THE EFFECTS OF DIETARY SOYBEAN HULLS, WHEAT, CRYSTALLINE AMINO ACIDS AND HIGH PROTEIN CORN DRIED DISTILLER'S GRAINS ON NURSERY AND/OR FINISHING PIG GROWTH AND CARCASS CHARACTERISTICS

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Abstract

Six experiments using 3,659 nursery and finishing pigs were conducted to evaluate the effects of dietary soybean hulls and ingredient processing in corn-soybean meal or corn-soybean meal-DDGS diets on nursery and finishing performance. Experiment 1 tested increasing soybean hulls (0, 5, 10, 15, and 20%) and increasing soybean hulls decreased ADG and G:F. Experiment 2 evaluated increasing soybean hulls (0, 10, and 20%) in diets balanced or not for NE and showed reduced performance with increasing soybean hulls. Balancing for NE resulted in G:F similar to pigs fed the control. Experiments 3 and 4 evaluated increasing dietary soybean hulls in corn-soybean meal and corn-soybean meal-DDGS diets. Soybean hulls in either diet worsened G:F and improved caloric efficiency, suggesting current INRA (2004) values for soybean hulls underestimate their energy value. Experiment 5 evaluated 10 and 20% ground or unground soybean hulls in meal and pelleted diets. Caloric efficiency improved with high levels of soybean hulls. Pelleting improved ADG and eliminated negative effects on G:F with increasing soybean hulls, while grinding soybean hulls reduced performance. Experiment 6 tested increasing ground and unground soybean hulls (0, 7.5, and 15%). Increasing soybean hulls worsened G:F, carcass yield, and hot carcass weight. Grinding soybean hulls to finer particle sizes did not improve ADG and worsened G:F. Experiments 7 and 8 evaluated the replacement of corn with wheat and crystalline amino acids in nursery and finishing pig diets. Replacing 50% of corn with wheat did not affect growth performance in either nursery or finishing; however 100% replacement of corn with wheat reduced performance. In addition, feeding wheat improved carcass fat IV, while use of high levels of crystalline amino acids in wheat-based diets did not influence performance in either study. Experiment 9 evaluated the replacement of soybean meal with high-protein dried distiller's grains with solubles and crystalline amino acids. High-protein DDGS and crystalline AA can replace 50% of the SBM in finishing diets without negatively affecting performance or carcass yield. Replacing 100% of SBM with high-protein DDGS reduced growth rate, but increasing crystalline AA levels can help mitigate negative effects on carcass yield and fat IV.

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Chapter 1 - The effects of soybean hulls level, distillers dried grains with solubles and NE formulation on nursery pig performance.

ABSTRACT

Four experiments were conducted to investigate the effects of added dietary soybean hulls and their use with distillers dried grains with solubles (DDGS) or with NE formulation on nursery pig performance. In Exp. 1, a total of 210 nursery pigs (6.6 ± 0.1 kg BW and 28 d of age) were used in a 34 d study. Pigs were fed 1 of 5 diets that contained increasing soybean hulls (0, 5, 10, 15, and 20%). Diets were not balanced for energy. Increasing soybean hulls decreased (linear, $P < 0.01$) ADG and G:F, and tended to decrease ADFI (quadratic, $P < 0.10$). In Exp. 2, 210 nursery pigs (13.6 ± kg BW and 35 d of age) were used in a 20 d study to determine the effect of NE formulation in diets with soybean hulls. Pigs were fed 1 of 5 diets containing 0, 10, or 20% soybean hulls either balanced on a NE basis to the control diet or not balanced for energy. Diets balanced to equal NE contained 3.6 and 7.15% added soybean oil in the 10 and 20% soybean hull diets, respectively. Increasing soybean hulls decreased (linear, $P < 0.01$) ADG regardless of formulation method; however, pigs fed increasing soybean hulls without added fat had similar ADFI but decreased (linear, $P < 0.01$) G:F. Pigs fed diets containing soybean hulls balanced for NE had decreased (linear, $P < 0.02$) ADFI, but improved ($P < 0.01$) G:F compared with pigs fed soybean hulls with no added fat, resulting in G:F similar to pigs fed the control diet. In Exp. 3, 600 pigs (BW 6.7 ± 0.1 kg BW and 28 d of age) were used in a 42 d study. Pigs were fed one of 10 diets containing 0, 3, 6, 9, or 12% soybean hulls without or with DDGS (15% from d 0 to 21, 30% from d 15 to 42). Adding soybean hulls decreased G:F quadratically ($P < 0.03$) when added to diets without DDGS, but decreased G:F linearly ($P < 0.01$) in diets with DDGS (soybean hull × DDGS interaction, $P < 0.05$). Adding soybean hulls did not influence ADG or ADFI, but adding DDGS reduced ($P < 0.04$) ADG and ADFI, and tended to increase ($P < 0.06$) G:F. In Exp. 4, 304 barrows (BW 11.7 ± 0.2 kg BW and 35 d of age) were used in a 21 d study. Pigs were fed 1 of 8 diets containing 0, 5, 10, or 15% soybean hulls with or without 20% DDGS. No soybean hull × DDGS interactions were observed. Increasing soybean hulls tended to decrease (linear, $P < 0.08$) G:F. Pigs fed diets with increasing soybean hulls without DDGS had decreased G:F (linear, $P < 0.04$). Overall, these studies show 5% soybean hulls did not affect nursery pig performance. Higher soybean hulls levels worsened G:F, but improved caloric efficiency, indicating published energy values (INRA, 2004) undervalues the energy content of soybean hulls.

Key words: DDGS, growth, net energy, nursery pig, soybean hulls

INTRODUCTION

Soybeans make up 56% of world oilseed production with 83.18 million metric tons produced in the United States in 2011 (Soy Stats®, 2012). The majority of soybeans in the United States are processed by solvent extraction procedures to produce the main products of oil and soybean meal. During soybean preparation, the seed is cracked or dehulled and the hulls are removed from the rest of the soybean. The hulls are then marketed as an ingredient co-product to be used in livestock diets. However, due to the soybean hull's high fiber and ash content, it has a much lower published energy value then other common ingredients, (corn NE = 2,650 kcal/kg; soybean hulls NE = 1,003 kcal/kg; INRA 2004). Furthermore, limited data is available evaluating the effects soybean hulls on nursery pig performance with the majority of research before the year 2000 (Kornegay, 1978; Gore et al., 1986; Kornegay et al., 1995) with a consensus that increasing soybean hulls from 8 to 16% decreased G:F. Furthermore, only two papers evaluating soybean hulls were published in the last decade (Barbosa et al., 2008; Moreira et al., 2009).

Dried distillers grains with solubles (**DDGS**) is a co-product from ethanol production commonly used in swine diets. Whitney and Shurson (2004) reported DDGS could be included in diets for nursery pigs weighing 8 to 24 kg BW at an inclusion of 25% without negatively affecting growth performance. However, no data is available using DDGS and soybean hulls together in nursery diets.

Therefore, the objectives of these studies was to determine: 1) the effects of increasing soybean hulls (0 to 20%) on nursery pig performance; 2) whether balancing diets on a NE-basis by adding dietary fat affects pig performance, and 3) the influence of using soybean hulls and DDGS in combination on growth performance of nursery pigs in a research and commercial settings.

MATERIALS AND METHODS

General

All experimental procedures and animal care were approved by the Kansas State Institutional Animal Care and Use Committee. The ME values for corn and soybean hulls used in diet formulation were 3,420 kcal/kg (NRC, 1998) and 1,864 kcal/kg (INRA, 2004), respectively. The NE values used in formulation for corn and soybean hulls were 2,650 and 1,003 kcal/kg (INRA, 2004), respectively. Dietary ME and NE were allowed to decrease with the inclusion of soybean hulls except for Exp. 2 when a portion of the treatments were balanced to a constant NE. In all experiments, caloric efficiencies of pigs were determined on both an ME (NRC, 1998) and NE (INRA, 2004) basis. Efficiencies were calculated by multiplying total feed intake by energy content of the diet (kcal/kg) and dividing by total gain.

Experiment 1

A total of 210 pigs (327 × 1050; PIC, Hendersonville, TN; initially 6.6 ± 0.1 kg BW and 28 d of age) were used in 34 d growth experiment to evaluate the effects of soybean hulls in corn-soybean meal-based nursery pig diets. Pigs were allotted to pens by BW, and pens were assigned to 1 of 5 treatments in a completely randomized design. There were 7 pigs per pen and 6 replications per treatment. Five dietary treatments consisted of corn-soybean meal-based diets and were formulated with increasing soybean hulls: 0, 5, 10, 15, and 20% soybean hulls. Diets were in meal form and pigs were fed in 2 phases from d 0 to 13 and d 13 to 34 (Table 1.1). Treatment diets were formulated to a constant standardized ileal digestible (SID) lysine of 1.32% in phase 1 and 1.28% in phase 2. The SID lysine levels were selected based on the required level for the diets without soybean hulls.

This experiment was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. Each pen (1.22 × 1.52 m) contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pig weight and feed disappearance were measured weekly to determine ADG, ADFI, and G:F. All diets were manufactured at the Kansas State University Animal Sciences Feed Mill. Samples of each diet were collected from every feeder for each phase and subsampled into a composite sample of each treatment for both phases.

Experiment 2

A total of 210 pigs (327 × 1050; PIC, Hendersonville, TN; initially 13.6 ± 0.1 kg BW and 35 d of age) were used in a 20 d growth experiment to determine the effects of increasing dietary soybean hulls with or without a constant NE level on nursery pig performance. Pigs were allotted to pens by initial BW, and pens were assigned to 1 of 5 dietary treatments in a completely randomized design. There were 7 pigs per pen with 6 replications per treatment. All pigs were initially fed a common commercial diet for the first 14 d after weaning. Starting on d 14 post-weaning (d 0 of the experiment), pigs were fed the experimental diets. Diets were fed in meal form from d 0 to 20 (Table 1.2). The 5 treatments were corn-soybean meal-based diets and included 10 or 20% soybean hulls either balanced on a NE basis equal to the corn-soybean meal diet or 10 or 20% soybean hulls not balanced for energy. Diets were formulated to a constant SID lysine of 1.28% and the SID lysine levels fed were selected based on the required level for the diets without soybean hulls. The diets balanced for NE contained 3.6 and 7.15% added soybean oil in the 10 and 20% soybean hull diets to achieve the same NE as the control diet.

This experiment was conducted, feed manufactured, and samples collected similar to that of Exp. 1. Pig weight and feed disappearance were measured on d 0, 7, 13, and 20 of the trial to determine ADG, ADFI, and G:F.

Experiment 3

A total of 600 pigs (C-29 × 359; PIC, Hendersonville, TN; initially 6.6 ± 0.1 kg BW and 28 d of age) were used in a 42 d growth study to evaluate the effects of soybean hulls in corn-soybean meal-based diets with and without DDGS on nursery pig growth performance. Pigs were allotted to pens by initial BW and pens of pigs were blocked by initial pen weight, gender, and room location and assigned to 1 of 10 treatments. There were 10 pigs per pen (5 barrows and 5 gilts) and 10 replications per dietary treatment. All pigs were fed a common pelleted starter diet for 10 d after weaning. Starting on d 10 post-weaning (d 0 of the experiment), pigs were fed the experimental diets. Diets were fed in meal form in 2 phases from d 0 to 14 and d 14 to 42 (Table 1.3 and 1.4). The 10 treatments included diets containing 0, 3, 6, 9, or 12% ground soybean hulls (408 µ) in either corn-soybean meal or corn-soybean meal-DDGS–based diets (15 and 30% DDGS for Phases 1 and 2, respectively).

A single batch of soybean hulls was ground at the Kansas State University Grain Science Feed Mill through a hammer mill (P-250D Pulverator, Jacobson Machine Works, Minneapolis, MN) equipped with a 1.59 mm screen and shipped to Kalmbach Feeds, Inc. (Upper Sandusky, OH) for diet manufacturing. All diets within each phase were formulated on a common SID lysine concentration of 1.32% in phase 1 and 1.28% in phase 2. The SID lysine levels fed were selected based on the required level for the diets without soybean hulls. All Phase 1 diets contained 4% fish meal and 10% spray-dried whey.

This experiment was conducted at the Cooperative Research Farm's Swine Research Nursery (Sycamore, OH), which is owned and managed by Kalmbach Feeds, Inc. Each pen had slatted metal floors and was equipped with a 4-hole stainless steel feeder and on nipple-cup waterer for ad-libitum access to feed and water. Individual pen weight and feed disappearance were measured weekly to determine ADG, ADFI, and G:F. Samples of each dietary treatment were collected from every feeder for each phase and sent to Kansas State University where they were subsampled into composite samples of each treatment for both phases.

Experiment 4

A total 304 pigs (1050; PIC, Hendersonville TN; initially 11.7 ± 0.2 kg BW and 35 d of age) were used in a 21 d growth trial to determine the effects of soybean hulls in corn-soybean meal-based diets with and without corn dried distillers grains with solubles (DDGS) on nursery pig growth performance. Pigs were allotted to pens by BW, and pens were assigned to 1 of 8 treatments. There were 9 replicate pens per treatment with 4 to 5 pigs per pen. All pigs were initially fed common commercial diets for the first 14 d. On d 14 post-weaning (d 0 of the experiment), diets comprising the 8 experimental treatments were fed to the nursery pigs. Treatments were arranged in a 2 × 4 factorial with main effects of DDGS (0 or 20%) and soybean hulls (0, 5, 10, and 15%). Diets were fed in meal form from d 0 to 21 (Table 1.5). Treatment diets were formulated to a constant SID lysine level of 1.28%. The SID lysine levels fed were selected based on the required level for the diets without soybean hulls.

This experiment was conducted at the Kansas State University Segregated Early Weaning Research Facility in Manhattan, KS. Each pen (1.22 × 1.22 m) contained a 4-hole dry self-feeder and 1 cup waterer to provide ad libitum access to feed and water. Pig weight and feed disappearance were measured weekly to determine ADG, ADFI, and G:F. All diets were manufactured at the Kansas State University Animal Sciences Feed Mill. Samples of each dietary treatment were collected from every feeder for each phase and subsampled into a composite sample of each treatment for both phases.

Chemical Analysis

In all four experiments, soybean hulls were collected at the time of feed manufacturing and a single composite sample for each experiment was analyzed for moisture (AOAC 934.01, 2006), CP (AOAC 990.03, 2006), ADF (ANKOM Technology, 1998a), NDF (ANKOM Technology, 1998b), crude fiber (AOAC 978.10, 2006), Ca (AOAC 965.14/985.01, 2006.), and P (AOAC 965.17/985.01, 2006) at Ward Laboratories (Kearney, NE). Composite diet samples by treatment for each phase were measured for bulk density using a Seedburo test weight apparatus and computerized grain scale (Seedburo Model 8800, Seedburo Equipment, Chicago, IL).

For Exp. 3 and 4, DDGS were collected at the time of feed manufacturing and a single composite sample for each experiment was analyzed for the same analyses as described for the soybean hulls with the addition of crude fat (AOAC 920.39 A, 2006).

Statistical Analysis

In all four experiments, data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. In Exp. 1, polynomial contrasts were used to compare linear and quadratic effects of increasing soybean hulls. In Exp. 2, pre-planned polynomial contrasts were used to compare linear and quadratic effects of increasing soybean hulls with and without balancing for NE. Additionally, diet formulation method and soybean hull level effects were also tested, along with interactions between soybean hulls inclusion level and diet formulation method. For Exp. 3 and 4, pre-planned contrasts were: 1) the two-way interaction between soybean hull and DDGS inclusions, 2) main effects of DDGS, and 3) linear and quadratic effects of increasing soybean hulls in both non-DDGS and DDGS diets. In all four experiments, results were considered significant at $P < 0.05$ and a trend at $P \leq 0.10$.

RESULTS

Chemical Analysis

In all four experiments, ingredient samples of soybean hulls were verified to be similar to those used in diet formulation (Table 1.6), with the exception of a lower Ca and ADF value in the soybean hulls for Exp. 4. The minor differences among other nutrients would not be expected to influence the results of the experiment. Analyzed nutrients levels of DDGS in Exp. 3 were similar to those used in diet formulation; however, the DDGS in Exp. 4 differed, with less fat than expected. The NRC (2012) classified DDGS as high oil if oil is greater than 10%, which was the case in Exp. 3, however, the DDGS in Exp. 4 would be classified as medium oil DDGS with oil content less than 9% and greater than 6%. As soybean hulls and DDGS were added to the diets in increasing amounts, dietary bulk density decreased, while crude fiber and NDF increased as expected**.**

Experiment 1

In phase 1 (d 0 to 13), increasing soybean hulls decreased (linear, $P < 0.01$) ADG and G:F, though there were no differences ($P > 0.16$) in ADFI or caloric efficiencies on either an ME or NE basis (Table 1.7). Similarly, for phase 2 (d 13 to 34), pigs fed increasing soybean hulls had decreased (linear, $P < 0.01$) ADG and G:F, with a tendency (quadratic, $P < 0.10$) for increased ADFI. Unlike phase 1, caloric efficiency improved (linear, $P < 0.004$) on an NE basis from d 13 to 34. Overall, (d 0 to 34), pigs fed increasing soybean hulls had decreased (linear, $P < 0.01$) ADG and G:F, with a tendency for decreased (quadratic, $P < 0.10$) ADFI because of lower intake for pigs fed the diet containing 20% soybean hulls. Although G:F decreased, increasing soybean hulls in the diet improved (linear, $P < 0.02$) caloric efficiency on an NE basis. Pig BW decreased (linear, $P < 0.02$) with increasing soybean hulls throughout the duration of the experiment.

Experiment 2

The only soybean hulls level × net energy interaction was a tendency ($P < 0.09$) for caloric efficiency on an NE-basis, where increasing soybean hulls improved caloric efficiency when oil was not added to the diet, but did not influence caloric efficiency when oil was added to the diet (Table 1.8). Overall (d 0 to 20), pigs fed increasing soybean hulls had (linear, $P < 0.04$) decreased ADG and final BW, whether or not diets were formulated to a constant NE. When diets were not balanced for NE (no added soybean oil), ADFI did not change (quadratic, P = 0.21), but poorer (linear, $P < 0.001$) G:F and improved caloric efficiency on an NE basis ($P < 0.05$) were observed. When adding fat to diets containing soybean hulls, G:F was similar to pigs fed the control diet and G:F improved ($P < 0.001$), while ADFI decreased ($P < 0.001$) compared with pigs fed diets not balanced for NE.

Experiment 3

For the overall period (d 0 to 42), soybean hulls × DDGS interactions (quadratic $P < 0.05$) were observed for G:F and caloric efficiency on an ME and NE basis (Table 1.9 and 1.10). Increasing soybean hulls worsened G:F quadratically ($P < 0.03$) when added to diets without DDGS and linearly ($P < 0.01$) when added to diets with DDGS. Caloric efficiencies improved on an ME and NE basis (quadratic, $P < 0.04$) with increasing soybean hulls in diets without DDGS but were not influenced when soybean hulls were added to diets containing DDGS. Including DDGS in diets decreased ($P < 0.04$) ADG and ADFI and tended to improve ($P < 0.10$) G:F and caloric efficiency on an ME basis but not ($P > 0.10$) on an NE basis. Increasing soybean hulls in diets containing DDGS further reduced (quadratic, $P < 0.05$) ADG and tended to decrease (quadratic, $P < 0.08$) ADFI, whereas adding soybean hulls to diets without DDGS had no effect ($P > 0.10$) on ADG or ADFI. No significant differences were observed in weight on d 42; nevertheless, pigs fed the diet containing 12% soybean hulls and DDGS were 2.9 kg lighter than pigs fed 12% soybean hulls in diets without DDGS.

Experiment 4

Overall (d 0 to 21), there were no soybean hulls × DDGS interactions observed ($P > 0.25$) (Table 1.11 and 1.12). Adding soybean hulls or DDGS to the diet did not influence ADG or ADFI. Increasing soybean hulls tended to worsen (linear, $P < 0.08$) G:F, but caloric efficiency improved (linear, $P < 0.008$) on an ME and NE basis. Increasing soybean hulls in diets without DDGS worsened (linear, $P < 0.04$) G:F, but caloric efficiency was improved (linear, $P < 0.01$) on an NE basis. Increasing soybean hulls in diets with DDGS did not impact growth performance, but caloric efficiency improved (linear, $P < 0.007$) on an ME an NE basis. Adding 20% DDGS to diets had no effect ($P > 0.10$) on growth performance or caloric efficiency on an ME and NE basis. There were no differences ($P > 0.10$) in pig BW for the duration of this study.

DISCUSSION

Soybean hulls are a low energy ingredient that will increase the fiber in nursery pig diets if used. Pigs are able to digest some forms of dietary fiber better than others. Chabeauti et al. (1991) reported high fiber ingredients containing more lignin are less digestible than a fibrous ingredient which contains more pectin and less non-starch polysaccharides. Noblet and Le Goff (2001) illustrated that sources of dietary fiber will have an impact on NE value due to its chemical properties. For instance, dietary fiber in the form of pectin is highly digestible while lignin and cellulose is mostly indigestible.

Just et al. (1983), Noblet and Perez (1993) and Zhang et al. (2013) illustrated that energy digestibility is reduced as dietary fiber is increased in the diet. In all of the current experiments, increasing soybean hulls increased dietary fiber and decreased the calculated ME and NE of the diets as expected. Consequently, pigs fed increasing soybean hulls had poorer G:F, but it was not until dietary inclusion rates of 6 to 10%. These results are generally similar to those of Kornegay (1978), Gore et al. (1986), and Kornegay et al. (1995) who all reported reduced G:F when 8 to 16% of soybean hulls were included in nursery diets. These findings suggest that lower amounts of soybean hulls can be added to nursery diets without affecting G:F, even when diets are not balanced to the same energy level.

Interestingly, in all the current studies, adding 5% or more soybean hulls to corn-soybean meal or corn-soybean meal-DDGS diets actually improved caloric efficiency on an NE basis. The improved caloric efficiency potentially indicates that the INRA (2004) published energy value for soybean hulls that were used in diet formulation (1,003 kcal/kg) may underestimate the energy content of soybean hulls. This may explain why G:F is not influenced at low inclusion rates of soybean hulls. Conversely, Stewart et al. (2013) suggested that soybean hulls had lower NE values than those suggested by INRA (2004). However, a higher inclusion of soybean hulls (30%) was used in the diets of that study and consequently dietary energy density is significantly lower than the diets used in current trials. Additionally, Stewart et al. (2013) used growing-finishing pigs instead of nursery pigs and the comparative slaughter and difference procedures (de Goey and Ewan, 1975). The difference in methodology used by Stewart et al. (2013) and those used to obtain the INRA (2004) values may explain the difference in NE. The difference procedure (de Goey and Ewan, 1975) used to calculate the NE of soybean hulls assumes the addition of a feed ingredient such as soybean hulls to the basal diet would not affect the energy utilization of the basal diet. Therefore, any increase or decrease of the energy value of feces by pigs fed the added ingredient would be accredited to the undigested portion of that added ingredient. However, there may be some issues with the different procedure with high fiber ingredients. Just et al. (1983) and Zhang et al. (2013) illustrated that an increase of dietary fiber would decrease the digestibility of GE and the utilization of ME from the entire diet. Therefore, fiber is affecting energy utilization of not only the test ingredient, but also the basal diet. This illustrates that the different procedure may need to be conducted with multiple inclusion rates for high fiber ingredients, as the NE may be influenced by the inclusion rate. Increased pig weight may also influence the energy level of soybean hulls with different estimates for nursery and finishing pigs (Noblet and Le Goff, 2001; Le Gall et al. 2009).

A common practice in swine diet formulation has been to add fat to increase dietary energy in diets that contain a lower energy ingredient such as soybean hulls. Gore et al. (1986) indicated that adding soybean oil to diets containing soybean hulls tended to reduce ADFI and improve G:F, but added oil had no effect on ADG. Similar results were found in Exp. 2 when soybean oil was added to the diets containing 10 or 20% soybean hulls to balance energy on a NE basis. Pigs had reduced ADFI compared to pigs fed diets containing soybean hulls without added soybean oil, but improved G:F. Similarly to Baird et al. (1975) and Gore et al. (1986), added dietary energy from fat additions decreased consumption and improved G:F. While nursery pigs are in an energy dependent state of growth, the effects of adding fat to nursery diets on ADG are variable. Cera et al. (1990) and Tokach et al. (1995) reported added fat from corn oil, soybean oil, medium-chain triglycerides, or animal-vegetable blend did not impact nursery pig's ADG for the first 14 days after weaning, but improved performance when fed after 35 days of age. An improvement in ADG was expected in Exp. 2 as pigs were approximately 35 d of age at the initiation of the experiment; however pigs responded by decreasing ADFI, instead of increased ADG.

Baird et al. (1975) evaluated effects of different levels of crude fiber, CP, and bulk density in diets for pigs and reported that the pig can tolerate a variety of crude fiber levels in diets and that diet energy density determined ADFI. It has been hypothesized that a low enough diet bulk density, increased NDF, and reduced palatability can prevent pigs from consuming enough feed to reach their energy requirement for optimal growth. Kornegay (1978) observed high levels of added soybean hulls (24%) increased ADFI, but pigs were unable to maintain the growth rate of pigs fed low fiber diets, suggesting a low energy, low bulk density diet containing soybean hulls restricted intake to the point of reducing growth rate. Corn DDGS also have higher crude fiber (6 to 8%) and NDF content (30 to 33%) than corn (crude fiber, 1.98 and NDF, 9.11; NRC, 2012). High levels of soybean hulls or combining DDGS with soybean hulls substantially increases the fiber content and lowers the bulk density of the diet, potentially to levels that prevent pigs from consuming enough of a low energy diet to maintain growth rate of pigs fed a corn-soybean meal diet. This effect was observed in Exp. 1, 3 and 4 with the lowest ADFI and ADG for the diets with the highest crude fiber and NDF.

Barbosa et al. (2008) evaluated the effects of 15% DDGS and 4% soybean hulls in nursery pig diets. They observed DDGS × soybean hulls interactions for ADFI and a trend for G:F. Soybean hulls increased ADFI to a greater extent when added to the control diet, but when added to the diet containing DDGS, intake did not increase as much. For G:F adding DDGS to the control diet tended to improve G:F, but adding DDGS to diets containing soybean hulls did not affect G:F (DDGS × soybean hull interaction). In Exp. 3, a DDGS × soybean hulls interaction was also observed for G:F. Diets containing DDGS and soybean hulls were affected linearly, while diets with soybean hulls were affected quadratically. Similarly to Barbosa et al., (2008), feeding soybean hulls and DDGS resulted in reduced ADFI in the current experiments and in Exp. 3 caused poorer growth performance. Diets containing DDGS and soybean hulls have a lower bulk density and increased fiber concentration. It is plausible that the lower bulk density or higher dietary fiber could increase gut fill. The increased gut fill could prevent the pig from increasing intake enough to reach its energy requirement. Higher amounts of soybean hulls and DDGS were used in Exp. 3. Therefore, bulk density would be lower and dietary fiber higher than the diets used by Barbosa et al. (2008). In the case of Exp. 3, 12% soybean hulls with DDGS (15% in phase 1 and 30% in phase 2, respectively) resulted in the lowest ADG, ADFI, and pigs that were 2.9 kg BW lighter than pigs fed 12% soybean hulls without DDGS. This further indicates a level of bulk density or dietary fiber to physically restrict ADFI enough that pigs had lowered intake and reduced growth performance.

Contrary to Barbosa et al. (2008) and the results from Exp. 3, there were no DDGS × soybean hull interactions in Exp. 4. The difference in the interactions between Exp. 3 and Exp. 4 may be caused by the difference between trial designs. In Exp. 4, pigs started on diets at a heavier weight and the amount of dietary fiber was lower, because less DDGS (20%) were used.

Also, analysis of DDGS differed between trials with the DDGS in Exp. 4 being a medium oil DDGS instead of a high oil (11.8 versus 8.7%). With the lower oil content and thus lower energy level of the DDGS, the decreased ADFI and improved G:F found in Exp. 3 was not observed in Exp. 4.

In conclusion, these data indicate that soybean hulls do not affect nursery pig performance when added at 5% or less, but 6 to 20% decreased G:F. The use of high levels (up to 20%) can result in equal G:F by balancing on a NE basis. Caloric efficiency was improved on an NE basis when increasing soybean hulls, indicating that the published energy values underestimate the actual energy value. When combining high levels of soybean hulls and DDGS, ADFI was reduced. Further research is needed to further understand potential interaction between high levels of high-fiber ingredients on growth performance and caloric efficiency of nursery pigs.

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TABLES

Table 1.1 Phase 1 and phase 2 diet composition and bulk density, Exp. 1 (as-fed basis) [1]

	Phase 1					Phase 2				
	Soybean hulls, %					Soybean hulls, %				
Item	0	5	10	15	20	0	5	10	15	20
Corn	54.70	50.10	45.50	40.90	36.29	63.75	59.07	54.39	49.71	45.04
Soybean meal, 46.5% CP	29.40	29.06	28.71	28.36	28.02	32.79	32.53	32.26	31.99	31.72
Soybean hulls	--	5.00	10.00	15.00	20.00	--	5.00	10.00	15.00	20
Select menhaden fish meal	3.00	3.00	3.00	3.00	3.00	--	--	--	--	--
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	--	--	--	--	--
Monocalcium P, 21% P	0.65	0.65	0.65	0.65	0.65	1.05	1.05	1.05	1.05	1.05
Limestone	0.88	0.81	0.75	0.69	0.63	0.95	0.89	0.83	0.77	0.71
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Lys HCl	0.248	0.243	0.238	0.233	0.228	0.330	0.323	0.315	0.308	0.300
DL-Met	0.120	0.130	0.140	0.150	0.160	0.130	0.138	0.145	0.153	0.160
L- Thr	0.130	0.135	0.140	0.145	0.150	0.125	0.130	0.135	0.140	0.145
Phytase[4]	0.125	0.125	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	100.0	100.0
Calculated analysis										
Standardized Ileal Digestible (SID) amino acids, %										
Lys	1.32	1.32	1.32	1.32	1.32	1.28	1.28	1.28	1.28	1.28
Ile:Lys	62	62	62	62	62	61	61	61	61	61
Leu:Lys	127	125	124	122	121	129	127	126	124	123
Met:Lys	34	34	35	35	35	33	34	34	34	34
Met & Cys:Lys	58	58	58	58	58	58	58	58	58	57
Thr:Lys	65	65	65	65	65	63	63	63	63	63
Trp:Lys	18	18	18	17	17	17	18	18	18	18
Val:Lys	68	68	67	67	66	68	68	67	67	66
Total Lys, %	1.46	1.47	1.48	1.49	1.50	1.42	1.43	1.44	1.45	1.46

ME, Mcal/kg	3.31	3.21	3.11	3.01	2.91	3.31	3.21	3.11	3.02	2.92
SID Lys:ME, g/Mcal	3.99	4.12	4.25	4.39	4.54	3.86	3.98	4.11	4.24	4.39
CP, %	21.8	21.8	21.8	21.8	21.9	21.1	21.2	21.2	21.3	21.3
Crude fiber,%	2.4	3.9	5.5	7.0	8.6	2.7	4.2	5.8	7.3	8.9
ADF, [5] %	3.1	5.0	6.9	8.7	10.6	3.6	5.4	7.3	9.2	11.1
NDF, [5] %	7.9	10.2	12.6	14.9	17.3	9.0	11.4	13.7	16.1	18.4
Ca, %	0.80	0.80	0.80	0.80	0.80	0.69	0.69	0.69	0.69	0.69
P, %	0.66	0.65	0.64	0.63	0.62	0.63	0.62	0.61	0.60	0.60
Available P, %	0.48	0.48	0.48	0.48	0.48	0.42	0.42	0.42	0.42	0.42
Bulk density,[6] g/L	810	769	714	676	659	802	772	718	720	666

[1] Diets were fed in meal form from d 0 to 13 for phase 1 and d 13 to 34 for phase 2.

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

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

[4] Phyzyme 600 (Danisco, Animal Nutrition, St. Louis, MO) provided 509 phytase units (FTU)/kg, with a release of 0.10% available P.

[5] Soybean hulls ADF and NDF values are from INRA (Institut National de la Recherche Agronomique), 2004. All other values taken from NRC (1998).

[6] Diet samples collected from each feeder during each phase and combined and then sub-sampled for analysis.

Table 1.2 Phase 1 diet composition and bulk density, Exp. 2 (as-fed basis)[1]

	Soybean hulls, %:	0	10	20	10	20
Item	NE, Mcal/kg:	2.37	2.21	2.05	2.37	2.37
Corn		63.75	54.39	45.03	50.49	37.29
Soybean meal, 46.5% CP		32.79	32.26	31.72	32.55	32.30
Soybean hulls		--	10.00	20.00	10.00	20.00
Soybean oil		--	--	--	3.60	7.15
Monocalcium P, 21% P		1.05	1.05	1.05	1.05	1.05
Limestone		0.95	0.83	0.71	0.83	0.71
Salt		0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]		0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]		0.15	0.15	0.15	0.15	0.15
L-Lys HCl		0.330	0.315	0.300	0.315	0.300
DL-Met		0.130	0.150	0.170	0.155	0.180
L-Thr		0.125	0.135	0.145	0.135	0.145
Phytase[4]		0.125	0.125	0.125	0.125	0.125
Total		100.0	100.0	100.0	100.0	100.0
Calculated analysis						
Standardized Ileal Digestible (SID) amino acids, %						
Lys		1.28	1.28	1.28	1.28	1.28
Ile:Lys		61	61	61	61	60
Leu:Lys		129	126	123	124	119
Meth:Lys		33	34	35	34	35
Met & Cys:Lys		58	58	58	58	58
Thr:Lys		63	63	63	63	63
Trp:Lys		17	18	18	17	17
Val:Lys		68	67	66	67	65
Total Lys, %		1.42	1.44	1.46	1.44	1.46
ME, Mcal/kg		3.31	3.11	2.92	3.30	3.27
SID Lys:ME, g/Mcal		3.86	4.11	4.39	3.88	3.91
CP, %		21.1	21.2	21.3	21.0	20.9
Crude fiber,%		2.7	5.8	5.7	8.9	8.7
ADF, [6] %		3.6	7.3	7.2	11.1	10.9
NDF, [6] %		9.0	13.7	13.4	18.4	17.7
Ca, %		0.69	0.69	0.69	0.69	0.69
P, %		0.63	0.61	0.60	0.60	0.58
Available P, %		0.42	0.42	0.42	0.42	0.42
Bulk density,[6] g/L		805	698	649	743	685

[1] Dietary treatment fed in meal form from d 0 to 20.

[2] Provided per kg of premix: 4,408,000 IU vitamin A; 551,000 IU vitamin D3; 17,632 IU vitamin E; 1,763 mg vitamin K; 3,306 mg riboflavin; 11,020 mg pantothenic acid; 19,836 mg niacin; and 15.0 mg vitamin B12.

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

[4] Phyzyme 600 (Danisco, Animal Nutrition, St. Louis, MO), providing 509 phytase units (FTU)/kg, with release of 0.10% available P.
[5] Soybean hulls ADF and NDF values are from INRA (Institut National de la Recherche Agronomique), 2004. All other values taken from NRC, 1998.
[6] Diet samples collected from each feeder during each phase and combined and then sub-sampled for analysis.

Table 1.3 Composition of Phase 1 diets, Exp. 3 (as-fed basis)[1]

	Phase 1									
Dried distillers grains with solubles (DDGS), %:	0	0	0	0	0	15	15	15	15	15
Item Soybean hulls, %:	0	3	6	9	12	0	3	6	9	12
Corn	55.23	52.53	49.76	47.06	44.28	43.14	40.36	37.65	34.95	32.25
Soybean meal, 46.5% CP	28.19	27.92	27.73	27.46	27.27	25.54	25.35	25.08	24.81	24.54
Soybean hulls	--	3.00	6.00	9.00	12.00	--	3.00	6.00	9.00	12.00
DDGS	--	--	--	--	--	15.00	15.00	15.00	15.00	15.00
Select menhaden fish meal	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Spray dried whey	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Monocalcium P, 21% P	0.50	0.50	0.50	0.50	0.50	0.15	0.15	0.15	0.15	0.15
Limestone	0.83	0.80	0.76	0.72	0.69	1.00	0.98	0.95	0.91	0.88
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Lys HCl	0.230	0.228	0.223	0.220	0.215	0.260	0.255	0.253	0.250	0.248
DL-Met	0.123	0.128	0.133	0.138	0.143	0.050	0.055	0.060	0.065	0.070
L-Thr	0.130	0.133	0.135	0.138	0.138	0.088	0.090	0.093	0.095	0.098
Phytase[4]	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Total	100.0	100.0	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	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32
Ile:Lys	63	62	62	62	62	65	65	65	65	65
Leu:Lys	128	127	126	125	124	143	142	141	140	139
Met:Lys	35	35	35	35	36	32	32	32	32	33
Met & Cys:Lys	58	58	58	58	58	58	58	58	58	58
Thr:Lys	65	65	66	66	65	65	65	65	65	65
Trp:Lys	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5

Val:Lys	69	69	69	68	68	73	73	73	72	72
Total Lys, %	1.46	1.47	1.47	1.48	1.49	1.49	1.49	1.50	1.51	1.52
ME, Mcal/kg	3.32	3.27	3.23	3.18	3.13	3.32	3.28	3.23	3.19	3.14
SID Lys:ME, g/Mcal	3.98	4.05	4.13	4.21	4.29	3.97	4.05	4.12	4.20	4.28
CP, %	21.9	21.9	22.0	22.0	22.0	23.7	23.7	23.7	23.8	23.8
Crude fiber, %	2.3	3.2	4.2	5.1	6.0	1.9	2.9	3.8	4.7	5.7
ADF,[5] %	3.1	4.2	5.3	6.4	7.6	5.0	6.2	7.3	8.4	9.5
NDF,[5] %	7.8	9.2	10.6	12.0	13.5	11.6	13.0	14.4	15.8	17.2
Ca, %	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
P, %	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
Available P, %	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46

[1] Dietary treatment fed in meal form from d 0 to for phase 1.

[2] Provided by kg of the diet: 14,330 IU vitamin A; 2,205 IU vitamin D_3; 77.2 IU vitamin E; 8.8 mg vitamin K; 7.7 mg riboflavin; 33.1 mg pantothenic acid; 55.1 mg niacin; and 0.40 mg vitamin B_{12}.

[3] Provided per kg of the diet: 25 mg Mn from manganese oxide, 88 mg Fe from iron sulfate, 2000 mg Zn from zinc sulfate, 264 g Cu from copper sulfate, 1.36 mg I from calcium iodate, and 0.30 mg Se from sodium selenite.

[4]Ronozyme CT (10,000) (International Nutrition, Omaha, NE), providing 1852 phytase units (FTU)/kg, with a release of 0.10% available P.

[5] Soybean hulls ADF and NDF values taken from INRA (Institut National de la Recherche Agronomique), 2004. All other values taken from NRC, 1998.

Table 1.4 Composition of Phase 2 diets, Exp. 3 (as-fed basis)[1]

	Phase 2									
Dried distillers grains with solubles (DDGS), %:	0	0	0	0	0	30	30	30	30	30
Item Soybean hulls, %:	0	3	6	9	12	0	3	6	9	12
Corn	63.94	61.03	58.35	55.60	52.93	39.74	36.98	34.20	31.44	28.73
Soybean meal (46.5% CP)	32.71	32.67	32.40	32.21	31.94	27.34	27.15	26.96	26.77	26.50
Soybean hulls	--	3.00	6.00	9.00	12.00	--	3.00	6.00	9.00	12.00
DDGS	--	--	--	--	--	30.00	30.00	30.00	30.00	30.00
Monocalcium P (21% P)	1.05	1.05	1.05	1.05	1.05	0.35	0.35	0.35	0.35	0.35
Limestone	0.95	0.89	0.83	0.77	0.71	1.35	1.30	1.28	1.23	1.20
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Lys HCL	0.333	0.323	0.320	0.315	0.313	0.395	0.390	0.385	0.380	0.378
DL-Met	0.130	0.138	0.145	0.150	0.158	0.005	0.008	0.010	0.013	0.015
L-Thr	0.125	0.130	0.135	0.138	0.140	0.048	0.050	0.053	0.055	0.058
Phytase[4]	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Total	100.0	100.0	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	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28
Ile:Lys	61	62	61	61	61	66	66	66	66	66
Leu:Lys	129	128	127	126	125	160	159	158	157	156
Met:Lys	33	33	34	34	35	29	29	29	29	29
Met & Cys:Lys	58	58	58	58	59	59	58	58	58	58
Thr:Lys	63	63	63	63	63	63	63	63	63	63
Trp:Lys	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Val:Lys	68	68	68	67	67	77	77	76	76	76
Total Lys, %	1.42	1.42	1.43	1.44	1.44	1.47	1.48	1.49	1.50	1.50
ME, Mcal/kg	3.32	3.27	3.23	3.19	3.14	3.31	3.28	3.24	3.19	3.15

SID Lys:ME, g/Mcal	3.86	3.93	4.00	4.07	4.15	3.85	3.92	3.99	4.06	4.14
CP, %	21.13	21.23	21.25	21.29	21.31	24.67	24.71	24.75	24.79	24.80
Crude fiber, %	2.7	3.6	4.5	5.5	6.4	1.9	2.9	3.8	4.7	5.7
ADF,[5] %	3.6	4.7	5.8	6.9	8.1	7.5	8.6	9.7	10.9	12.0
NDF,[5] %	9.1	10.5	11.9	13.3	14.7	16.6	18.0	19.5	20.9	22.3
Ca, %	0.69	0.68	0.67	0.66	0.65	0.69	0.69	0.69	0.69	0.69
P, %	0.63	0.62	0.62	0.61	0.61	0.59	0.58	0.58	0.57	0.57
Available P, %	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40

[1] Dietary treatment fed in meal form from d 14 to 42 for phase 2.

[2] Provided by kg of the diet: 14,330 IU vitamin A; 2,205 IU vitamin D_3; 77.2 IU vitamin E; 8.8 mg vitamin K; 7.7 mg riboflavin; 33.1 mg pantothenic acid; 55.1 mg niacin; and 0.40 mg vitamin B_{12}.

[3] Provided per kg of the diet: 25 mg Mn from manganese oxide, 88 mg Fe from iron sulfate, 2000 mg Zn from zinc sulfate, 264 g Cu from copper sulfate, 1.36 mg I from calcium iodate, and 0.30 mg Se from sodium selenite.

[4] Ronozyme CT (10,000) (International Nutrition, Omaha, NE), providing 1852 phytase units (FTU)/kg, with a release of 0.10% available P.

[5] Soybean hulls ADF and NDF values taken from INRA (Institut National de la Recherche Agronomique), 2004. All other values taken from NRC, 1998.

Table 1.5 Composition of diets, Exp. 4 (as-fed basis)[1]

Dried distillers grains with solubles (DDGS),%	0	0	0	0	20	20	20	20
Item — Soybean hulls, %	0	5	10	15	0	5	10	15
Corn	64.42	59.84	55.16	50.72	48.25	43.82	39.21	34.48
Soybean meal (46.5% CP)	32.08	31.73	31.47	30.97	28.55	28.05	27.71	27.52
Soybean hulls	-	5.00	10.00	15.00	-	5.00	10.00	15.00
DDGS	-	-	-	-	20.00	20.00	20.00	20.00
Monocalcium P (21% P)	1.05	1.05	1.05	1.05	0.6	0.6	0.6	0.6
Limestone	1.00	0.93	0.88	0.80	1.25	1.18	1.13	1.05
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Lys HCL	0.328	0.320	0.310	0.308	0.368	0.365	0.358	0.345
DL-Met	0.125	0.130	0.140	0.150	0.043	0.045	0.053	0.060
L-Thr	0.125	0.123	0.125	0.130	0.065	0.070	0.073	0.075
Phytase[4]	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	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26
Ile:Lys	61	61	61	61	65	65	65	65
Leu:Lys	129	128	127	125	151	149	147	146
Met:Lys	33	33	34	34	30	30	30	31
Met & Cys:Lys	58	58	58	58	58	58	58	58
Thr:Lys	63	63	63	63	63	63	63	63
Trp:Lys	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Val:Lys	68	68	67	67	74	74	73	73
Total lysine, %	1.39	1.41	1.42	1.43	1.43	1.44	1.46	1.47
ME, Mcal/kg	3.31	3.21	3.11	3.02	3.32	3.22	3.12	3.02

SID Lysine: ME, g/Mcal	3.80	3.92	4.05	4.18	3.80	3.91	4.04	4.17
CP, %	20.9	20.9	21.0	21.0	23.2	23.2	23.3	23.4
Crude fiber, %	2.7	4.2	5.8	7.3	2.2	3.7	5.3	6.8
ADF, [5] %	3.5	5.4	7.3	9.2	6.2	8.0	9.9	11.8
NDF, [5] %	9.0	11.4	13.7	16.1	14.1	16.4	18.8	21.1
Ca, %	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
P, %	0.62	0.61	0.61	0.60	0.60	0.59	0.58	0.58
Available P, %	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Bulk density,[6] g/L	749	730	696	640	702	666	633	648

[1] Dietary treatment fed in meal form d 0 to 21.

[2] Provided per kg of premix: 4,408,000 IU vitamin A; 551,000 IU vitamin D3; 17,632 IU vitamin E; 1,763 mg vitamin K; 3,306 mg riboflavin; 11,020 mg pantothenic acid; 19,836 mg niacin; and 15.0 mg vitamin B12.

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

[4] Phyzyme 600 (Danisco, Animal Nutrition, St. Louis, MO), providing 509 phytase units (FTU)/kg, with release of 0.10% available P.

[5] Soybean hulls ADF and NDF values taken from INRA (Institut National de la Recherche Agronomique), 2004. All other values taken from NRC, 1998.

[6] Diet samples collected from each feeder during each phase and combined and then sub-sampled for analysis.

Table 1.6 Chemical analysis and bulk density of soybean hulls and DDGS, (as-fed basis)

	Exp. 1	Exp. 2	Exp. 3		Exp. 4	
Item	Soybean Hulls	Soybean Hulls	Soybean Hulls	DDGS	Soybean Hulls	DDGS
DM, %	91.9	90.6	91.40	91.01	91.71	90.77
CP, %	11.2	10.2	10.1	26.3	13.4	29.5
ADF, %	44.0	42.0	42	13.3	25.2	16.1
NDF, %	59.0	56.2	58.3	25.5	51.2	27.5
Crude fiber, %	34.2	33.3	34.3	9.3	31.8	8.1
Fat (oil), %	--	--	--	11.8	--	8.7
Ca, %	0.64	0.65	0.66	0.07	0.11	0.04
P, %	0.11	0.11	0.10	0.85	0.17	0.87
Bulk density, g/L	359	444	486	--	518	--

Table 1.7 The effects of soybean hulls in nursery diets on nursery pig performance (Exp. 1)[1]

							Probability, *P* <	
Soybean hulls, %:	0	5	10	15	20	SEM	Linear	Quadratic
d 0 to 13								
ADG, g	218	210	201	186	175	12	0.01	0.79
ADFI, g	329	322	343	324	300	14	0.21	0.16
G:F	0.673	0.663	0.591	0.583	0.594	0.023	0.003	0.23
Caloric efficiency[2]								
ME	4.99	4.99	5.44	5.41	5.24	0.20	0.17	0.29
NE	3.63	3.59	3.88	3.81	3.65	0.14	0.58	0.27
d 13 to 34								
ADG, g	579	582	571	558	510	14	0.01	0.07
ADFI, g	897	889	918	911	847	23	0.30	0.10
G:F	0.646	0.654	0.622	0.612	0.603	0.009	0.01	0.62
Caloric efficiency								
ME	5.13	4.95	5.09	5.05	5.00	0.08	0.52	0.70
NE	3.67	3.50	3.55	3.48	3.41	0.05	0.004	0.68
d 0 to 34								
ADG, g	441	440	429	415	382	11	0.01	0.11
ADFI, g	680	673	698	685	638	18	0.23	0.10
G:F	0.651	0.656	0.616	0.607	0.602	0.009	0.001	0.88
Caloric efficiency								
ME	5.10	4.96	5.14	5.10	5.04	0.07	0.96	0.85
NE	3.66	3.51	3.60	3.53	3.44	0.05	0.02	0.84
BW, kg								
d 0	6.64	6.64	6.75	6.64	6.64	0.06	1.00	0.38
d 13	9.48	9.37	9.36	9.17	8.91	0.17	0.02	0.47
d 34	21.67	21.61	21.37	20.92	19.64	0.40	0.01	0.09

[1] A total of 210 nursery pigs (PIC 337 × 1050, initially 6.6 ± 0.1 kg) were used in a 34-d study with 7 pigs per pen and 6 replications per treatment.
[2] Caloric efficiency is expressed as Mcal/kg gain.

Table 1.8 The effects of soybean hulls and diet NE on nursery pig performance (Exp. 2)[1]

							Probability, $P <$				
							Soybean hulls[2]		Soybean hulls + oil[3]		
Soybean hulls, %:	0	10	20	10	20						
Item NE, Mcal/kg:	2.37	2.21	2.05	2.37	2.37	SEM	Linear	Quadratic	Linear	Quadratic	NE Effect[4]
d 0 to 20											
ADG, g	680	663	625	671	636	10	0.001	0.39	0.003	0.28	0.32
ADFI, g	1,070	1,109	1,094	1,046	1,006	17	0.33	0.21	0.02	0.68	0.001
G:F	0.637	0.597	0.571	0.641	0.631	0.008	0.001	0.61	0.62	0.49	0.001
Caloric efficency[5]											
ME	5.21	5.22	5.14	5.11	5.18	0.06	0.49	0.52	0.19	0.43	0.96
NE[6]	3.72	3.69	3.59	3.69	3.74	0.04	0.05	0.48	0.70	0.43	0.11
BW, kg											
d 0	13.6	13.6	13.6	13.6	13.5	0.26	0.99	0.96	0.93	0.96	0.93
d 20	27.2	26.9	26.0	27.0	26.3	0.31	0.02	0.56	0.04	0.47	0.58

[1] A total of 210 nursery pigs (PIC 337 × 1050, initially 13.6 ± 0.10 kg) were used in a 20-d study with 7 pigs per pen and 6 replications per treatment.
[2] Comparisons of 0, 10, and 20% added soybean hulls without constant NE value.
[3] Comparison of 0, 10, and 20% with constant NE value.
[4] Comparison of diets 2 and 3 versus 4 and 5.
[5] Caloric efficiency is expressed as Mcal/kg gain.
[6] Soybean hulls × NE interaction, $P > 0.09$.

Table 1.9 Interactive effects of soybean hulls and dried distillers grains with solubles (DDGS) on nursery pig performance (Exp. 3)[1]

	DDGS, %[2]:	-	-	-	-	-	+	+	+	+	+		Probability, $P <$			
													Soy hulls w/out DDGS		Soybean hulls with DDGS	
Item	Soybean hulls, %:	0	3	6	9	12	0	3	6	9	12	SEM	Linear	Quadratic	Linear	Quadratic
d 0 to 42																
ADG, g		568	544	548	553	563	538	544	554	535	496	16	0.99	0.28	0.08	0.05
ADFI, g		858	839	858	876	852	794	801	849	830	763	32	0.81	0.93	0.74	0.08
G:F[3]		0.662	0.650	0.641	0.631	0.661	0.678	0.680	0.654	0.644	0.655	0.024	0.47	0.03	0.01	0.46
Caloric efficiency[4]																
ME[3]		5.01	5.04	5.05	5.04	4.75	4.91	4.60	4.96	4.96	4.83	0.08	0.04	0.04	0.89	0.46
NE[3]		3.59	3.59	3.57	3.54	3.32	3.56	3.48	3.55	3.53	3.42	0.05	0.002	0.04	0.17	0.45
BW, kg																
d 0		6.6	6.5	6.6	6.7	6.7	6.6	6.6	6.7	6.6	6.6	0.4	0.89	0.84	0.91	0.95
d 42		30.5	29.4	29.7	30.3	30.3	29.2	29.6	29.9	29.2	27.4	1.1	0.88	0.51	0.25	0.19

[1] A total of 600 nursery pigs (PIC C-29 x 359, initially 6.6 ± 0.1) were used in a 42-d growth trial with 10 replications per pen.

[2] Phase 1 = 15% DDGS, Phase 2 = 30% DDGS.

[3] Soybean hulls level × DDGS interaction, quadratic, $P < 0.05$.

[4] Caloric efficiency is express as Mcal/kg gain.

Table 1.10 Main effects of soybean hulls and dried distillers grains with solubles on nursery pig performance (Exp. 3)[1]

	Soybean hulls, %:						DDGS[2]			Probability, $P <$		
										Soybean hulls		
Item	0	3	6	9	12	SEM	-	+	SEM	Linear	Quadratic	DDGS
d 0 to 42												
ADG, g	553	544	551	544	529	12	555	533	7	0.23	0.55	0.04
ADFI, g	826	820	854	853	807	23	857	807	14	0.95	0.20	0.02
G:F	0.670	0.665	0.647	0.638	0.658	0.007	0.648	0.662	0.005	0.03	0.04	0.06
Caloric efficiency[3]												
ME	4.96	4.93	5.00	5.00	4.79	0.06	4.98	4.90	0.04	0.12	0.05	0.10
NE	3.58	3.54	3.56	3.54	3.37	0.04	3.52	3.51	0.03	0.002	0.05	0.73
BW, kg												
d 0	6.7	6.6	6.6	6.6	6.6	0.3	6.6	6.6	0.2	0.98	0.92	0.92
d 42	29.9	29.5	29.8	29.7	28.9	0.8	30.0	29.1	0.5	0.47	0.65	0.16

[1] A total of 600 nursery pigs (PIC C-29 x 359, initially 6.6 ± 0.10 kg) were used in a 42-d growth trial with 10 replications per pen.

[2] Phase 1 = 15% DDGS, Phase 2 = 30% DDGS.

[3] Caloric efficiency is express as Mcal/kg gain.

Table 1.11 The interactive effects of soybean hulls and dried distillers grains with solubles on nursery pig performance (DDGS) diets (Exp. 4)[1]

	DDGS, %:									Probability, $P <$			
	0	0	0	0	20	20	20	20		Soybean hulls w/out DDGS		Soybean hulls with DDGS	
Item Soybean hulls, %:	0	5	10	15	0	5	10	15	SEM[2]	Linear	Quadratic	Linear	Quadratic
d 0 to 21													
ADG, g	531	537	525	512	514	520	518	499	15	0.27	0.53	0.43	0.36
ADFI, g	819	826	830	826	806	818	811	792	24	0.82	0.82	0.61	0.50
G:F	0.649	0.651	0.632	0.623	0.638	0.636	0.640	0.630	0.011	0.04	0.59	0.68	0.69
Caloric efficiency[3]													
ME	5.11	4.99	5.01	4.97	5.21	5.11	4.96	4.93	0.09	0.27	0.62	0.007	0.66
NE	3.65	3.53	3.51	3.44	3.76	3.65	3.51	3.44	0.06	0.01	0.63	0.001	0.68
BW, kg													
d 0	11.8	11.6	11.6	11.6	11.7	11.6	11.7	11.7	0.3	0.66	0.78	0.98	0.97
d 21	22.9	22.9	22.9	22.4	22.5	22.5	22.9	22.1	0.5	0.40	0.62	0.74	0.35

[1] A total of 304 pigs (PIC, 337 × 1050, initially 11.7 ± 0.2 kg BW) were used in a 21-d growth trial with 9 replications per treatment.
[2] No soybean hulls × DDGS interactions, $P > 0.10$.
[3] Caloric efficiency is express as Mcal/kg gain.

Table 1.12 Main effects of soybean hulls and dried distillers grains with solubles on nursery pig performance (Exp. 4)[1]

	Soybean hulls, %					DDGS			Probability, $P <$		
									Soybean hulls		
Item	0	5	10	15	SEM	0	20%	SEM	Linear	Quadratic	DDGS
d 0 to 21											
ADG, g	523	528	521	506	9.94	526	513	7	0.18	0.28	0.17
ADFI, g	813	822	821	809	16.4	825	807	11	0.85	0.52	0.26
G:F	0.644	0.644	0.636	0.623	0.008	0.639	0.636	0.005	0.08	0.51	0.72
Caloric efficiency[2]											
ME	5.16	5.05	4.99	4.95	0.06	5.02	5.05	0.04	0.008	0.50	0.59
NE	3.71	3.59	3.51	3.44	0.04	3.53	3.59	0.03	0.001	0.53	0.15
BW, kg											
d 0	11.7	11.6	11.6	11.6	0.18	11.7	11.7	0.1	0.77	0.82	0.94
d 21	22.7	22.7	22.9	22.2	0.33	22.8	22.5	0.2	0.41	0.32	0.40

[1] A total of 304 pigs (PIC, 337 × 1050, initially 11.7 ± 0.2 kg BW) were used in a 21-d growth trial with 9 replications per treatment.

[2] Caloric efficiency is express as Mcal/kg gain.

Chapter 2 - The effects of dietary soybean hulls particle size and diet form on nursery and finishing pig performance.

Abstract

Two experiments were conducted to investigate the effects of increasing unground and finely ground soybean hulls fed in meal or pelleted form in nursery and finishing pig diets. In Exp. 1, 1,100 nursery pigs (6.8 ± 0.1 kg BW and 28 d of age) were used in a 42-d study with 11 replicates per treatment. Treatments were arranged in a 2×2×2 factorial with main effects of 10 or 20% unground (617 μ) or ground (398 μ) soybean hulls with diets in pelleted or meal form. No 3-way or particle size × soybean hull interactions were observed. Diet form × particle size interactions were observed for G:F ($P < 0.05$) and a tendency for ADFI ($P < 0.10$). This was the result of pigs fed ground soybean hulls having reduced ADFI and improved G:F in meal diets but did not change G:F and had less effect on ADFI when diets were pelleted. There were diet form × particle size interactions ($P < 0.05$) for caloric efficiency on an ME and NE basis and a tendency for diet form × soybean hull interaction ($P < 0.06$) for ADFI, G:F, and caloric efficiency. Grinding soybean hulls decreased ($P < 0.01$) ADG and tended ($P < 0.08$) to reduce ADFI and final BW. In Exp. 2, 1,215 finisher pigs (21.1 ± 0.1 kg BW) were used in a 118-d study and were fed 1 of 5 diets arranged in a 2×2+1 factorial with 9 replications per treatment and main effects of soybean hull particle size (787 and 370 μ) and soybean hull level (7.5 or 15%) in corn-soybean meal–based diets. All diets were fed in meal form. No particle size × soybean hull interactions were observed. Increasing dietary soybean hulls, regardless of particle size, did not affect ADG or ADFI, but resulted in poorer (linear, $P < 0.02$) G:F. Increasing dietary soybean hulls improved (linear, $P < 0.05$) caloric efficiency on an ME and NE basis. Pigs fed ground soybean hulls had poorer G:F ($P < 0.05$) and caloric efficiencies ($P < 0.03$). Carcass yield, HCW, and backfat depth decreased (linear, $P < 0.03$) while percentage lean increased ($P < 0.01$) with increasing soybean hulls. Pigs fed ground soybean hulls had increased backfat depth ($P < 0.05$) and decreased ($P < 0.05$) percentage lean and FFLI. In summary, increasing soybean hulls lowered G:F in both nursery and finishing pigs, however pelleting nursery diets provided the expected improvement in ADG and eliminated the negative effect of increasing soybean hulls on G:F. Grinding soybean hulls reduced growth performance in nursery pigs and finishing pigs.

Key words: finishing pig, growth, nursery pig, particle size, pelleting, soybean hulls

Introduction

Soybean hulls are a feed co-product resulting from the cracking and dehulling process in soybean oil extraction. Due to its low energy value (corn NE = 2,650 kcal/kg; soybean hulls NE = 1,003 kcal/kg; INRA 2004) and high crude fiber (35.75%; NRC 2012) they are not typically used in swine diets. Furthermore, use of fibrous ingredients has been shown to have different effects depending on pig age. As pigs develop they substantially increase GI tract size, consequently slowing the rate of passage of digest and increasing fiber fermentation capabilities (Fernandez and Jorgensen, 1986; Noblet and Le Goff 2001; Noblet and Van Milgen, 2004). Therefore, nursery and finishing pigs may respond to soybean hulls differently.

Kornegay (1978), Gore et al. (1986), and Kornegay et al. (1995) observed nursery pigs fed dietary soybean hulls have reduced G:F. However, including soybean hulls at 3 - 10% of diet has been shown to improve (DeCamp et al., 2001) or not impact finishing pig performance (Bowers et al., 2000). However, at high levels of soybean hulls (24 – 30%), Kornegay (1978) and Stewart et al. (2013) observed reduced gain, with no changes or slight increases in intake. This would suggest that diet bulk density of low energy diets can impact intake and performance in nursery and finishing pigs. Therefore, feed processing techniques such as pelleting to increase diet bulk density or grinding to improve digestibility of soybean hulls may mitigate its negative growth effects. In a recent study, Moreira et al. (2009) found that grinding soybean hulls increased ME for growing and finishing pigs when soybean hulls were ground from 751 µ to 430 µ. However, no growth performance effects from this improvement have been studied.

Therefore, the objectives of this study were to evaluate the effects of: 1) soybean hulls level, soybean hull particle size, and complete diet form on growth performance of nursery pigs, and 2) increasing amounts of soybean hulls and soybean hull particle size on the growth performance and carcass characteristics of finishing pigs.

Materials and Methods

General

All experimental procedures and animal care were approved by the Kansas State Institutional Animal Care and Use Committee. The ME values for corn and soybean hulls used in diet formulation were 3,420 kcal/kg (NRC, 1998) and 1,864 kcal/kg (INRA, 2004), respectively. The NE values used in formulation for corn and soybean hulls were 2,650 and 1,003 kcal/kg (INRA, 2004). Caloric efficiencies of pigs in both experiments were determined on both an ME (NRC, 1998) and NE (INRA, 2004) basis. Caloric efficiency was calculated by multiplying total feed intake by energy in the diet (kcal/kg) and dividing by total gain.

Experiment 1

A total of 1,100 pigs (C-29 × 359; PIC, Hendersonville, TN; initially 6.8 ± 0.1 kg BW and 28 d of age) were used in a 42-d growth experiment to evaluate the effect of increasing dietary soybean hulls inclusion and soybean hull particle size in nursery pig diets fed in both meal and pelleted form. Pigs were allotted to pens by initial BW and pens of pigs were randomly allotted to 1 of 8 dietary treatments. There were 10 pigs per pen (5 barrows and 5 gilts) and 11 replications per treatments. All pigs were fed a common pelleted starter diet for 10 d after weaning. Starting on d 10 post-weaning (d 0 of the experiment), pigs were fed the experimental treatments. The 8 experimental diets were fed in a 2 phases from d 0 to 14 and 14 to 42 (Table 2.1). Treatments were arranged in a 2 × 2 × 2 factorial with main effects of 10 or 20% of unground or ground soybean hulls with diets in pelleted or meal form.

This experiment was conducted at the Cooperative Research Farm's Swine Research Nursery (Sycamore, OH), which is owned and managed by Kalmbach Feeds, Inc. (Upper Sandusky, OH). Each pen had slatted metal floors and was equipped with a 4-hole stainless steel feeder and one nipple-cup waterer for ad-libitum access to feed and water. Individual pen weight and feed disappearance were measured weekly to determine ADG, ADFI, and G:F. Samples of each dietary treatment were collected from every feeder for each phase and subsampled.

A single lot of soybean hulls were used for the study with 50% used as received, whereas the other 50% was ground through a hammer mill (P-250D Pulverator, Jacobson Machine Works, Minneapolis, MN) equipped with a 1.59 mm screen at K-State Grain Science Feed Mill. The resulting particle sizes were 617 and 398 µ, respectively. All soybean hulls were then shipped to Kalmbach Feeds, Inc. (Upper Sandusky, OH) for feed manufacturing. All diets within each phase were formulated on a common standardized ileal digestible (SID) lysine concentration. The SID lysine levels fed were selected based on the required level for the diets without soybean hulls. All phase 1 diets contained 4% fish meal and 10% spray-dried whey. Phase 2 diets contained no specialty protein or lactose sources.

The ASAE (1983) standard method was used to determine the particle size of soybean hulls and complete meal diets. Tyler sieves, with numbers, 6, 8, 12, 16, 20, 30, 40, 50, 70, 100, 140, 200, 270, and a pan were used for particle size determination. A Ro-Tap® shaker (W. S. Tyler, Mentor, Ohio) was used to sift the 100 g samples for ten minutes. A geometric mean particle size and the log normal standard deviation were calculated by measuring the amount of ground grain remaining on each screen. Pellet quality was measured using the tumbling box procedure ASAE S269.4 (ASAE, 1991) and results are reported as the pellet durability index (**PDI**). Two standard and two modified (inclusion of five 12.7 mm hex nuts) PDI tests were conducted for each diet in each phase and an average value for each was determined.

Experiment 2

A total of 1,235 pigs (1050 × 337; PIC, Hendersonville TN; initially 31.1 ± 0.1 kg BW) were used in a 118 d growth trial to determine the effects of 7.5 and 15% ground or unground soybean hulls on growth performance and carcass characteristics of finishing pigs raised in a commercial environment. Pens of pigs were balanced by initial weight and randomly allotted to 1 of 5 dietary treatments in a completely randomized design with 26 to 28 pigs per pen and 9 replications per treatment. Treatments were arranged in a 2 × 2 + 1 factorial, and main effects were soybean hull particle size (unground or ground, 787 and 370 µ, respectively) and amount of soybean hulls (7.5 or 15%) in corn-soybean meal–based diets. The fifth treatment was a positive control, a corn-soybean meal–based diet. Diets were fed in meal form and pigs were fed in four phases from d 0 to 118 with approximate weight ranges of 31 to 42, 42 to 77, 77 to 109, and 109 to 128 kg BW (Table 2.2). Treatment diets were formulated to a constant SID lysine within each phase.

This experiment was conducted at the commercial research-finishing barn in southwestern Minnesota. The barns were naturally ventilated and double-curtain-sided. Pens had completely slatted flooring and deep pits for manure storage. The research barn contained 48 pens (3.05 × 5.49 m) equipped with a 5-hole conventional dry feeder (STACO, Inc., Schaefferstown, PA) and a cup waterer which afforded ad libitum consumption of feed and water. Daily feed additions to each pen were accomplished through a robotic feeding system

(FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed amounts for individual pens. All soybean hulls were sourced from the same location (South Dakota Soybean Processors, Volga, SD). Each lot of soybean hulls was split into equal portions, and half was transported to the South Dakota State University Feed Mill (Brookings, SD) and ground through a hammer mill (G7HFS Prater-Sterling, Bolingbrook, IL) equipped with a 1.59 mm screen. After grinding, soybean hulls were transported along with the unground soybean hulls to the feed mill (New Horizon Farm; Pipestone, MN) for diet manufacturing. All diets were formulated to meet or exceed all requirement estimates (NRC, 1998). Pens of pigs were weighed and feed disappearance was recorded at d 0, 14, 28, 42, 53, 66, 82, 94, and 118 to determine ADG, ADFI, and G:F.

On d 94 of the experiment, the 4 heaviest pigs (2 barrows and 2 gilts, determined visually) per pen were weighed and sold according to the farm's normal marketing procedure. At the end of the trial (d 118), pigs were transported to a commercial packing plant (JBS Swift and Company; Worthington, MN) for processing and carcass data collection. Pigs were individually tattooed according to pen number to allow for data retrieval by pen and carcass data collection at the abattoir. Hot carcass weights (HCW) were measured immediately after evisceration and each carcass was evaluated for percentage yield, backfat and loin depth. Percentage yield was calculated by dividing HCW by live weight obtained at the plant. Fat depth and loin depth were measured with an optical probe (SFK; Herlev, Denmark) inserted between the 3rd and 4th ribs located anterior to the last rib at a distance approximately 7.1 cm from the dorsal midline. Fat-free lean index (FFLI) was calculated using NPPC (2000) guidelines for carcasses measured with the Fat-O-Meater such that FFLI = ((15.31 + (0.51 × HCW, lb.) – (31.277 × last rib fat thickness, in.) + (3.813 × loin muscle depth, in.))/HCW, lb.).

Chemical Analysis

Soybean hull samples were collected from both experiments for analysis of moisture (AOAC 934.01, 2006), CP (AOAC 990.03, 2006), ADF (ANKOM Technology, 1995a), NDF (ANKOM Technology, 1995b) crude fiber (AOAC 978.10, 2006), Ca (AOAC 965.14/985.01, 2006.), and P (AOAC 965.17/985.01, 2006) at Ward Laboratories (Kearney, NE). For both experiments, soybean hulls and composite diet samples by treatment for each phase were measured for bulk density using a Seedburo test weight apparatus and computerized grain scale (Seedburo Model 8800, Seedburo Equipment, Chicago, IL).

Statistical Analysis

In both experiments, data were analyzed using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. In Exp. 1, room was included in the model as a random effect and polynomial contrasts were used to test for the following interactions: 1) diet form × soybean hulls × soybean hull particle size, 2) diet form × soybean hull particle size, 3) form × soybean hulls, and 4) soybean hulls × soybean hull particle size. Main effects of diet form, soybean hulls, and soybean hull particle size were also tested. In Exp. 2, interactions between particle size and dietary soybean hull levels were analyzed, as well as the main effects of particle size and the linear and quadratic effects of increasing soybean hulls, regardless of particle size. Analysis of backfat depth, loin depth, and percentage lean were adjusted to a common carcass weight using HCW as a covariate. Results in both trials were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results

Chemical analysis

In both trials soybean hull samples were verified to be similar to those used in formulation and values were similar to NRC (2012) values (Table 2.3). The minor differences, particularly the value of CP would not be expected to influence results of the experiment. Unground soybean hulls were 617 and 787 µ for Exp. 1 and 2, respectively. By grinding the soybean hulls through a hammer mill equipped with a 1.59 mm screen, they were reduced to 398 and 370 µ for Exp. 1 and 2. Grinding soybean hulls increased its bulk density by approximately 66 g/L in both trials.

For complete diets, increasing soybean hulls in both nursery and finishing diets increased dietary fiber as expected. As soybean hulls increased, bulk density of diets decreased (Table 2.4 and 2.5). Pelleting diets increased bulk density. Grinding soybean hulls in Exp. 1 and Exp. 2 increased bulk density, particularly when high levels of soybean hulls were used. In both phases of Exp. 1, grinding soybean hulls had a limited impact on diet particle size when 10% soybean hulls were used; however, using ground soybean hulls at 20% of the diet reduced the particle size of the diet to a greater extent. In all phases of Exp. 2, grinding soybean hulls reduced diet particle size of complete diets regardless of soybean hull inclusion. Pellet quality in Exp. 1 was exceptional in both phases and soybean hulls did not affect pellet durability, regardless of inclusion or particle size. However, diets with 20% soybean hulls had numerically decreased percentage of fines (Table 2.6).

Experiment 1

From d 0 to 14, no interactions ($P > 0.10$) were observed (Table 2.7). Increasing dietary soybean hulls from 10 to 20% improved ($P < 0.003$) ADG, G:F, and caloric efficiency on an ME and NE basis (Table 2.8). Grinding soybean hulls worsened ($P < 0.003$) ADG, G:F, and caloric efficiency, whereas pelleted soybean hull diets increased ($P < 0.001$) ADG and ADFI but did not affect G:F or caloric efficiency.

In phase 2 (d 14 to 42), there were tendencies for diet form × soybean hull particle size and diet form × soybean hulls interactions ($P < 0.10$) in which grinding soybean hulls reduced ADFI in meal diets but had less of an effect on ADFI in pelleted diets. Similarly, increasing soybean hulls from 10 to 20% increased ADFI and worsened G:F in meal diets but had no effect on G:F and a smaller increase in ADFI in pelleted diets. Additionally, there were tendencies for diet form × soybean hull interactions ($P < 0.10$) for ME and NE caloric efficiencies in which 20% soybean hulls improved caloric efficiency to a greater extent in pelleted diets than in meal diets. For main effects, increasing soybean hulls from 10 to 20% increased ($P < 0.002$) ADFI and worsened ($P < 0.001$) G:F but had no effect on ADG. Increasing soybean hulls also improved ($P < 0.04$) caloric efficiency on an ME and NE basis, indicating the energy value of soybean hulls was underestimated in diet formulation. Grinding soybean hulls tended ($P < 0.06$) to decrease ADG and decreased ($P < 0.001$) ADFI without influencing G:F or caloric efficiency. Pigs fed pelleted diets also increased ($P < 0.001$) ADG and ADFI but had no effect on G:F or caloric efficiency.

Overall (d 0 to 42), there were no soybean hull level × particle size × diet form or particle size × soybean hull level interactions observed ($P > 0.10$); however, diet form × particle size interactions occurred for G:F and ADFI ($P < 0.05$ and $P < 0.10$, respectively). This was the result of pigs fed ground soybean hulls having reduced ADFI and improved G:F in meal diets, but did not change G:F and had less effect on ADFI when diets were pelleted. Additionally, diet form × particle size interactions (P < 0.05) were observed for caloric efficiency on an ME and NE basis, where grinding soybean hulls improved caloric efficiency on an ME and NE basis in meal diets, but not in pelleted diets. A tendency for a diet form × soybean hulls level interactions (P < 0.06) was observed for ADFI and G:F. This was the result of pigs fed increased soybean hulls having increased ADFI and decreased G:F in meal diets, but did not change G:F and had less effect on ADFI when diets were pelleted. Furthermore, tendencies for diet form × soybean hulls level interactions (P < 0.06) were observed for caloric efficiency on an ME and NE basis, where increasing soybean hulls improved caloric efficiency on an ME an NE basis to a greater extent in pelleted diets than meal diets.

For overall main effects (d 0 to 42), increasing soybean hulls from 10 to 20% increased (P < 0.007) ADFI but worsened *(P* < 0.03) G:F. Because ADG was unchanged by soybean hull inclusion rate, pigs gained the same amount on lower energy diets, resulting in improved (P < 0.001) caloric efficiency on an ME and NE basis. Pigs fed ground soybean hulls had reduced (P < 0.005) ADG and ADFI, and had a tendency (P < 0.08) for to reduced final pig BW. Pigs fed pelleted diets had improved (P < 0.001) ADG, ADFI, and final BW. However, neither pelleting or grinding soybean hulls affected G:F or caloric efficiency.

Experiment 2

Overall (d 0 to 118), increasing dietary soybean hulls resulted in no effects on ADG, ADFI, or final live BW; however, G:F (P < 0.02) decreased (Table. 2.9). Caloric efficiency improved (P < 0.002) on an ME and NE basis as soybean hulls were added. Feeding pigs diets with reduced particle size soybean hulls did not influence ADG or ADFI, but resulted in poorer (P < 0.04) G:F and caloric efficiency on an ME and NE basis.

For carcass characteristics, increasing soybean hulls, regardless of soybean hull particle size, reduced (linear, P < 0.03) carcass yield and HCW. Backfat depth also was reduced (linear, P < 0.001) when soybean hulls were added to the diet. Because of the reduction in backfat depth, percent lean and FFLI increased (linear, P < 0.003) as soybean hull level increased in the diet. Reducing the particle size of soybean hulls reduced (P < 0.002) backfat depth, resulting in an increase (P < 0.004) in percent lean and FFLI.

Discussion

The impact of dietary fiber on pig performance is dependent on age. Research has shown that when fibrous ingredients are included in a swine diet, the pigs hindgut becomes more active, digesting the majority of the fiber (Fernandez and Jorgensen, 1986; Noblet et al., 1994; Jorgensen et al., 1996). Fernandez and Jorgensen (1986) observed that increasing dietary fiber decreased digestibility in young pigs, but as pigs aged and increased body weight, the digestibility of fiber significantly improved. These findings have been replicated by Noblet and Le Goff (2001), Noblet and van Milgen (2004), and Stewart et al. (2013). It is speculated that because of increased development of the gastrointestinal tract pigs can more easily digest fiber. As the pig matures and increases BW the GI tract increases in size, resulting in a larger intestine and larger hindgut, consequently slowing the rate of passage of digesta and increasing the fermentation capacity in a larger hindgut. Due to the slower rate of passage, increased fermentation capacity, and increased VFA production and use, dietary fiber becomes more digestible (Fernandez and Jorgensen, 1986; Noblet and Le Goff, 2001). Since digestibility of dietary fiber is improved in finishing pigs and sows the NE values of high fiber ingredients should be higher than that of nursery pigs (Noblet et al., 1994; Noblet and Le Goff, 2001; Le Gall et al., 2009). However, in the current studies, increasing soybean hulls did not affect ADG, ADFI, or BW in finishing pigs, but G:F still decreased in nursery and finishing pigs.

Finishing pigs have the potential ability to better digest fiber that nursery pigs, Stewart et al. (2013) reported that 30% soybean hulls had no effect on growth performance in finishing pigs (85 to 127 kg BW) but did decrease G:F in growing pigs (25 to 55 kg BW). In contrast, Bowers et al. (2000) reported that ADG and G:F in finishing pigs was reduced with the addition of 6 and 9% of dietary soybean hulls, while DeCamp et al. (2001) reported improvements in ADG and tendencies for improved G:F when 10% dietary soybean hulls were included in the diet. However, DeCamp et al. (2001) added fat in diets containing soybean hulls to increase dietary energy and resulted in the improvement in ADG and G:F. In the current finishing study, increasing soybean hull inclusion had no impact on ADG or ADFI, however G:F decreased when diets were not balanced for energy.

Just (1982), Noblet and Perez (1993), and Noblet et al. (1994) illustrated that dietary fiber acts as a diluent to NE as fermentation of fiber increased N losses. However, increased pig BW reduces these effects on N loss. In both the nursery and grow-finish study, the ME and NE of the diets decreased with increasing soybean hulls. Interestingly, in both the nursery and finishing study increasing soybean hulls improved caloric efficiency on an NE basis, while GF was poorer. It is theorized that pigs were more efficient than expected with increasing soybean hulls. Consequently, the soybean hull NE value used in diet formulation (INRA, 2004) undervalued the NE value of soybean hulls. Contrary to the current study, Stewart et al. (2013) showed feeding 30% soybean hulls resulted in NE values that were lower than those calculated in INRA (2004) when the comparative slaughter procedure and the difference procedure (de Goey and Ewan, 1975) were used. The difference in methodology used by Stewart et al. (2013) and those used to obtain the INRA (2004) values may explain the difference in NE. The difference procedure (de Goey and Ewan, 1975) used to calculate the NE of soybean hulls in the Stewart et al. (2013) experiment assumes that adding a feed ingredient such as soybean hulls to the basal diet would not affect the energy utilization (or diet digestibility) of the basal diet. Therefore, an increase or decrease of the energy value of feces by pigs fed the added ingredient would be accredited to the undigested portion of the added ingredient. However, Just et al. (1983) reported that an increase of dietary fiber by 1% would decrease the digestibility of GE and the utilization of ME from the entire diet. Therefore, fiber is affecting energy utilization and the difference procedure may need to be conducted at multiple levels of the test ingredient, as NE may change with inclusion rate.

Feed processing techniques have been used on complete diets and cereal to improve digestibility and pig performance. Reducing cereal grain particle size has been shown to improve pig performance and nutrient digestibility (Healy et al., 1994; Wondra et al., 1995a; Wondra et al., 1995b). However, little data is available on reducing particle size of non-cereal grains, such as soybean hulls, in diets for swine. It was hypothesized that by reducing the particle size of soybean hulls the digestibility would be improved. A study in South America conducted by Moreira et al. (2009) observed an improvement in DE and ME when soybean hulls were ground through a 2.5 mm screen. However, soybeans are process differently in South America than in the United States. In South America the soybean hulls are separated before roasting and trypsin inhibitors may still be present in the hull. The improvement in digestibility observed by Moreira et al. (2009) could be the result of reducing the negative effects of trypsin inhibitors and not improving digestibility of soybean hulls. In the present nursery study grinding soybean hulls resulted in reduced ADG, ADFI, and tended to reduce final BW. Feed efficiency and caloric efficiency also worsened with soybean hull grinding. These results imply that grinding soybean hulls did not improve pig performance by means of improved digestibility and in fact, the opposite may have occurred. It has been observed that increasing the amounts of fiber in the diet will increase the rate of passage of digesta (Ehle et al., 1982; Stanogias and Pearce, 1985). It could be possible that an increased rate of passage caused by smaller particles of fiber occurred or the additional surface area of the fibrous portion of soybean hulls decreased diet digestibility.

Feeding pigs a pelleted diet has consistency shown improvements in growth performance and efficiency (Hansen et al., 1992; Stark et al., 1995; Wondra et al., 1995b). In the current nursery study, pelleting diets increased ADG and final BW as expected, however the observed increase in ADFI resulted in no impact on G:F. In the current nursery study, reducing the particle size and feeding pelleted and meal diets resulted in diet form × soybean hull particle size interactions for G:F, caloric efficiency and a tendency for ADFI. This was the result of grinding soybean hulls to 398 µ, which reduced the ADFI and improved G:F in meal diets. However, this did not change G:F and had less effect on ADFI when diets were pelleted. Additionally, by grinding soybean hulls caloric efficiency was improved in meal diets and had no effect in pelleted diets. This interaction for ADFI could be explained by bulk density of the diet, as meal diets had a lower bulk density and due to gut fill ADFI was reduced. Studies by Baird et al. (1975) and Frank et al. (1983) observed that bulk density could restrict ADFI. Recent studies by Salyer et al. (2012) and Stewart et al. (2013) similarly observed high levels fiber and lowered diet bulk density may allow for increased gut fill. Thus, pigs cannot increase intake to meet an energy requirement.

Tendencies for diet form × soybean hull level interactions were also observed in the nursery study for ADFI, G:F, and caloric efficiency on an ME and NE basis. This was the result of increased ADFI, decreased G:F, and improved caloric efficiency when soybean hulls increased from 10 to 20% in meal diets. The premise that pigs will increase intake on a low energy diet to meet an energy requirement (Baird, 1973; Frank et al., 1983) would suggest pigs were expected to increase ADFI with 20% soybean hulls in the diet in an attempt to meet that requirement. Furthermore, a study by Wondra et al. (1995a) observed improved digestibility in pelleted diets versus meal diets; therefore if digestibility was improved by pelleting, ADFI and consequently G:F would not be as affected as it was in meal diets.

From a carcass trait standpoint, it was not surprising that increasing soybean hulls from 0 to 15% decreased carcass yield in finishing pigs. This data agrees with previous research by

Salyer et al. (2012), Asmus et al. (2012) and Stewart et al. (2013), which all showed a reduction in carcass yield as fiber increased in the diet. In addition, as dietary fiber is an increased, visceral organ weight increase, consequently decreasing carcass yield (Ferrell, 1988). The increased organ weight caused by fiber has been speculated to increase the animals' maintenance requirement by redirecting nutrients from carcass to the visceral organs (Ferrell, 1988). However, in the current study there was no effect of soybean hulls on ADG or ADFI. If the maintenance requirement increased due to organ weight, it was not increased enough to significantly increase intake to meet the higher maintenance requirement caused by increased organ weight. Baird et al. (1975) indicated decreased dietary energy reduced backfat depth and increased percent lean. In the current study, as soybean hull inclusion increased dietary energy was allowed to decrease and consequently, less energy was partitioned toward fat. Therefore, backfat decreased with decreased diet energy from increasing soybean hull inclusion. Due to the decreased backfat, there were increases in percent lean and fat-free lean index in pigs fed soybean hulls.

In summary, increasing soybean hulls reduced G:F in both nursery and finishing pigs, however, caloric efficiency improved. This suggests that the published energy values used in diet formulation (1,003 kcal/kg; INRA, 2004) for soybean hulls may be underestimated. Pelleting nursery diets provided the expected improvement in ADG and eliminated the negative effect of increasing soybean hulls on G:F. The hypothesis that reducing the particle size of soybean hulls may improve its energy value was proven false. Grinding soybean hulls reduced ADFI and ADG in the nursery and G:F in the finisher.

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Tables

Table 2.1 Phase 1 and Phase 2 diet composition, Exp.1 (as-fed basis)[1,2,3]

		Phase 1		Phase 2	
Item	Soybean hulls, %:	10%	20%	10%	20%
Ingredient, %					
Corn		46.15	37.06	55.07	45.91
Soybean meal, 46.5% CP		26.83	26.06	31.33	30.64
Soybean hulls		10.00	20.00	10.00	20.00
Select menhaden fish meal		4.00	4.00	--	--
Spray-dried whey		10.00	10.00	--	--
Monocalcium P, 21% P		0.50	0.50	1.05	1.05
Limestone		0.65	0.50	0.80	0.65
Salt		0.35	0.35	0.35	0.35
Zinc oxide		0.25	0.25	--	--
Vitamin premix[4]		0.128	0.128	0.128	0.128
Trace mineral premix[5]		0.09	0.09	0.09	0.09
L-Lys HCl		0.213	0.200	0.315	0.300
DL-Met		0.140	0.158	0.148	0.165
L-Thr		0.115	0.120	0.130	0.135
Phytase[6]		0.019	0.019	0.019	0.019
CTC 50		0.40	0.40	0.40	0.40
Medication[7]		0.175	0.175	0.175	0.175
Total		100	100	100	100
Calculated analysis					
Standardized Ileal Digestible (SID) amino acids, %					
Lys		1.30	1.30	1.26	1.26
Ile:Lys		62	62	61	61
Leu:Lys		125	122	126	123
Met:Lys		36	36	34	35
Met & Cys:Lys		59	59	58	58
Thr:Lys		64	64	63	63
Trp:Lys		17.5	17.5	17.5	17.5
Val:Lys		68	67	67	66
Total Lys, %		1.46	1.48	1.42	1.44
ME, Mcal/kg		3.15	3.00	3.15	3.00
NE, Mcal/kg		2.25	2.09	2.21	2.05
SID Lys:ME, g/Mcal		4.20	4.48	4.05	4.33
CP, %		21.7	21.8	21.0	21.1
Crude fiber, %		5.4	8.5	5.8	8.9

ADF,[8] %	6.8	10.6	7.3	11.0
NDF,[8] %	12.5	17.2	13.7	18.4
Ca, %	0.78	0.77	0.67	0.66
P, %	0.63	0.61	0.61	0.59
Available P, %	0.46	0.46	0.40	0.40

[1] Dietary treatments fed from 6.8 to 9.3 for phase 1 and from 9.3 to 27 kg BW for phase 2

[2] Diets were fed in both meal and pelleted forms.

[3] Diets were fed with soybean hulls ground to 389 μ or unground at 617 μ

[4] Provided per kg of the diet: 14,330 IU vitamin A; 2,205 IU vitamin D_3; 77.2 IU vitamin E; 8.8 mg vitamin K; 7.7 mg riboflavin; 33.1 mg pantothenic acid; 55.1 mg niacin; 0.40 mg vitamin B_{12}; and 0.30 mg selenium.

[5] Provided per kg of the diet: 25 mg Mn from manganese oxide, 88 mg Fe from iron sulfate, 2000 mg Zn from zinc sulfate, 264 g Cu from copper sulfate, 1.36 mg I from calcium iodate, and 0.30 mg Se from sodium selenite.

[6] Ronozyme CT (10,000) (DSM, Parsippany, NJ) provided 1848 phytase units (FTU)/kg, with a release of 0.10% available P.

[7] Denagard 10 (Novartis Animal Health, NJ).

[8] Soybean hulls ADF and NDF values taken from INRA (Institut National de la Recherche Agronomique), 2004. All other values taken from NRC (1998).

Table 2.2 Phase 1, 2, 3, and 4 diet composition, Exp. 2, (as-fed basis)[1]

Item	Phase 1			Phase 2			Phase 3			Phase 4		
Soybean hulls,[2] %:	0	7.5	15	0	7.5	15	0	7.5	15	0	7.5	15
Ingredient, %												
Corn	73.09	66.09	58.98	78.78	71.61	64.63	83.01	75.84	64.63	75.24	68.03	60.94
Soybean meal, 46.5% CP	24.44	24.02	23.71	18.96	18.75	18.33	14.89	14.67	18.33	22.62	22.41	22.09
Soybean hulls	-	7.50	15.00	-	7.50	15.00	-	7.50	15.00	-	7.50	15.00
Monocalcium P, 21% P	0.62	0.63	0.65	0.51	0.50	0.48	0.40	0.40	0.40	0.25	0.28	0.28
Limestone	0.95	0.85	0.75	0.95	0.85	0.75	0.93	0.83	0.73	0.90	0.80	0.70
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
DL-Met	0.03	0.045	0.06	-	0.015	0.030	-	0.005	0.010	0.050	0.060	0.075
L-Thr	0.045	0.05	0.0525	0.015	0.019	0.030	0.03	0.035	0.040	0.070	0.075	0.080
Biolys[5]	0.370	0.360	0.345	0.325	0.305	0.295	0.030	0.035	0.040	0.008	0.008	0.008
Phytase[6]	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.000	0.008
Ractopamine HCl[7]	-	-	-	-	-	-	-	-	-	0.05	0.05	0.05
Total	100	100	100	100	100	100	100	100	100	100	100	100
Calculated analysis												
Standardized Ileal Digestible (SID) amino acids,%												
Lys	1.00	1.00	1.00	0.84	0.84	0.84	0.72	0.72	0.72	0.95	0.95	0.95
Ile:Lys	65	64	64	66	66	66	68	68	67	65	65	65
Leu:Lys	146	143	140	159	156	152	173	168	164	150	147	143
Met:Lys	29	30	31	28	29	30	30	30	30	32	32	33
Met & Cys:Lys	57	57	57	58	58	58	63	61	60	60	60	60
Thr:Lys	61	61	61	61	61	61	65	65	65	65	65	65
Trp:Lys	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Val:Lys	74	73	72	77	76	75	81	79	78	75	74	73
Total Lys, %	1.12	1.13	1.14	0.94	0.96	0.97	0.81	0.83	0.84	1.06	1.08	1.09
ME, Mcal/kg	3.34	3.23	3.12	3.35	3.24	3.12	3.36	3.24	3.13	3.36	3.24	3.13

NE, Mcal/kg	2.44	2.32	2.20	2.48	2.36	2.24	2.51	2.39	2.27	2.46	2.34	2.22
SID Lys:ME, g/Mcal	2.99	3.13	3.28	2.51	2.62	2.75	2.15	2.25	2.35	2.83	2.96	3.10
CP, %	17.9	17.9	17.8	15.8	15.8	15.7	14.2	14.2	14.2	17.3	17.3	17.3
Crude fiber, %	2.6	4.9	7.2	2.5	4.8	7.1	2.4	4.7	7.1	2.5	4.9	7.2
ADF,[8] %	3.4	6.2	9.0	3.2	6.1	8.9	3.1	6.0	8.8	3.3	6.2	9.0
NDF,[8] %	9.2	12.7	16.2	9.3	12.8	16.3	9.3	12.8	16.3	9.2	12.8	16.3
Ca, %	0.58	0.58	0.58	0.54	0.54	0.54	0.50	0.50	0.50	0.49	0.49	0.49
P, %	0.50	0.49	0.48	0.46	0.44	0.42	0.42	0.41	0.39	0.42	0.41	0.40
Available P, %	0.29	0.29	0.29	0.25	0.25	0.25	0.23	0.23	0.23	0.21	0.21	0.21

[1] Phase 1 diets fed from d 0 to 14, Phase 2 from d 14 to 53, Phase 3 from d 53 to 94, and Phase 4 from 94 to 118.

[2] In diets containing soybean hulls, the soybean hulls were either unground at 787 μ or ground to 370 μ.

[3] Provided per kg of premix: 4,508,182 IU vitamin A; 701,273 IU Vitamin D_3; 24,043 IU vitamin E; 1,402 mg vitamin K; 3,006 mg riboflavin; 12,023 mg pantothenic acid; 18,033 mg niacin; 15.03 mg Vitamin B_{12}.

[4] Provided per kg per kg of premix: 40.1 g MN from manganous oxide; 90.2 g Fe from ferrous sulfate; 100.2 g Zn from zinc oxide; 10.0 g Cu from copper sulfate; 0.5 g I from ethylenediamine dihydroiodide; 0.3 g Se from sodium selenite.

[5] Lysine source (Evonik INC., Kennesaw, GA).

[6] Optiphos 2000 (Enzyva LLC, Sheridan, IN), providing 375.23 phytase units (FTU)/kg, with a release of 0.10% available P.

[7] Paylean (Elanco Animal Health, Greenfield, IN). fed at 20 g/kg.

[8] Soybean hulls ADF and NDF values are from INRA (Institut National de la Recherche Agronomique), 2004. All other values taken from NRC, 1998.

Table 2.3 Chemical analysis and bulk density of soybean hulls (as-fed basis)

Item	Exp. 1		Exp. 2[1]	
DM, %	91.91		91.51	
CP, %	9.8		10.61	
ADF, %	40.1		43.6	
NDF, %	55.3		55.9	
Crude fiber, %	32.7		36.3	
Ca, %	0.54		0.58	
P, %	0.11		0.11	
	Ground	Unground	Ground	Unground
Bulk density, g/L	490	421	531	468
Particle size, D_{gw} (µ)	398	617	370	787

[1] Samples of every batch of soybean hulls used were composited, analyzed, and averages are reported.

Table 2.4 Bulk density and particle size of experimental diets, Exp. 1 (as-fed basis)[1]

		Treatments							
	Grind type:	Unground	Unground	Ground	Ground	Unground	Unground	Ground	Ground
	Diet form:	Meal	Meal	Meal	Meal	Pellet	Pellet	Pellet	Pellet
Item	Soybean hulls, %:	10%	20%	10%	20%	10%	20%	10%	20%
Bulk density, g/L									
Phase 1		617	575	624	600	767	717	740	732
Phase 2		699	632	702	646	772	753	772	774
Particle size, μ									
Phase 1		355	400	360	364	--	--	--	--
Phase 2		430	558	423	500	--	--	--	--

[1] Diet samples collected from the tops of each feeder during each phase.

Table 2.5 Bulk density and particle size of experimental diets, Exp. 2 (as-fed basis)[1]

		Treatments				
	Grind type:	--	Unground	Unground	Ground	Ground
Item	Soybean hulls, %:	0%	7.5%	15%	7.5%	15%
Bulk density, g/L						
Phase 1		672	679	645	699	655
Phase 2		706	647	604	670	652
Phase 3		664	629	589	625	629
Phase 4		674	638	603	653	633
Particle size, µ						
Phase 1		583	573	582	566	551
Phase 2		491	567	590	524	529
Phase 3		540	573	615	555	540
Phase 4		588	577	594	537	552

[1] Diet samples collected from each feeder during each phase.

Table 2.6 Quality of pelleted diets, Exp. 1[1]

Item	Grind type: / Soybean hull level, %:	Unground 10%	Unground 20%	Ground 10%	Ground 20%
Phase 1					
Std. PDI,[2] %		95	95	94	95
Mod. PDI,[2] %		93	92	89	92
Fines, %		7.6	0.5	6.6	3.6
Phase 2					
Std. PDI,[2] %		97	97	95	94
Mod. PDI,[2] %		94	95	92	92
Fines, %		6.1	1.5	1.8	0.8

[1] Samples were taken from each feeder during each phase. A composite sample was made for each treatment.

[2]Pellet durability index.

Table 2.7 Interactions of soybean hulls level, particle size and complete diet form on nursery pig performance[1], Exp. 1.

Grind type:	Unground	Unground	Ground	Ground	Unground	Unground	Ground	Ground		Probability, *P* <	
Diet form:	Meal	Meal	Meal	Meal	Pellet	Pellet	Pellet	Pellet		Diet form × soybean hulls particle size	Diet form × Soybean hulls
Item / Soybean hulls, %:	10%	20%	10%	20%	10%	20%	10%	20%	SEM[2,3]		
d 0 to 14											
ADG, g	159	182	151	166	204	206	176	196	28	0.35	0.33
ADFI, g	276	293	273	282	337	316	325	335	28	0.45	0.19
G:F	0.567	0.619	0.539	0.583	0.613	0.650	0.538	0.586	0.042	0.21	0.88
Caloric efficiency[4]											
ME	5.62	4.91	5.96	5.18	5.34	4.65	6.14	5.24	0.44	0.23	0.90
NE	4.02	3.43	4.26	3.62	3.82	3.25	4.39	3.66	0.31	0.23	0.90
d 14 to 42											
ADG, g	634	625	614	619	651	639	630	637	14.5	0.86	0.96
ADFI, g	924	956	879	922	951	946	922	947	30.6	0.10	0.07
G:F	0.687	0.653	0.699	0.671	0.686	0.646	0.684	0.675	0.012	0.18	0.09
Caloric efficiency											
ME	4.60	4.60	4.52	4.49	4.61	4.45	4.62	4.47	0.08	0.19	0.10
NE	3.22	3.14	3.16	3.06	3.23	3.04	3.23	3.05	0.06	0.19	0.10
d 0 to 42											
ADG, g	475	477	460	467	502	494	478	490	18	0.91	0.79
ADFI, g	708	735	677	708	746	736	722	743	29	0.10	0.06
G:F	0.672	0.649	0.679	0.660	0.673	0.673	0.662	0.661	0.007	0.05	0.06
Caloric efficiency											
ME	4.70	4.64	4.65	4.56	4.69	4.47	4.77	4.56	0.05	0.05	0.06
NE	3.29	3.17	3.26	3.12	3.29	3.06	3.34	3.12	0.04	0.05	0.06
BW, kg											
d 0	6.8	6.8	6.7	6.8	6.8	6.8	6.9	6.8	0.1	0.22	0.52
d 14	9.0	9.4	8.9	9.1	9.6	9.7	9.3	9.5	0.4	0.80	0.36

d 42	26.8	26.9	26.1	26.4	27.9	27.6	26.9	27.4	0.8	0.96	0.73

[1] A total of 1,100 pigs (PIC C-29 × 359, initially 6.8 ± 0.1 kg BW) were used in a 42-d study with 11replications per treatment.

[2] No soybean hull × particle size × diet form interactions, $P > 0.37$.

[3] No particle size × soybean hull interaction, $P > 0.17$.

[4] Caloric efficiency is express as Mcal/kg gain.

Table 2.8 Main effects of soybean hulls, particle size, and complete diet from on nursery pig performance[1], Exp. 1.

	Diet form		Soybean hulls particle size		Soybean hulls			Probability, *P* <		
Item	Meal	Pellet	Unground	Ground	10%	20%	SEM	Soybean hulls	Soybean hulls particle size	Diet Form
d 0 to 14										
ADG, g	164	195	188	172	172	188	27	0.003	0.003	0.0001
ADFI, g	281	328	305	304	303	306	26	0.58	0.84	0.0001
G:F	0.577	0.597	0.612	0.562	0.564	0.610	0.039	0.002	0.002	0.63
Caloric efficiency[2]										
ME	5.42	5.34	5.13	5.63	5.76	5.00	0.39	0.0001	0.002	0.63
NE	3.83	3.78	3.63	3.98	4.12	3.49	0.28	0.0001	0.002	0.63
d 14 to 42										
ADG, g	623	639	637	625	632	630	12	0.71	0.06	0.01
ADFI, g	921	941	944	918	919	943	29	0.002	0.0008	0.008
G:F	0.677	0.680	0.676	0.682	0.689	0.669	0.009	0.001	0.31	0.70
Caloric efficiency										
ME	4.55	4.54	4.57	4.52	4.59	4.50	0.06	0.04	0.30	0.74
NE	3.15	3.14	3.16	3.13	3.21	3.07	0.04	0.0001	0.30	0.75
d 0 to 42										
ADG, g	470	491	487	474	479	482	17	0.45	0.005	0.0001
ADFI, g	707	737	731	713	713	731	28	0.007	0.004	0.0001
G:F	0.665	0.667	0.667	0.666	0.672	0.661	0.004	0.03	0.82	0.69
Caloric efficiency										
ME	4.63	4.62	4.62	4.63	4.70	4.55	0.03	0.0001	0.83	0.76
NE	3.21	3.20	3.21	3.21	3.30	3.12	0.02	0.0001	0.82	0.78
BW, kg										
d 0	6.8	6.8	6.8	6.8	6.8	6.8	0.1	0.83	0.87	0.71
d 14	9.1	9.5	9.4	9.2	9.2	9.4	0.4	0.002	0.002	0.0001
d 42	26.5	27.4	27.3	26.7	26.9	27.1	0.8	0.42	0.08	0.0001

[1] A total of 1,100 pigs (PIC C-29 × 359, initially 6.8 ± 0.1 kg BW) were used in a 42-d study with 11replications per treatment.
[2] Caloric efficiency is express as Mcal/kg gain.

Table 2.9 Effects of ground and unground soy hulls on growth performance and carcass characteristics[1]

Item	Soybean hulls, %:	0	7.5	15	7.5	15		Probability, $P <$			
								Soybean hull	Soybean	Soybean hulls	
	Particle size:	-	Unground	Unground	Ground	Ground	SEM[2]	particle size	hulls level	Linear	Quadratic
d 0 to 118											
ADG, kg		0.837	0.839	0.845	0.843	0.822	0.010	0.34	0.45	0.78	0.53
ADFI, kg		2.13	2.15	2.18	2.21	2.18	0.024	0.31	0.96	0.11	0.31
G:F		0.391	0.387	0.384	0.381	0.375	0.004	0.04	0.26	0.02	0.75
Caloric efficency[3]											
ME		8.54	8.32	8.08	8.49	8.29	0.09	0.03	0.01	0.002	0.60
NE		6.33	6.07	5.80	6.20	5.95	0.06	0.03	0.0002	0.0001	0.61
BW, kg											
d 0		31.0	31.0	31.1	31.1	31.1	0.79	0.99	0.97	0.96	0.99
d 118		128.3	127.7	128.9	128.8	126.5	1.39	0.64	0.68	0.73	0.83
Carcass characteristics											
Plant carcass yield, %		76.26	75.42	74.96	75.23	75.16	0.361	0.55	0.12	0.001	0.13
HCW, kg		94.7	92.9	91.9	94.0	91.8	1.05	0.62	0.13	0.03	0.83
Backfat depth, mm		15.6	14.2	13.5	15.1	14.5	0.29	0.002	0.13	0.0006	0.38
Loin depth, mm		67.4	66.0	64.8	65.5	65.6	0.81	0.84	0.67	0.32	0.25
Lean, %		57.44	58.06	58.39	57.54	57.82	0.186	0.004	0.12	0.008	0.89
FFLI[4]		54.12	54.75	55.07	54.28	54.50	0.168	0.003	0.13	0.003	0.63

[1] A total of 1,235 pigs (PIC 337 x 1050; initially 31.1 ± 0.06 kg BW) were used in a 118-d study with 9 replications per treatment.
[2] No soybean hull particle size × soybean hull level interactions $P > 0.18$.
[3] Caloric efficiency is express as Mcal/kg gain.
[4] Fat-free lean index was calculated using NPPC (2000) guidelines for carcasses measured with the Fat-O-Meater such that FFLI = ((15.31 + HCW, lb.) – (31.277 × last-rib fat thickness, in.) + (3.813 × loin muscle depth, in))/HCW, lb.

Chapter 3 - The effects of dietary wheat and crystalline amino acids on nursery and finishing pig performance.

Abstract

Two experiments were conducted to evaluate the effects of wheat and crystalline AA on the growth performance of nursery and finishing pigs. In both studies, pigs were assigned to 1 of 4 dietary treatments in a completely randomized design. Treatments included: 1) corn-soybean meal diet, 2) diet 1 with wheat replacing approximately 50% of the corn, 3) wheat replacing 100% of the corn in diet 1 with high amounts of crystalline AA, and 4) diet 3 with soybean meal replacing a portion of the crystalline AA (5 and approximately 2.5 % in the nursery and finisher respectively). In Exp. 1, a total of 192 pigs (PIC; 337 × 1050, initially 12.1 ± 0.1 kg BW) were used in a 21 d nursery study with 6 pigs per pen and 8 replications per treatment. Overall (d 0 to 20), no growth performance differences were observed when replacing 50% of corn with wheat. There was a tendency for reduced ADG (linear, $P < 0.08$) when replacing 100% corn with wheat. Replacing 100% of corn with wheat improved (linear, $P < 0.05$) caloric efficiency on an ME basis and tended to improve (linear, $P < 0.07$) caloric efficiency on an NE basis. In wheat-based diets, more soybean meal and less crystalline AA tended to improve ($P < 0.07$) G:F and improved ($P < 0.03$) caloric efficiency on an NE basis. In Exp. 2, 288 pigs (PIC; 327 × 1050, initially 72.4 ± 0.1 kg BW) were used in a 61 d finishing study. Pens of pigs (8 or 7 pigs per pen) were randomly allotted by initial BW to treatments with 9 replications per treatment. Overall (d 0 to 61), pigs fed increasing wheat had decreased ADG (linear, $P < 0.04$) and poorer G:F (linear, $P < 0.003$), which was primarily due to worsening of each when wheat was fed at 100% compared with 50% of the diet. Replacing corn with wheat tended to improve (linear, $P < 0.08$) caloric efficiency on an ME basis, but not on an NE basis. Adding more soybean meal to lower the level of crystalline AA in wheat-based diets had no effect on growth. A tendency for increased backfat ($P < 0.08$) was observed for pigs fed 50% wheat compared with 100% corn. For carcass fat quality, jowl fat IV decreased (linear, $P < 0.001$) with increasing wheat. In summary, wheat can be used to replace at least 50% of corn in finishing pig diets without negatively affecting growth performance while carcass fat firmness improves with increasing dietary wheat levels. Use of high levels of crystalline AA in wheat-based diets had minimal effects in nursery pigs and none on growth performance of finishing pigs.

Key words: Crystalline amino acids, growth, nursery pig, finishing pig, wheat

Introduction

Wheat is commonly grown worldwide and is commonly used in swine diets. However, in the United States, corn is used more than wheat in swine diets due to production levels. In 2012, approximately 2.3 billion bushels of wheat were harvested (USDA, 2013a) compared to the 12 billion bushels of corn (USDA, 2013b). In the NRC (2012), wheat possesses an ME value of 3,215 and NE value of 2,472 kcal/kg, which is approximately 95 and 93% the energy of corn on an ME and NE basis. In terms of AA profile, wheat has an increased concentration of the amino acids most limiting to pigs in most diets, specifically lysine, tryptophan, and threonine (NRC, 2012). Furthermore, wheat has more total phosphorus and greater phosphorus digestibility than corn (Stein, 2010).

Research has indicated that nursery and growing-finishing pigs fed wheat-based diets can perform and have similar carcass composition as pigs fed corn-based diets if diets are formulated to contain similar energy and nutrient concentrations (McConnel et al., 1975; Erickson et al., 1980; Han et al., 2005). Due to the high AA profile found in wheat, there are several diet formulation options. For example, higher inclusion rates of crystalline AA could be used than in corn-based diets to maintain similar minimum AA ratios relative to lysine. Consequently, crystalline AA can be used to replace a larger portion of soybean meal in nursery diets and all of the soybean meal in late finishing diets containing wheat as the only grain source. Myer et al. (1996) indicated supplementation of crystalline lysine and threonine could replace a portion of soybean meal in wheat-based diets for growing-finishing pigs. However, little data with modern genetics are available on the effects of higher inclusion rates of crystalline AA in wheat-based diets. Therefore, the objectives of this study were: 1) to determine the effects of replacing corn with wheat and 2) the influence of crystalline AA levels in wheat diets on growth performance of nursery and finishing pigs.

Materials and Methods

General

All experimental procedures and animal care were approved by the Kansas State Institutional Animal Care and Use Committee. All wheat used was hard red winter wheat and was sourced from the same location (Farmers Coop, Manhattan, KS). All diets were manufactured at the Kansas State University Animal Sciences Feed Mill and fed in meal form. Caloric efficiencies of pigs were determined on both ME (NRC, 1998) and NE (INRA, 2004) basis. Efficiencies were calculated by multiplying total feed intake by energy in the diet (kcal/kg) and dividing by total gain.

Experiment 1

A total of 192 pigs (PIC 327 × 1050; PIC, Hendersonville, TN; initially 12.1 ± 0.1 kg BW) were used in a 21 d growth trial to evaluate the effects of wheat and crystalline AA on growth performance of nursery pigs. Pigs were allotted to pens by BW, and pens were assigned to 1 of 4 treatments in a completely randomized design. There were 6 pigs per pen and 8 replications per treatment. Dietary treatments included: 1) a corn-soybean meal diet, 2) diet 1 with wheat replacing approximately 50% of the corn, 3) wheat replacing 100% of the corn in diet 1 with high levels of crystalline AA, and 4) diet 3 with 5% more soybean meal and low crystalline AA. Diets were fed in 1 phase in meal form from d 0 to 21 (Table 3.1). Crystalline AA (lysine, threonine, and methionine) were added to the corn and wheat diets (diet 1 and 3) until another AA became limiting. Tryptophan was the fourth limiting AA in the corn-based diet, and valine was the fourth limiting AA in the wheat-based diet. Diet 2 was formulated to have similar levels of corn and wheat in both experiments. The soybean meal level was increased by 5% in diet 4 to reduce the level of crystalline AA. All diets were formulated to meet or exceed requirements (NRC, 1998) with a constant standardized ileal digestible (**SID**) lysine level of 1.26% as required by diet 1 (highest-energy diet).

This experiment was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. Each pen (1.22 × 1.52 m) contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pig weight and feed disappearance were measured weekly to determine ADG, ADFI, and G:F. All diets were manufactured at the Kansas State University Animal Sciences Feed Mill. Samples of each dietary treatment were collected from every feeder and subsampled into a composite sample of each treatment for both phases.

Experiment 2

A total of 288 barrows and gilts (PIC 327 × 1050; PIC, Hendersonville, TN; initially 72.4 ± 0.1 kg BW) were used in a 61 d growth trial to evaluate the effects of wheat and crystalline AA on growth performance and carcass characteristics of finishing pigs. Pens of mixed sex pigs (7 or 8 per pen) were randomly allotted by initial BW to 1 of 4 dietary treatments with 9 replications per treatment. Dietary treatments were similar to experiment 1 and included: 1) a corn-soybean meal diet, 2) diet 1 with wheat replacing approximately 50% of the corn, 3) wheat replacing 100% of the corn in diet 1 with high levels of crystalline AA, and 4) diet 3 with approximately 2.5% more soybean meal and low crystalline AA. Diets were fed in 2 approximately 30-d phases from 60 to 95 and 95 to 127 kg BW (Table 3.2). Crystalline AA (lysine, threonine, and methionine) were added to the corn and wheat diets (diet 1 and 3) until another AA became limiting. Tryptophan was the fourth limiting AA in the corn-based diet, while valine was the fourth limiting AA in the wheat-based diet. All diets were formulated to a constant SID lysine level of 0.72 and 0.62% for phase 1 and 2, respectively. Diets were fed via the FeedPro™ system (Feedlogic Corp, Willmar MN). Pigs and feeders were weighed on d 0, 14, 30, 44, and 61 to calculate ADG. Feed intake and G:F were determined from feed delivery data generated through the automated feeding system and the amount of feed remaining in each pen's feeder on every weigh day.

On d 61, all pigs were individually weighed and tattooed for carcass data collection and transported 210 km to a commercial packing plant (Triumph Foods LLC, St. Joseph, MO) for collection of standard carcass data and jowl fat IV. Jowl fat IV was calculated using Near Infrared Spectroscopy (NIR; Bruker MPA; Multi-Purpose Analyzer) using the equation of Cocciardi et al. (2009). Hot carcass weights were measured immediately after evisceration and each carcass was evaluated for percentage yield, backfat, loin depth, and percentage lean. Fat depth and loin depth were measured with an optical probe inserted approximately 7.1 cm from the dorsal midline between the 3rd and 4th last rib (counting from the ham end of the carcass). Percentage yield was calculated by dividing HCW at the plant by live weight at the farm.

This study was conducted at the Kansas State University Swine Teaching and Research Center, Manhattan, KS. The facility was a totally-enclosed, environmentally-controlled and mechanically-ventilated barn with completely slatted floors containing 38 pens. Each pen was 2.4 × 3.1 m and equipped with a single-sided, dry self-feeder (Farmweld; Teutopolis, IL) and a cup waterer.

Chemical Analysis

In both experiments, wheat was collected from each batch at the time of feed manufacturing and a single composite sample for each experiment was analyzed for moisture (AOAC 934.01, 2006), CP (AOAC 990.03, 2006), ADF (ANKOM Technology, 1998a), NDF (ANKOM Technology, 1998b) crude fiber (AOAC 978.10, 2006), Ca (AOAC 965.14/985.01, 2006.), and P (AOAC 965.17/985.01, 2006; Ward Laboratories, Kearney, NE). Corn and wheat samples for each trial were analyzed (University of Missouri-Columbia, MO; AOAC) for AA profile (AOAC, 2006). Composite diet samples by treatment for each phase were measured for bulk density using a Seedburo test weight apparatus and computerized grain scale (Seedburo Model 8800, Seedburo Equipment, Chicago, IL).

Statistical Analysis

In both experiments, data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Linear and quadratic contrasts were used to determine the effects of wheat replacing 50 or 100% of the corn (Treatments 1, 2, and 3). Single degree of freedom contrast were used to determine the effects of low vs. high amounts of crystalline AA in wheat diets (Treatments 3 vs. 4) and to compare the corn diet compared with the 50% wheat replacement (Treatment 1 vs. 2). In Exp. 2, analysis of backfat depth, loin depth, and percentage lean were adjusted to a common carcass weight using HCW as a covariate. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results

Chemical Analysis

Proximate analysis of wheat samples in both experiments were verified to be similar to those used in diet formulation and were similar to NRC (2012) values for hard red winter wheat (Table 3.3). The AA profiles of wheat samples were similar across experiments and were comparable to NRC (2012) values (Table 3.4). The minor differences would not be expected to influence results of the experiments. As wheat replaced corn in the diet, the dietary bulk density increased. The minor differences in particle size (approximately 30 microns) between wheat and corn would not be expected to affect results of the studies.

Experiment 1

In Exp. 1, no differences ($P > 0.75$) in growth performance were observed when replacing 50% of corn with wheat (Table 3.5). A tendency was observed for reduced ADG (linear, $P < 0.08$) when replacing 100% of corn with wheat. Also, replacing 100% of corn with wheat improved (linear, $P < 0.05$) caloric efficiency on an ME basis and tended to improve (linear, $P < 0.07$) caloric efficiency on an NE basis. Finally, using less crystalline AA and more soybean meal to the wheat-based diets tended to improve ($P < 0.07$) G:F and ($P < 0.03$) caloric efficiency ($P < 0.03$) on an NE basis.

Experiment 2

For the overall period (d 0 to 61), replacing 50% of corn with wheat had no effect on growth performance (Table 3.6). However, a 100% wheat replacement for corn decreased (linear, $P < 0.04$) ADG and worsened (linear, $P < 0.003$) G:F. Caloric efficiency tended to be improved (linear, $P < 0.08$) on an ME basis with increasing amounts of wheat, but not on an NE basis. Also, level of crystalline AA in wheat-based diets had no effect ($P > 0.32$) on growth performance.

For carcass characteristics, a tendency was observed for pigs fed 50% wheat to have increased ($P < 0.08$) backfat depth compared with pigs fed the corn-based diet. Increasing wheat in the diet reduced (linear, $P < 0.001$) jowl fat IV. Differing levels of crystalline AA in wheat-based diets had no effect (P > 0.21) on carcass characteristics or IV values.

Discussion

Wheat is a common feed ingredient worldwide used in swine diets. Research from the 1960’s to 2005 has demonstrated that wheat can replace corn in diets and yield similar performance (Jensen et al., 1969; McConnel et al., 1975; and Han et al., 2005). Furthermore, wheat as a primary energy source offers several formulating options because of its different nutritional profile compared with corn. First, wheat has higher concentrations of AAs (NRC, 2012) most noticeably lysine, tryptophan, and threonine than corn. Due to the high concentrations of AA, less intact AA sources, such as soybean meal are required in nursery and grower rations and can be removed entirely in finishing rations (Maxwell et al., 1987; Myer et al., 1996). Maxwell et al. (1987) evaluated the complete removal of dietary soybean meal by supplementing crystalline Lys, Met, Thr, and Ile and observed performance similar to pigs fed a wheat-soybean meal diet. While, Myer et al. (1996) more recently reduced the amount of soybean meal used by only supplementing crystalline Lys and Thr to replace soybean meal and observed no effect on pig growth or carcass characteristics. In the current studies only crystalline Lys, Thr, and Met were needed in diet formulation to reduce the soybean meal used in the nursery or to remove it completely in late finishing.

Trials by Jensen et al. (1969), McConnel et al. (1975), and Han et al. (2005) all concurred that using wheat as the sole energy source did not affect performance compared to corn-based diets. Despite similar observations, formulation strategies differed. The trial conducted by McConnel et al. (1975) formulated both the corn-based and wheat-based diets to substitute each other without adjusting other dietary ingredients. The corn-based diet was formulated first and then wheat was simply used to replace the corn. Therefore, due to the differences in ingredient nutrient profiles, the wheat-based diet would be expected to have high CP and AA content than the corn-based diet. Meanwhile the corn-based diet would be expected to have a slightly higher energy value than the wheat-based diet. However, McConnel et al. (1975) showed no difference ($P > 0.05$) in growth performance. Jensen et al. (1969) and Han et al. (2005) used different formulation methods and obtained similar results. In a finishing study, Jensen et al. (1969) used crystalline lysine in a wheat-based diet to completely remove soybean meal and compared it with a corn-soybean meal diet without crystalline lysine and observed similar performance. A more recent study by Han et al. (2005) evaluated wheat-based and corn-based diets were formulated to have equal digestible lysine and DE levels with soybean meal as the only additional AA source in the wheat-based diet. They reported no difference in growth rates, but improved feed conversion ($P < 0.05$) in pigs fed the wheat-based diet.

There are several wheat varieties that can be used in swine diets. Growing region and the type of weather in that region can affect wheat nutritional composition (Kim et al. 2004). Digestible energy may vary in wheat depending on variety and growing conditions (Kim et al., 2004; Zijlstra et al., 1999). In review of literature, many publications did not indicate the type of wheat used (hard or soft, spring or winter, red or white, waxy or non-waxy). However, studies have showed that wheat variety does not impact feeding value in pigs. Bowland et al. (1974) and Jha et al. (2011) evaluated the effects of several wheat cultivars and classes in diets for young pigs and reported no differences amongst wheat types on pig performance. In the current studies, hard red winter wheat was used in both trials and sourced from the same location within the same year.

Due to the higher SID AAs in wheat compared to corn, less additional AAs from protein sources need to be included to formulate a complete diet. In the current nursery study, replacing all of the corn with wheat tended to reduce ADG and improved caloric efficiency on an NE basis. The decreased ADG in wheat-based diets was primarily observed in the diet containing the lowest amount of soybean meal and high synthetic AAs. On the contrary, Erickson et al. (1980) observed starter pigs fed wheat-based and corn-based diets performed similarly. Compared to the current study, Erikson et al. (1980) used less soybean meal in the wheat-based diets with no additional crystalline AAs and lighter pigs were used on test (10 kg). Furthermore, the improvement in caloric efficiency on an NE basis is the result of nursery pigs having similar G:F on a lower energy diet.

Decreasing the amount of soybean meal in the current nursery study by increasing inclusions of crystalline Lys, Met, and Thr tended to worsen G:F compared to the wheat-based diet with 5% more soybean meal. It is plausible that crystalline AA in cereal-based diets can only replace a portion of intact protein which agrees with Hansen et al. (1993) and Brudevold and Southern, (1994) who both observed a reduction in performance when crystalline AAs replaced soybean meal. However, the amount of crystalline AAs used to replace an intact protein source is not fully understood, as Cromwell et al. (1996), Kerr et al. (2003), and Hinson et al. (2007) observed crystalline AAs did not affect growth performance. In diet formulation, crystalline Lys, Thr, and Met was added in diet 3 and Val was the fourth limiting amino acid at with the Val:Lys ratio of 66. While this diet was formulated to be close to the Val requirement, the combination of wheat analyzing slightly higher in Lys and Val than the assumed values used in formulation, pig performance should have not been affected.

In the current finishing study, replacing 100% of corn with wheat decreased ADG and worsened G:F regardless of soybean meal or AA inclusion levels. It could be speculated that the decreased ADG and G:F could be the result of diet formulation. However, the wheat used throughout the finishing study analyzed higher in Lys and Val and would not be expected to affect performance. The reduced ADG and G:F is most likely a result of lower energy diets. Furthermore, the poorer ADG and G:F agreed with the observations on growing-finishing pigs fed wheat based diets by Erickson et al. (1980). On the contrary, McConnel et al. (1975) and Han et al. (2005) indicated that pigs fed wheat-based diets gained at a similar rate to those on a traditional corn-soybean meal diet. Han et al. (2005) also showed an improvement in G:F, due to numerically lower intake in wheat-based diets compared to corn-based diets. In the case of McConnel et al. (1975), the differences in formulation yielded differences in dietary energy, protein, and AA profiles between wheat and corn-based diets. These differences did not alter performance in the study. Meanwhile, Han et al. (2005) formulated the wheat-based diet to contain tallow and be isocaloric to the corn-based diet. Wheat has a lower energy concentration than corn; therefore a wheat-based diet would be expected to have less energy (NRC, 2012). When a fat source such as tallow is added to increase dietary energy, intake is expected to decrease because energy density increases with added fat (Quiniou and Noblet, 2012). However, because Han et al. (2005) formulated diets to be isocaloric intake would be expected to be similar. It is possible that the energy in the wheat-based was higher than the corn-based diet if the energy values of wheat and tallow were underestimated thus explaining the numerically reduced ADFI and improved G:F reported by Han et al. (2005).

Despite different formulation and trial designs utilizing wheat based diets, Erickson et al. (1980), McConnell et al. (1975), and Han et al. (2005) reported no statistical differences in carcass yield, backfat, or loin depth. With the exception of backfat, replacing corn with wheat had no impact on carcass yield, hot carcass weight, loin depth, or percent lean in the current study. The tendency for increased backfat in diets containing wheat is unexplained.

For carcass fat quality, jowl fat iodine values were less than 70 g/100 g and acceptable across all treatments (Benz et al., 2010 and NPPC, 2000). Jowl fat iodine values were decreased by approximately 1 point when wheat was included in the diet; however the decrease in jowl IV could be explained by two means. First, it was a mechanism of increased backfat. Benz et al. (2011) observed higher unsaturated fatty acid to saturated fatty acid ratios in pigs with less backfat. Pigs with more backfat have more de novo synthesis resulting in firmer or more saturated fat (Benz et al., 2011). Secondly, wheat contains less fat than corn, thus less unsaturated fatty acids are consumed thus resulting in a lower amount to be deposited in carcass fat. In the current study, pigs on wheat diets had increased backfat, therefore since they were fatter pigs, more de novo synthesis occurred resulting in firmer, more saturated fat and lower IV.

In summary, 50% of corn can be replaced with wheat and have no negative impacts on growth performance or carcass characteristics. Replacing 100% of corn with wheat in nursery and grow-finish diets decreased ADG. In finishing diets replacing 100% of corn with wheat also reduced G:F. Furthermore, increasing crystalline AA in wheat-based diets to replace a greater portion of soybean meal reduced G:F in the nursery, however did not affect finishing pig performance.

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Tables

Table 3.1 Diet composition and bulk density, Exp. 1 (as-fed basis)[1]

	Wheat replacement of corn, %:			
Ingredient, %	0	50	100	100 + SBM[1]
Corn	62.42	33.62	--	--
Hard red winter wheat	--	33.70	70.80	66.30
Soybean meal, 46.5% CP	32.08	29.16	25.45	30.46
Monocalcium P, 21% P	1.05	0.95	0.75	0.80
Limestone	1.00	1.05	1.15	1.08
Salt	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15
L-Lys HCl	0.33	0.39	0.475	0.318
DL-Met	0.125	0.115	0.095	0.055
L-Thr	0.125	0.145	0.160	0.100
Phytase[4]	0.125	0.125	0.125	0.125
Total	100.0	100.0	100.0	100.0
Calculated analysis				
Standardized ileal digestible (SID) AA, %				
Lys	1.26	1.26	1.26	1.26
Ile:Lys	61	61	59	66
Leu:Lys	129	120	109	119
Met:Lys	33	32	30	29
Met & Cys:Lys	58	58	58	58
Thr:Lys	63	63	63	63
Trp:Lys	17.5	18.5	19.4	21.2
Val:Lys	68	68	66	73
Total Lys, %	1.39	1.39	1.38	1.39
ME, Mcal/kg	3.31	3.24	3.16	3.18
NE, Mcal/kg	2.37	2.32	2.27	2.25
SID Lys:ME, g/Mcal	3.80	3.88	3.98	3.96
CP, %	20.9	21.5	22.0	23.5
Crude fiber, %	2.7	2.6	2.6	2.6
ADF	3.5	3.9	4.2	4.3
NDF	9.0	10.4	11.8	11.7
Ca, %	0.70	0.70	0.70	0.70
P, %	0.62	0.62	0.60	0.62
Available P, %	0.42	0.42	0.42	0.42
Bulk density,[5] g/L	748	767	790	806

[1] Dietary treatment fed in meal form from 12.1 to 23.5 kg BW.

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

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

110 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.
[4] Phyzyme 600 (Danisco, Animal Nutrition, St. Louis, MO), providing 509 phytase units (FTU)/kg, with a release of 0.10% available P.
[5] Diet samples collected from the top of each feeder during each phase.

Table 3.2 Phase 1 and 2 diet composition and bulk density, Exp. 2 (as-fed basis)[1]

	Phase 1[2]				Phase 2[2]			
Wheat replacement of corn, %:	0	50	100	100 + SBM	0	50	100	100 + SBM
Ingredient, %								
Corn	81.89	44.39	--	--	85.97	46.58	--	--
Hard red winter wheat	--	44.30	96.05	95.20	--	46.50	97.85	95.45
Soybean meal, 46.5% CP	16.04	9.15	1.57	2.50	12.06	4.86	--	2.51
Monocalcium P, 21% P	0.24	0.06	--	--	0.21	0.03	--	--
Limestone	1.01	1.03	1.09	1.09	0.99	1.00	1.09	1.09
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.08
Trace mineral premix[4]	0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.08
L-Lys HCl	0.150	0.330	0.525	0.496	0.150	0.338	0.446	0.368
DL-Met	--	0.005	0.025	0.023	--	--	0.013	--
L-Thr	--	0.065	0.130	0.120	--	0.068	0.098	0.065
Phytase[5]	0.125	0.125	0.038	0.038	0.125	0.125	0.028	0.028
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis								
Standardized ileal AA (SID), %								
Lys	0.72	0.72	0.72	0.72	0.62	0.62	0.62	0.62
Ile:Lys	71	62	53	55	71	61	58	64
Met:Lys	31	29	29	29	33	30	30	30
Met & Cys:Lys	64	63	65	66	68	67	72	73
Thr:Lys	63	63	63	63	65	65	65	65
Trp:Lys	18.8	18.8	19.3	19.9	18.4	18.5	21.3	23.2
Val:Lys	83	75	66	68	86	76	73	80
Total Lys, %	0.82	0.80	0.79	0.79	0.71	0.69	0.68	0.69
ME, Mcal/kg	3.35	3.27	3.17	3.17	3.36	3.27	3.16	3.17
NE, Mcal/kg	2.50	2.46	2.41	2.40	2.52	2.48	2.42	2.40
CP, %	14.6	14.4	14.3	14.6	13.1	12.9	13.7	14.5
Crude fiber, %	2.4	2.3	2.2	2.2	2.4	2.2	2.2	2.2

ADF	3.2	3.5	3.9	3.9	3.1	3.4	3.9	4.0
NDF	9.3	11.1	13.1	13.1	9.3	11.2	13.2	13.1
Ca, %	0.51	0.47	0.48	0.48	0.48	0.44	0.47	0.48
P, %	0.39	0.36	0.37	0.37	0.37	0.34	0.36	0.37
Available P, %	0.22	0.22	0.22	0.22	0.21	0.21	0.21	0.21
Bulk density,[6] g/L	721	767	807	801	721	771	803	824

[1] A total of 288 pigs (PIC 327 × 1050; PIC, Hendersonville, TN; initially 72.4 ± 0.1 kg BW) were used in a 61-d growth with 9 replications.

[2] Phase 1 diets were fed from d 0 to d 30; Phase 2 from d 30 to 61.

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

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

[5] Phyzyme 600 (Danisco, Animal Nutrition, St. Louis, MO), providing 509 phytase units (FTU)/kg, with a release of 0.10% available P.

[6] Diet samples collected from each feeder during each phase and combined and then sub-sampled for analysis.

Table 3.3 Chemical analysis of corn and wheat (as-fed basis)

	Corn	Wheat	
Item	Exp. 1 and 2	Exp. 1	Exp. 2[1]
Nutrient, %			
DM	88.01	89.1	89.2
CP	8.2	12.3	12.3
Fat (oil)	3.3	1.8	1.9
Crude fiber	1.7	2.6	2.5
ADF	2.5	3.8	3.2
NDF	7.9	11.1	9.0
Ca	0.05	0.06	0.06
P	0.32	0.39	0.40
Particle size, D_{gw} (µ)	671	640	638

[1] Values are means of three samples.

Table 3.4 Analyzed AA profile of corn and wheat (as-fed basis)

	Corn	Wheat	
Item	Exp. 1 and 2	Exp. 1	Exp. 2[1]
AA, %			
Lys	0.27 (0.26)[2]	0.39 (0.34)	0.38 (0.34)
Met	0.18 (0.17)	0.23 (0.20)	0.22 (0.20)
Thr	0.26 (0.29)	0.36 (0.37)	0.35 (0.37)
Trp	0.07 (0.06)	0.16 (0.15)	0.16 (0.15)
Cys	0.17 (0.19)	0.31 (0.29)	0.29 (0.29)
Ile	0.29 (0.28)	0.49 (0.41)	0.48 (0.41)
Leu	0.97 (0.99)	0.93 (0.86)	0.91 (0.86)
Val	0.42 (0.39)	0.62 (0.54)	0.61 (0.54)

[1] Values are means of three samples.
[2] Values in parenthesis used in diet formulation.

Table 3.5 Effects of wheat and crystalline AA on nursery pig performance (Exp. 1)[1]

	Wheat replacement of corn, %					Probability, $P <$			
						Wheat			
Item	0	50	100	100 + SBM	SEM	Linear[3]	Quadratic[4]	0 vs. 50%	Extra SBM[5]
d 0 to 21									
ADG, g	549	553	524	540	10	0.08	0.16	0.75	0.23
ADFI, g	862	869	834	834	17	0.25	0.32	0.77	0.99
G:F	0.636	0.636	0.629	0.648	0.007	0.44	0.70	0.99	0.07
Caloric efficiency[6]									
ME	5.21	5.10	5.04	4.91	0.06	0.05	0.78	0.21	0.13
NE	3.72	3.65	3.61	3.48	0.04	0.07	0.75	0.24	0.03
Wt, kg									
d 0	12.1	12.1	12.1	12.1	0.2	0.99	0.99	0.99	0.98
d 21	23.7	23.8	23.1	23.5	0.3	0.69	0.64	0.84	0.43

[1] A total of 192 pigs (PIC 327 × 1050, initially 12.1 ± 0.1 kg) were used in a 21-d study with 8 replications per treatment.
[3] Comparison of 0%, 50%, and 100% with high AA.
[4] Comparison of 0%, 50%, and 100% with high AA.
[5] 100% vs. 100% + SBM.
[6] Caloric efficiency is expressed as Mcal/kg gain.

Table 3.6 Effects of wheat and crystalline AA on finishing pig performance and carcass characteristics (Exp. 2)[1]

	Wheat replacement of corn, %				Probability, $P <$				
						Wheat			
Item	0	50	100	100 + SBM	SEM	Linear[3]	Quadratic[4]	0 vs. 50%	Extra SBM[5]
d 0 to 61									
ADG, kg	0.833	0.824	0.793	0.788	0.012	0.04	0.49	0.64	0.80
ADFI, kg	2.71	2.71	2.68	2.65	0.042	0.56	0.69	0.94	0.61
G:F	0.307	0.303	0.295	0.297	0.003	0.003	0.50	0.32	0.73
Wt, kg									
d 0	72.4	72.5	72.5	72.6	0.86	0.92	0.93	0.90	0.91
d 61	123.1	122.8	121.0	120.8	1.43	0.26	0.66	0.86	0.95
Caloric efficiency[6]									
ME	10.92	10.77	10.69	10.66	0.092	0.08	0.72	0.23	0.82
NE	8.18	8.15	8.15	8.09	0.074	0.76	0.82	0.73	0.55
Carcass characteristics									
Carcass yield, [7]%	73.4	73.5	73.4	73.1	0.19	0.37	0.40	0.51	0.21
HCW, kg	91.8	91.8	90.0	89.7	1.10	0.82	0.18	0.98	0.42
Backfat depth, mm	19.9	21.2	21.0	21.2	0.52	0.15	0.25	0.08	0.78
Loin depth, mm	57.3	58.3	57.2	57.9	0.67	0.87	0.19	0.29	0.42
Lean, %	52.3	52.0	51.9	51.8	0.27	0.31	0.94	0.56	0.75
Jowl fat iodine value	68.9	67.7	67.1	67.4	0.24	0.001	0.35	0.002	0.27

[1] A total of pigs 288 (PIC 327 × 1050, initially 72.4 ± 0.1 kg) were used in a 61-d study with 8 replications per treatment.
[3] Comparison of 0%, 50%, and 100% with high AA.
[4] Comparison of 0%, 50%, and 100% with high AA.
[5] 100% vs. 100% + SBM.
[6] Caloric efficiency is expressed as Mcal/kg gain.
[7] Percent carcass yield was calculated by dividing HCW by the live weights obtained at the farm before transported to the packing plant.

Chapter 4 - The effect of high-protein dried distillers grains with solubles and crystalline amino acid level on growth performance, carcass characteristics, and carcass fat quality in finishing pigs.

Abstract

A total of 204 barrows and gilts (PIC, 337 × 1050, initially 58.8 ± 0.3 kg) were used in a 73 d study to determine the effects of high-protein dried distillers grains with solubles (HPDDGS; 33% CP; 9% fat; Lifeline Foods, St. Joseph, MO) and crystalline AA levels on growth performance, carcass characteristics, and carcass fat quality. Pens of pigs (3 barrows and 3 gilts per pen) were randomly allotted by initial BW to 1 of 4 treatments with 8 or 9 replications per treatment. Treatment diets were fed in 3 phases and included: 1) corn-soybean meal control; 2) HPDDGS and crystalline AA (L-Lys, L-Trp and L-Thr) replacing 50% of the soybean meal in diet 1; and two diets in which 100% of the soybean meal was replaced by either: 3) HPDDGS and a high level of crystalline AA or 4) HPDDGS and low levels of crystalline AA. Treatment 3 diets contained 10% less HPDDGS then treatment 4 diets (30 vs. 40%, 27.5 vs. 37.5% and 17.5 vs. 27.5% for phases 1, 2, and 3, respectively). Overall, replacing 50% of the soybean meal with HPDDGS and crystalline AA had no effect ($P > 0.74$) on growth performance. Replacing 100% of soybean meal with HPDDGS and crystalline AA resulted in decreased ($P < 0.02$) ADG and ADFI, but no difference ($P > 0.75$) in G:F. In the two diets where 100% of the soybean meal was replaced with HPDDGS, the amount of added crystalline AA had no effect ($P > 0.56$) on growth performance. Jowl fat iodine value increased (linear, $P < 0.001$) as HPDDGS increased. However, the high level of added crystalline AA resulted in less HPDDGS in the diet and consequently reduced ($P < 0.001$) jowl IV. Similarly, carcass yield decreased ($P < 0.01$) as HPPDDGS replaced 100% of the soybean meal; however, using higher levels of crystalline AA increased ($P < 0.01$) carcass yield compared with lower amounts of crystalline AA (higher dietary HPDDGS). Thus, HPDDGS and crystalline AA can replace 50% of soybean meal in finishing pig diets without negatively affecting growth performance or carcass yield. These results suggest that crystalline AA could play a role in mitigating the negative effects of HPDDGS, on fat iodine value and carcass yield.

Key words: amino acids, growth, high-protein dried distillers grains with solubles, iodine value, finishing pigs

Introduction

Due to growth of the ethanol industry, corn dried distillers grains with solubles (**DDGS**) have become a readily available co-product that has found use in swine diets production (Stein, 2007; Stein and Shurson, 2008). Variation in nutrient concentration can typically be found in DDGS from different sources (Cromwell et al., 1993; Spiehs et al., 2002; Stein et al., 2006). Not only can variation be seen within a ethanol plant, different plants use different methods of production resulting in further variation. Certain methods may focus on oil production, such as solvent extraction procedures or spinning out oil, which results in DDGS with different oil contents (Singh and Cheryan, 1998). Other processes such as dry fractionation, will focus on CP content. This process removes most of the bran and germ and yields high-protein dried distillers grains with solubles (**HPDDGS**; Murthey et al. 2006).

The CP of corn HPDDGS has been reported to be 36.5 to 44.9% (Widmer et al., 2007; Jacela et al., 2010; Kim et al., 2009). This high CP coincides with an increased AA concentration than traditional DDGS (Jacela et al., 2010; Kim et al., 2009). Due to the AA profile found in HPDDGS, more crystalline AA, specifically Lys can be used with HPDDGS to replace soybean meal in swine diets. To this, Widmer et al. (2008) observed replacing 50 or 100% of soybean meal with corn HPDDGS had no effect on ADG and ADFI compared to a traditional corn-soybean meal diet.

It has been well documented that carcass fat quality is a concern with DDGS added as carcass fat iodine value (**IV**) increases (Whitney et al. 2006; Benz et al. 2010). However, HPDDGS typically have a lower fat content than traditional DDGS. Also, through diet formulation, high levels of crystalline AA may be able to decrease the amount of HPDDGS in the diet, consequently improving carcass fat IV. Therefore, the objective of this experiment was to determine the effects of replacing soybean meal with HPDDGS and crystalline AA on growth performance, carcass characteristics, and carcass fat quality in finishing pigs.

Materials and Methods

General

The Institutional Animal Care and Use Committee at Kansas State University approved protocols used in this experiment. This experiment was conducted at the Kansas State University Swine Teaching and Research Center.

The facility was a totally-enclosed, environmentally-controlled, mechanically-ventilated barn. It had 2 identical rooms containing 38 pens with adjustable gates facing the alleyway allowing for 0.93 sq. m/pig. Each pen (2.4 × 3.1 m) was equipped with a single-sided, dry self-feeder with 2 eating spaces (Farmweld; Teutopolis, IL) in the fence line and a cup waterer. Pens were located over a completely slatted concrete floor with a 1.2-m pit underneath for manure storage. The facility was also equipped with an automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of delivering and recording diets as specified on an individual pen basis.

Animals and Diets

A total of 204 pigs (337 × 1050; PIC Hendersonville, TN; initially 58.8 kg ± 0.3 BW) were used in a 73 d experiment. Pens of pigs (3 barrows and 3 gilts per pen) were allotted in a completely randomized design by initial BW to 1 of 4 dietary treatments with 8 or 9 replications per treatment. Standardized ileal digestible amino acid coefficients for HPDDGS were previously determined by Jacela et al. (2010) and used in diet formulation. The ME value of corn, 3.42 Mcal/kg (NRC, 1998), was used in formulation for the ME value of HPDDGS and fat was not added to balance dietary energy. Dietary treatments were formulated to a constant SID lysine level within phase (0.86, 0.73, and 0.65, respectively). Dietary treatments included: 1) a corn-soybean meal control, 2) HPDDGS and crystalline AA (L-Lys, L-Trp, and L-Thr) replacing 50% of the soybean meal in diet 1, and two diets in which 100% of the soybean meal was replaced by either: 3) HPDDGS and high levels of crystalline AA or 4) HPDDGS and low levels of crystalline AA. Treatment 3 diets contained 10% less HPDDGS then treatment 4 diets (30 vs. 40%, 27.5 vs. 37.5% and 17.5 vs. 27.5% for phases 1, 2, and 3, respectively). Diets were fed in meal form in three phases from d 0 to 27, 27 to 54, and 54 to 73 (Table 4.1 and 4.2). The treatment 2 diet in all phases was a 50:50 blend of diets 1 and 3 delivered via the FeedPro system

(Feedlogic Corp., Willmar, MN). Pigs were allowed ad libitum access to food and water. Diets were formulated to meet or exceed all requirements recommended by NRC (1998).

Pigs were weighed on d 0, 27, 54, and 73 to calculate ADG. Feed intake and G:F were determined from feed delivery data generated through the automated feeding system and the amount of feed remaining in each pen's feeder on each weigh day.

On d 73, all pigs were individually weighed and tattooed for carcass data collection and transported (approximately 204 km) to a commercial processing plant (Triumph Foods Inc., St. Joseph, MO). Hot carcass weights were measured immediately after evisceration and each carcass was evaluated for backfat and loin depth. Percentage yield was calculated by dividing HCW by live weight obtained before transport to the packing plant. Fat depth and loin depth were measured with an optical probe inserted between the 3rd and 4th last rib (counting from the ham end of the carcass) at a distance approximately 7.1 cm from the dorsal midline. Fat-free lean index was calculated according to National Pork Producers Council (2000) procedures. Jowl samples were collected and analyzed by Near Infrared Spectroscopy (NIR; Bruker MPA; Multi-Purpose Analyzer) for fat IV using the equation of Cocciardi et al., (2009).

Chemical Analysis

One lot of HPDDGS was delivered to the Kansas State University Animal Sciences Feed Mill (LifeLine Foods, St. Joseph, MO) and a single composite sample was analyzed for moisture (AOAC 934.01, 2006), CP (AOAC 990.03, 2006), crude fat (AOAC 920.39 A, 2006), ADF (ANKOM Technology, 1995a), NDF (ANKOM Technology, 1995b), crude fiber (AOAC 978.10, 2006), Ca (AOAC 965.14/985.01, 2006.), and P (AOAC 965.17/985.01, 2006; Ward Laboratories, Kearney, NE). Corn and HPDDGS samples were sent to University of Missouri-Columbia, (Columbia, MO; AOAC) for amino acid profile (AOAC, 2006). Feed samples were collected from all feeders during each phase and subsampled into a composite sample of each treatment for each phase. Composite diet samples by treatment for each phase were measured for bulk density using a Seedburo test weight apparatus and computerized grain scale (Seedburo Model 8800, Seedburo Equipment, Chicago, IL).

Statistical Analysis

Data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Polynomial contrasts were used to compare linear and quadratic effects of HPDDGS and crystalline AA replacing 50 or 100% of the soybean meal (Treatments 1, 2, and 3). Additionally, single degree of freedom contrasts were used to compare low vs. high amounts of crystalline AA (Treatments 3 vs. 4) and 0 vs. 50% soybean meal replacement (Treatment 1 vs. 2). Finally, the control treatment vs. the combination of both 100% soybean meal replacements diets were tested (Treatments 1 vs. 3 and 4). Analysis of backfat depth, loin depth, and percentage lean were adjusted to a common carcass weight using HCW as a covariate. Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

Results and Discussion

The HPDDGS used in this experiment were verified to be similar to those used in diet formulation, with the exception of fat content (Table 4.3). Analyzed HPDDGS contained 11.2% fat, which was higher than expected as the NRC (2012) lists a concentration of 3.54%. Other research has reported HPDDGS to contain crude fat from 3.69 to 4.8% (Widmer et al., 2007, Jacela et al. 2009, and Kim et al., 2009). The CP was 33%, which is lower than the listed CP value of the NRC (45.35%; 2012) and HPDDGS evaluated by Widmer et al. (2007), Jacela et al. (2010), and Kim et al. (2009). With the exception of Lys and Thr, all other AA in HPDDGS used in the present study analyzed lower than listed in NRC (2012; Table 4.4). For diet bulk density, as HPDDGS increased, the dietary bulk density decreased as expected (Table 4.5). The decreased bulk density agrees with observations by Salyer et al. (2012) and Asmus et al. (2012) that bulk density decreased with increased DDGS inclusion.

For growth performance in the current study, pigs fed increasing HPDDGS and crystalline AA had no effect on G:F ($P > 0.10$), while ADG and ADFI decreased (linear, $P <$ 0.05; Table 4.6) as HPDDGS increased in the diet. The linear decrease in ADG and ADFI is a result of replacing 100% of soybean meal with HPDDGS, because replacing 50% of soybean meal with HPDDGS and crystalline AA had no effects ($P > 0.10$) on growth performance. Replacing 100% of soybean meal with HPDDGS resulted in decreased ADG and ADFI ($P <$ 0.02), but did not affect G:F ($P > 0.10$). In diets replacing 50% of soybean meal with HPDDGS, no more than 15% HPDDGS was used. Previous research feeding 15% or less of DDGS or HPDDGS has shown no effect on growth performance (Linneen et al., 2008; Widmer et al., 2008), which is consistent with our findings when 50% of the soybean meal was replaced with

HPDDGS. Widmer et al. (2008) similarly evaluated replacing 50 to 100% of soybean meal with HPDDGS in growing (22.0 to 59.1 kg BW) and finishing (59.1 to 124.7 kg BW) pigs. Contrary to the current study, Widmer et al. (2008) reported HPDDGS had no effect on ADG or ADFI. However, ADFI did decrease numerically and resulted in a tendency for improved G:F. The contradicting results for ADFI could be the result of differing amounts of HPDDGS used between experiments (higher inclusion of HPDDGS in the present study) and trial length. Widmer et al. (2008) used 30 and 20% HPDDGS to replace all of soybean meal in two separate early and late finishing pig studies. The shorter feeding duration in either may not have allowed for enough time for them to numerically lower ADFI to become statistically significant for ADFI as was found in the current study. Additionally, the difference in ADFI and ADG between Widmer et al. (2008) and the current study could also be from the difference in HPDDGS fat content. The inclusion of added fat has been shown to decrease ADFI in finishing pigs, as fat increases dietary energy and pigs require less feed to meet an energy requirement (Azain et al., 1991; Smith et al., 1999). The fat content of the HPDDGS was 11.4% in the current study compared 3.0 % used by Widmer et al. (2008). The high fat content in the current study would result in a high energy diet and could have reduced ADFI. However, a reduction in ADFI caused by increased energy from added fat typically results in improved G:F (De la Llata et al., 2001; Salyer et al., 2012), which was not observed in this trial. Due to the combination of decreased ADFI and ADG when 100% soybean meal was replaced with HPDDGS, it’s plausible that palatability was an issue. Hastad et al. (2005) and Seabolt et al. (2008) observed pigs prefer to consume diets without DDGS and ADFI was reduced with those DDGS diets.

Use of high or low levels of crystalline AA with HPDDGS to replace 100% of soybean meal had no effect on growth performance. It has been reported that reduced CP diets formulated with supplemental AA yield similar performance to high CP diets. Cromwell et al. (1996) and Kerr et al. (2003) evaluated feeding reduced-CP (3 or 4%), AA-supplemented diets to finishing pigs and observed growth similar to pigs fed high-CP diets. In the current trial, diets with high or low levels of crystalline AA and HPDDGS had no effects on growth performance even with the difference in CP. However, diets containing high and low levels of crystalline AA only had a difference of 2.3% CP content. While, Cromwell et al. (1996) and Kerr et al. (2003) had a larger difference (3 or 4%) of CP in low vs. high CP diets, yet still observed similar performance. Thus, the present data confirms that using the crystalline AA levels to alter HPDDGS dietary levels to replace all of the soybean meal does not alter finishing pig performance.

For carcass characteristics, replacing 50% of soybean meal with HPDDGS had no effect on carcass yield, backfat depth, loin depth, or percent lean. However, jowl fat IV was increased (linear, $P < 0.001$) as HPDDGS was included in the diet. The use of traditional DDGS in finishing rations has consistently increased jowl fat IV (Whitney et al., 2006; Stein and Shurson, 2009; Benz et al., 2010). The increased fat IV is due to the increased unsaturated fat provided by DDGS (Averette-Gatlin et al., 2003; Weber et al., 2006). When evaluating the fat content of typical HPDDGS previously tested, the increased jowl fat IV should not be as large as when traditional DDGS is fed due to a lower fat content of 3.69 to 4.8% (Widmer et al., 2007; Jacela et al. 2010; Kim et al., 2009). However, due to higher than anticipated levels of fat in the HPDDGS used in the present study, a clear increase in jowl fat IV value was found when replacing 50 or 100% of the soybean meal in the diet.

Replacing 100% of soybean meal with HPDDGS resulted in decreased ($P < 0.01$) carcass yield and a tendency ($P = 0.08$) for decreased loin depth. Whitney et al. (2006), Linneen et al. (2008), and Salyer et al. (2012) observed decreased carcass yield when traditional DDGS was fed. The reduced carcass yield could be due to the higher fiber content of the HPDDGS (11.2%) resulting in heavier organ weights and increased digesta weight in the large intestine. Asmus et al. (2012) observed pigs fed increased levels of dietary NDF (which included DDGS) had both heavier large intestine empty weight and a greater amount of digesta in the large intestine. Consequently, due to the heavier live weight, when heavier organs are removed during harvest, carcass yield is reduced. The reduction in loin depth from HPDDGS inclusion agrees with findings by Widmer et al. (2008). Widmer et al. (2008) did observe pigs on the highest level of HPDDGS had 6 kg lighter live weight and HCW. In the current trial, pigs on diets where 100% of soybean meal replaced by HPDDGS had a numerically lighter finishing weight and a tendency ($P = 0.06$) for a lighter HCW. However, HCW was accounted for as a covariate in statistical analysis of loin depth, suggesting HCW was not the cause of decreased loin depth.

Use of high levels of crystalline AA in conjunction with HPDDGS did decrease ($P < 0.001$) jowl fat IV and increased carcass yield ($P < 0.01$). This effect was the direct result of diet formulation. Using high levels of crystalline AA resulted in 10% less dietary HPDDGS in the diets. Benz et al. (2010) observed jowl fat IV increased 1.6 g/100 g for every 10% DDGS in grow-finishing diets, while Duttlinger et al. (2012) observed a 4.5g/100 g increase when 20% DDGS was used. Therefore, the difference of HPDDGS used resulted in increased jowl IV as expected. Furthermore, use of high levels of crystalline AAs decreased crude fiber of the diet as less HPDDGS was used. Consequently, carcass yield increased, because of the decreased fiber content. Asmus et al. (2012) observed pigs fed high NDF diets containing DDGS reduced carcass yield due to heavier organ weights and a greater amount of digesta. For other characteristics, Kerr et al. (2003) observed no effects on carcass composition with the exception of decreased loin depth when crystalline AA were supplemented in low-CP diets. Additionally, Cromwell et al. (1996) and Smith et al. (1999) observed reduced carcass leanness when low CP-AA supplemented diets were fed to finishing pigs. However, the effects of CP and AA on carcass characteristics have been variable, as Tuitoek et al. (1997) and Knowles et al. (1998) observed no effects on carcass leanness when reduced CP-AA supplemented diet were fed.

In summary, HPDDGS can be used in combination with crystalline AA to replace 50% of the soybean meal in finishing diets without negatively affecting growth performance and carcass yield. Also, high amounts of crystalline AA may play an important role in mitigating some of the negative effects of higher HPDDGS inclusion rates on reduced carcass yields and carcass fat quality.

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Tables

Table 4.1 Phase 1 and 2 diet composition (as-fed basis)[1,2]

	Phase 1				Phase 2			
HPDDGS[3] replacement of SBM, %:	0	50	100 w/ high AA	100 w/ low AA	0	50	100 w/ high AA	100 w/ low AA
Ingredient, %								
Corn	76.13	71.74	67.35	57.40	81.55	75.85	70.14	60.19
Soybean meal, 46.5% CP	21.62	10.82	--	--	16.44	8.23	--	--
HPDDGS	--	15.00	30.00	40.00	--	13.75	27.50	37.50
Monocalcium P, 21% P	0.40	0.20	--	--	0.25	0.13	--	--
Limestone	1.00	1.05	1.10	1.20	0.96	1.02	1.09	1.18
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[4]	0.13	0.13	0.13	0.13	0.10	0.10	0.10	0.10
Trace mineral premix[5]	0.13	0.13	0.13	0.13	0.10	0.10	0.10	0.10
L-Lys HCl	0.15	0.39	0.64	0.57	0.15	0.32	0.49	0.42
L-Thr	--	0.06	0.11	0.05	--	0.03	0.05	--
L-Trp	--	0.04	0.08	0.07	--	0.03	0.06	0.05
Phytase[6]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
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	0.86	0.86	0.86	0.86	0.73	0.73	0.73	0.73
Met:Lys	29	31	34	39	31	35	38	45
Met & Cys:Lys	60	62	65	75	64	69	74	85
Thr:Lys	62	62	62	62	63	63	63	65
Trp:Lys	19.2	19.2	19.2	19.2	18.8	18.8	18.8	18.8
Total Lys, %	0.97	0.99	1.00	1.03	0.83	0.85	0.87	0.90
ME, Mcal/kg	3.34	3.35	3.37	3.36	3.35	3.36	3.37	3.36
SID Lys:ME, g/Mcal	2.57	2.56	2.55	2.56	2.18	2.17	2.17	2.17
CP, %	16.7	16.5	16.4	18.7	14.7	15.2	15.6	17.9
Ca, %	0.55	0.50	0.46	0.50	0.49	0.47	0.45	0.49
P, %	0.45	0.41	0.37	0.40	0.39	0.38	0.36	0.39
Available P, %	0.26	0.27	0.27	0.32	0.22	0.24	0.26	0.31

[1] A total of 204 pigs (337 × 1050; PIC Hendersonville, TN; initially 58.8 kg ± 0.3 BW) were used in a 73-d experiment with 8 or 9 replications.
[2] Phase 1 diets were fed from approximately 58.8 to 88.9 for phase 1 and from 88.9 to 108.9 kg BW for phase 2.
[3] High-protein dried distillers grains with solubles (LifeLine Foods, St. Joseph, MO).
[4] Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.
[5] Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.
[6] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 600.4 phytase units (FTU)/kg., with a release of 0.11% available phosphorus.

Table 4.2 Phase 3 diet composition (as-fed basis)[1,2]

	Phase 3			
HPDDGS[3] replacement of SBM, %:	0	50	100 w/ high AA	100 w/ low AA
Ingredient				
Corn	84.87	82.61	80.34	70.40
Soybean meal, 46.5% CP	13.24	6.62	--	--
HPDDGS	--	8.75	17.50	27.50
Monocalcium P, 21% P	0.20	0.10	--	--
Limestone	0.94	0.96	0.99	1.08
Salt	0.35	0.35	0.35	0.35
Vitamin premix[4]	0.08	0.08	0.08	0.08
Trace mineral premix[5]	0.08	0.08	0.08	0.08
L-Lys HCl	0.15	0.30	0.45	0.39
L-Thr	--	0.04	0.08	0.01
L-Trp	--	0.03	0.05	0.04
Phytase[6]	0.10	0.10	0.10	0.10
Total	100.0	100.0	100.0	100.0
Calculated analysis				
Standardized ileal digestible (SID) amino acids,%				
Lys	0.65	0.65	0.65	0.65
Met:Lys	32	34	36	43
Met & Cys:Lys	67	68	70	83
Thr:Lys	64	64	64	64
Trp:Lys	18.5	18.5	18.5	18.5
Total Lys, %	0.74	0.75	0.76	0.79
ME, Mcal/kg	3.36	3.36	3.37	3.37
SID Lys:ME, g/Mcal	1.94	1.93	1.93	1.93
CP, %	13.5	13.3	13.1	15.5
Ca, %	0.46	0.44	0.41	0.45
P, %	0.37	0.35	0.33	0.36
Available P, %	0.21	0.22	0.22	0.26

[1] A total of 204 pigs (337 × 1050; PIC Hendersonville, TN; initially 58.8 kg ± 0.3 BW) were used in a 73-d experiment with 8 or 9 replications.
[2] Phase 3 diets were fed from approximately 108.9 to 127.0 kg BW.
[3] High-protein dried distillers grains with solubles (LifeLine Foods, St. Joseph, MO).
[4] Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.
[5] Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from

calcium iodate, and 198 mg Se from sodium selenite.

[6] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 600.4 phytase units (FTU)/kg., with a release of 0.11% available phosphorus.

Table 4.3 Chemical analysis of high-protein dried distillers grains with solubles (HPDDGS; as-fed basis)[1]

Item	HPDDGS[1]
DM, %	91.04
CP, %	33.0
ADF, %	14.7
NDF, %	31.7
Crude fiber, %	11.2
Fat (oil), %	11.4
Ca, %	0.06
P, %	0.59
Bulk density, g/L	567

[1] HPDDGS were collected at the time of feed manufacturing and a composite sample was analyzed (Ward Laboratories, Kearney, NE).

[2] High-protein dried distillers grains with solubles (LifeLine Foods, St. Joseph, MO).

Table 4.4 Amino acid profile of high-protein dried distillers grains with solubles (HPDDGS; as-fed basis)[1]

Amino acid, %	HPDDGS[2]
Arg	1.62
Lys	1.29
His	0.90
Phe	1.65
Met	0.75
Thr	1.25
Trp	0.30
Cys	0.64
Ile	1.29
Leu	3.94
Ala	2.31
Asp	2.25
Glu	4.60
Gly	1.42
Pro	2.42
Ser	1.43
Tyr	1.15
Val	1.78

[1] HPDDGS were collected at the time of feed manufacturing and a composite sample was analyzed (University of Missouri-Columbia, Columbia, MO).

[2] High-protein dried distillers grains with solubles (LifeLine Foods, St. Joseph, MO).

Table 4.5 Bulk density of experimental diets (as-fed basis)

	HPDDGS[1] replacement of SBM, %			
Bulk density,[2] g/L	0	50	100 w/ high AA	100 w/ low AA
Phase 1[3]	738	676	643	619
Phase 2	748	689	664	624
Phase 3	719	685	664	653

[1] High-protein dried distillers grains with solubles (LifeLine Foods, St. Joseph, MO).
[2] Diet samples were collected from each feeder during each phase.
[3] Phase 1 d 0 to 27; Phase 2 d 27 to 54; Phase 3 d 54 to 73.

Table 4.6 Effect of replacing soybean meal (SBM) with high-protein dried distillers grains with solubles (HPDDGS) on finishing pig performance[1]

	HPDDGS replacement of SBM, %					Probability, $P <$				
						HPDDGS[6]				
Item	0[2]	50[3]	100 w/ high AA[4]	100 w/ low AA[5]	SEM	Linear	Quadratic	Control vs. 50%	Low vs. high AA	Control vs. 100% replace[7]
d 0 to 73										
ADG, kg	0.95	0.96	0.91	0.90	0.01	0.04	0.13	0.84	0.56	0.01
ADFI, kg	2.91	2.92	2.79	2.77	0.04	0.05	0.12	0.74	0.73	0.02
G:F	0.328	0.327	0.327	0.326	0.003	0.90	0.91	0.87	0.77	0.75
Wt, kg										
d 0	58.9	58.9	59.6	58.9	1.0	0.60	0.79	0.96	0.63	0.74
d 73	128.3	128.8	126.2	125.2	1.5	0.32	0.40	0.83	0.63	0.16
Carcass characteristics										
Carcass yield,[8] %	73.1	72.7	72.5	71.6	0.23	0.11	0.75	0.26	0.01	0.01
HCW, kg	96.8	93.9	91.6	90.0	1.3	0.22	0.42	0.95	0.36	0.06
Backfat depth, mm	20.6	20.8	21.0	20.6	0.5	0.57	0.92	0.70	0.56	0.75
Loin depth, mm	57.5	56.6	55.8	55.5	0.8	0.15	0.91	0.39	0.75	0.08
Lean, %	51.9	51.6	51.5	51.6	0.3	0.29	0.85	0.47	0.84	0.28
Jowl fat iodine value	69.8	72.1	74.8	78.0	0.4	0.0001	0.71	0.0006	0.0001	0.0001

[1] A total of 204 pigs (PIC 327 x 1050, initial BW 58.8 ±0.3 kg BW) were used in a 73-d study with 6 pigs per pen and 8 or 9 pens per treatment.

[2] Corn-soybean meal diet with 0.15% crystalline lysine.

[3] HPDDGS and high amounts of crystalline amino acids replacing 50% of the soybean meal in diet 1.

[4] HPDDGS and high amounts of crystalline amino acids replacing 100% of the soybean meal in diet 1.

[5] HPDDGS and low amounts of crystalline amino acids replacing 100% of the soybean meal in diet 1.

[6] Linear comparisons of low-DDGS treatments (Treatments 1, 2, and 3).

[7] Comparison of HPDDGS replacing of soybean meal (Treatments 1 vs. 3 and 4).

[8] Percent carcass yield was calculated by dividing HCW by the live weights obtained at the farm before transported to the packing plant.