007
ADFI, g	636	651	10.36	626	661	10.36	0.323	0.023
G:F	0.673	0.681	0.005	0.672	0.681	0.005	0.273	0.214
BW, kg								
d 0	7.3	7.3	0.049	7.3	7.3	0.049	0.979	0.962
d 14	11.4	11.5	0.143	11.5	11.4	0.143	0.433	0.634
d 28	19.3	19.8	0.240	19.1	20.0	0.240	0.200	0.019

[1]A total of 240 weanling pigs (PIC 327 × 1050) were used in a 28-d trial to evaluate the effects of benzoic acid and antimicrobials on growth performance. There were 6 pigs per pen and 20 pens per main effect treatment.

[2]Pigs were fed diets without or with 0.5% Vevovitall (DSM Nutritional Products, Parsippany, NJ) from d 0 to 28.

[3]Mecadox (Philbro Animal Health Corp., Ridgefield Park, NJ) was added as a source of carbadox at 50 g/ton from d 0 to 14 and 25 g/ton from d 14 to 28.

Table 4-7. Effect of acidifiers on growth performance of nursery pigs under university research conditions, Exp. 3[1]

		Acidifier[2]				
	Control	Benzoic acid[3]	Acid blend[4]	Butyric acid[5]	SEM	Probability, *P* <
d 0 to 14						
ADG, g	245	236	263	240	10.96	0.066
ADFI, g	345	336	367	349	13.80	0.335
G:F	0.711	0.703	0.716	0.688	0.025	0.589
d 14 to 28						
ADG, g	481	476	463	476	15.11	0.676
ADFI, g	771	776	757	753	21.92	0.808
G:F	0.624	0.614	0.611	0.633	0.032	0.682
d 0 to 28						
ADG, g	372	363	372	367	14.83	0.897
ADFI, g	572	572	576	567	19.85	0.972
G:F	0.651	0.635	0.646	0.648	0.022	0.855
BW, kg						
d 0	6.9	6.9	6.9	6.9	0.087	0.994
d 14	10.1	9.9	10.1	10.0	0.198	0.473
d 28	17.3	17.1	17.3	17.1	0.388	0.812

[1] A total of 280 weanling pigs were used with 7 pigs per pen and 10 pens per treatment. Treatment diets were fed starting on d 3 after weaning.
[2] Acidifiers were fed from d 0 to 28.
[3] 0.5% benzoic acid (Vevovitall; DSM Nutritional Products, Parsippany, NJ).
[4] 0.2% blend of phosphoric, fumaric, lactic, and citric acid (KemGest; Kemin Americas, Des Moines, IA).
[5] 0.05% encapsulated butyric acid (Butipearl; Kemin Americas, Des Moines, IA).

Table 4-8. Effect of acidifiers on growth performance of nursery pigs fed under field conditions, Exp. 4[1]

		Acidifier[2]				
	Control	Benzoic acid[3]	Acid blend[4]	Butyric acid[5]	SEM	Probability, $P <$
d 0 to 14						
ADG, g	299[a]	367[b]	354[b]	363[b]	11.98	0.001
ADFI, g	408	454	435	440	16.32	0.286
G:F	0.733[a]	0.810[b]	0.813[b]	0.825[b]	0.009	0.001
d 14 to 28						
ADG, g	467	472	467	463	12.02	0.971
ADFI, g	567	585	590	585	13.15	0.637
G:F	0.824	0.806	0.792	0.791	0.017	0.564
d 0 to 28						
ADG, g	381	417	413	413	10.45	0.096
ADFI, g	485	517	513	513	12.86	0.367
G:F	0.785	0.807	0.805	0.805	0.010	0.342
BW, kg						
d 0	5.8	5.9	5.8	5.8	0.119	0.995
d 14	10.1[a]	11.2[b]	11.0[b]	11.1[b]	0.246	0.013
d 28	16.7	17.8	17.6	17.6	0.371	0.148

[1]A total of 1,728 nursery pigs (PIC 327 × 1050) were used. Each number represents the mean of 9 feeders. Each feeder was accessible by 2 adjacent pens (1 barrow and 1 gilt pen per feeder). There were 24 pigs per pen. Treatment diets were fed starting on d 10 after weaning.

[2]Treatment diets were fed from d 0 to 14 of the trial. A common diet with no acidifiers was fed from d 14 to 28 to determine any effects on subsequent performance.

[3] 0.5% benzoic acid (Vevovitall; DSM Nutritional Products, Parsippany, NJ).

[4] 0.2% blend of phosphoric, fumaric, lactic, and citric acid (KemGest; Kemin Americas, Des Moines, IA).

[5] 0.05% encapsulated butyric acid (Butipearl; Kemin Americas, Des Moines, IA).

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

Table 4-9. Effect of acidifiers on growth performance of nursery pigs fed under field conditions, Exp. 5[1]

		Acidifier[2]				
	Control	Benzoic acid[3]	Acid blend[4]	Butyric acid[5]	SEM	Probability, $P <$
d 0 to 14						
ADG, g	358	363	363	345	7.50	0.181
ADFI, g	544	535	522	508	13.46	0.321
G:F	0.658	0.678	0.696	0.679	0.010	0.143
d 14 to 28						
ADG, g	445	440	422	449	10.49	0.250
ADFI, g	748	748	694	730	21.42	0.268
G:F	0.594	0.588	0.608	0.615	0.008	0.284
d 0 to 28						
ADG, g	404	404	390	395	7.46	0.652
ADFI, g	644	640	608	621	14.02	0.233
G:F	0.627	0.631	0.642	0.635	0.006	0.121
BW, kg						
d 0	7.4	7.4	7.4	7.4	0.118	0.998
d 14	12.5	12.5	12.5	12.2	0.204	0.638
d 28	18.8	18.8	18.5	18.6	0.275	0.776

[1]A total of 1,800 nursery pigs (PIC 327 × 1050) were used. Each number represents the mean of 9 feeders. Each feeder was accessible by 2 adjacent pens (1 barrow and 1 gilt pen per feeder). There were 25 pigs per pen. Treatment diets were fed starting on d 13 after weaning.

[2]Acidifiers were fed from d 0 to 28.

[3] 0.5% benzoic acid (Vevovitall; DSM Nutritional Products, Parsippany, NJ).

[4] 0.2% blend of phosphoric, fumaric, lactic, and citric acid (KemGest; Kemin Americas, Des Moines, IA).

[5] 0.05% encapsulated butyric acid (Butipearl; Kemin Americas, Des Moines, IA).

Table 4-10. Combined effects of benzoic acid on growth performance of nursery pigs[1]

	Benzoic acid, %[2]			Probability, *P* <
	---	0.5	SEM	Benzoic acid
d 0 to 14[3]				
ADG, g	277	291	21.96	0.018
ADFI, g	398	404	28.59	0.346
G:F	0.696	0.716	0.019	0.011
d 14 to 28[4]				
ADG, g	534	542	25.74	0.199
ADFI, g	827	844	30.18	0.107
G:F	0.645	0.642	0.013	0.477

[1]Data from all 5 trials were combined to evaluate the overall effect of benzoic acid on growth performance.

[2]For Exp. 1 and 2, data from all treatments were included in the analysis. Blocks were assigned to pens based on diet complexity (simple vs. complex) and antimicrobial inclusion (without vs. with) for Exp. 1 and 2, respectively. Block within experiment was included as a random effect. For Exp. 3, 4, and 5, only data from the control (no acidifier) and benzoic acid fed pigs were included in the model.

[3]All experiments were included in the d 0 to 14 analysis.

[4]Data from Exp. 4 was excluded from the d 14 to 28 analysis because a common diet containing no acidifier was fed from d 14 to 28