EFFECTS OF DIETARY WHEAT MIDDLINGS, DRIED DISTILLERS GRAINS WITH SOLUBLES AND CHOICE WHITE GREASE ON GROWTH PERFORMANCE, CARCASS CHARACTERSITICS, AND CARCASS FAT QUALITY OF GROW-FINISH PIGS

by

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Abstract

Five experiments used 3,004 pigs to determine influences of wheat middlings (Midds), dried distillers grains with solubles (DDGS), and choice white grease (CWG) on growth, carcass traits, and carcass fat quality of finishing pigs and the optimal SID Trp:Lys in growing and finishing pigs fed 30% DDGS. In Exp. 1, pigs fed increasing dietary Midds had decreased (linear; $P \leq 0.02$) ADG and G:F. Feeding 30% DDGS did not influence growth performance. For carcass traits, increasing Midds decreased (linear; $P<0.01$) carcass yield, HCW, and backfat depth (quadratic; $P<0.02$) but increased (quadratic; $P<0.01$) FFLI. Feeding 30% DDGS decreased ($P<0.03$) carcass yield and backfat depth ($P<0.01$), but increased FFLI ($P<0.02$) and jowl fat IV ($P<0.001$). In Exp. 2, feeding 20% dietary Midds decreased ($P<0.01$) ADG and G:F. Pigs fed diets with increasing CWG had improved ADG (quadratic, $P<0.03$) and G:F (linear, $P<0.01$). Dietary Midds or CWG did not affect ADFI. For carcass traits, feeding 20% Midds decreased carcass yield ($P<0.05$), HCW, backfat depth, and loin depth, while increasing jowl fat IV ($P<0.001$). Pigs fed CWG also had decreased (linear, $P<0.05$) FFLI and increased (linear, $P<0.01$) jowl fat iodine value. In conclusion, feeding Midds reduced pig growth performance, carcass yield, and increased jowl fat IV. In Exp. 3, xylanase supplementation did not improve growth performance or carcass traits of pigs fed different dietary energy and fiber levels. Increasing dietary energy increased (linear; $P<0.001$) ADG and G:F with no affect on ADFI. Increasing dietary energy increased (linear; $P<0.01$) yield, HCW, backfat depth, and reduced FFLI (linear; $P<0.001$) and jowl fat iodine value (linear; $P<0.001$). Apparent total tract digestibility of ADF improved ($P<0.002$) with the addition of dietary xylanase; however, there were no differences in any other nutrient digestibility criteria. As dietary energy increased, there

was an increase (linear; $P<0.02$) in apparent digestibility of DM, N, fat, GE, ADF, and NDF. In Exp. 4 and 5, results indicated the optimal SID Trp:Lys was 16.5% from 36.3 to 72.6 kg, but at least 19.5% from 72.6 to 120.2 kg in corn-soybean meal diets containing 30% DDGS.

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Dedication

I dedicate this thesis to my family Mom, Dad, Jenna, and Brandon for making this possible. I love you guys.

Chapter 1 - A Review of Wheat By-products in Finishing Pig Diets

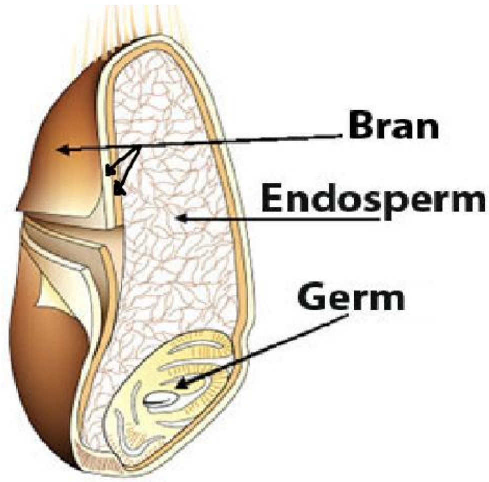
History

The United States is a major wheat-producing country, with production output typically exceeded only by China, the European Union, and India. Wheat ranks third among U.S. field crops in planted acreage behind corn and soybeans. In 2010, the United States produced approximately 2.2 billion bushels of wheat, harvesting approximately 47.6 million acres with an average yield of 46.4 bushels per acre (USDA; 2010). During the milling process, about 70 to 75% of the grain becomes flour and the remaining 25 to 30% becomes available as wheat by-products. Therefore, milling by-products are widely available for use in the animal feed industry. Wheat undergoes a series of processing steps to clean and separate the kernel parts to produce the by-products for use in feed.

Characteristics of Wheat

A wheat kernel is composed of three main parts (Figure 1.1). The hard, outer protective skin of the grain is called the bran layer. The bran layer protects the seed from weather, insects, and mold. The bran is composed of several layers with the largest layer defined as the aleurone layer (Martin et al., 1976). It is a concentrated source of dietary fiber. The inner part of the kernel is the endosperm, which supplies the food to the seed. White flour is produced from the endosperm and it is mostly made up of protein and carbohydrates. The third section of the wheat kernel is the germ. This is the plant embryo, and most of the kernel's fat and vitamin E is located in the germ.

Figure 1.1 Diagram of a wheat kernel



Milling of Wheat

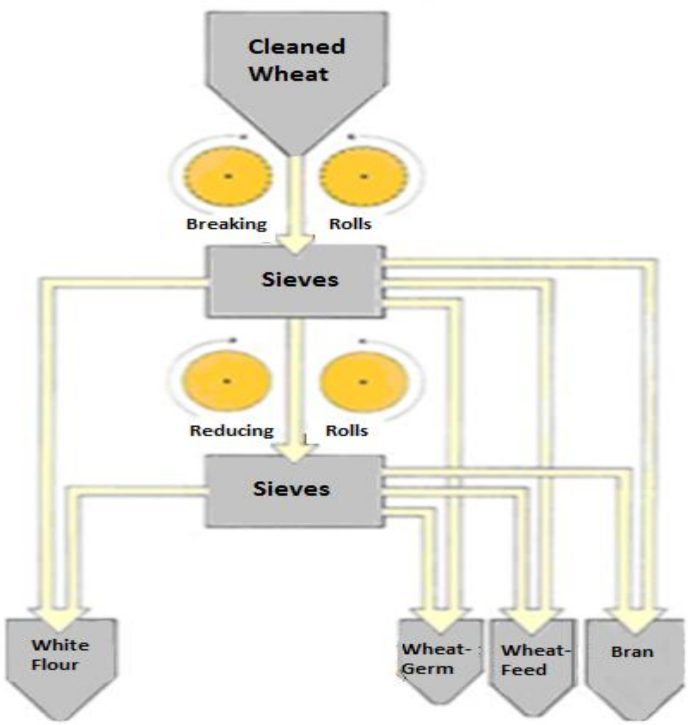
Before wheat kernels enter the actual milling process (Figure 1.2), they must first be cleaned and scoured. This process will remove the majority of damaged kernels and foreign materials. The clean acceptable kernels then move into a conditioning process. First, water is added to the kernels for a varying period of time (2 to 24 hours) with the goal of softening the endosperm and hardening the outer bran coat. This will then enable the bran to be easily separated from the flour in the breaking process (Posner and Hibbs, 1997).

The breaking process refers to pushing kernels through several pairs of corrugated rolls. The objective of breaking is to physically separate the bran and white endosperm portion of the original kernel. After the kernels have been broken, they are sifted through successive screens with increasing fineness and dropped into like-sized streams, where the coarsest materials progress to the next pair of breaker rolls with finer corrugations. The finest breaks are typically sifted out as flour and the germ is attached to large particles of bran (Posner and Hibbs, 1997).

Next, streams of particles advance through a similar process of breaking; however, they are now pushed through a series of reduction rolls in order to further reduce particle size.

Breaking and reduction rolls are very similar equipment, however, they generally differ in corrugations (pitch and spiral), grinding action (sharp to sharp, sharp to dull, dull to dull), and differential. After each set of rolls, flour is again sifted out and very fine bran particles are removed. A typical flour mill will have up to four breaking rolls and twelve reduction rolls, which lead to the production of approximately 16 product streams. These stream lines typically consist of a nearly pure bran stream, a germ stream, and stream lines containing mixtures of bran, flour, and germ, (also known as materials from the "tail of the mill") which make specified wheat by-products for animal feed, such as wheat middlings (Posner and Hibbs, 1997). Differences in fiber content are generally utilized as identifiers for these classifications of by-products.

Figure 1.2 A highly simplified diagram of wheat milling operations



Wheat By-Products

The AAFCO (2000) definitions for each wheat by-product are as follows:

Wheat Bran: the course outer covering of the wheat kernel as separated from the cleaned and scoured wheat in the usual process of commercial milling.

Wheat Flour: consists of wheat flour together with fine particles of wheat bran, wheat germ and the offal from the "tail of the mill". This product must be obtained in the usual process of commercial milling and must not contain more than 1.5% crude fiber.

Wheat Germ Meal: consists chiefly of wheat germ together with some bran and middlings or short. It must contain not less than 25% crude protein and 7% crude fat.

Wheat Mill Run: coarse wheat bran, fine particles of wheat bran, wheat shorts, wheat germ, wheat flour and the offal from the "tail of the mill". This product must be obtained in the usual process of commercial milling and must contain no more than 9.5% crude fiber.

Wheat Middlings: consist of fine particles of wheat bran, wheat shorts, wheat germ, wheat flour, and some of the offal from the “tail of the mill”. This product must be obtained in the usual process of commercial milling and must contain no more than 9.5% crude fiber.

Wheat Shorts: consist of fine particles of wheat bran, wheat germ, wheat flour, and the offal from the “tail of the mill”. This product must be obtained in the usual process of commercial milling and must contain no more than 7% crude fiber.

Wheat Red Dog: consists of the offal from the “tail of the mill” together with some fine particles of wheat bran, wheat germ, and wheat flour. This product must be obtained in the usual process of commercial milling and must contain no more than 4% crude fiber.

The major wheat by-products included in swine diets (Table 1.1) are wheat bran, wheat middlings, wheat shorts, and wheat red dog.

Table 1.1 Flour milling by-products (as-fed basis)[1]

Nutrient	Wheat bran	Wheat middlings	Wheat shorts	Wheat red dog
DM, %	89	89	88	88
CP, %	15.7	15.9	16.0	15.3
EE, %	4.0	4.2	3.3	4.6
ME, kcal/kg	2,275	3,025	2,820	2,925
ADF, %	13.0	10.7	4.3	8.6
NDF, %	42.1	35.6	18.7	28.4
Crude fiber[2], %	10.0	≤ 9.5	≤ 7.0	≤ 4.0
Ca, %	0.16	0.12	0.07	0.09
P, %	1.20	0.93	0.57	0.84
K, %	1.26	1.06	1.06	0.63
Mg, %	0.52	0.41	0.16	0.25
Cu, ppm	14.0	10.0	12.0	6.0
Zn, ppm	100.0	92.0	100.0	65.0
Biotin, ppm	0.36	0.33	0.24	0.11
Choline, ppm	1,232	1,187	1,170	1,534
Riboflavin, ppm	4.6	2.0	3.0	2.0
Thaimin, ppm	8.0	16.5	18.1	22.8
Vitamin B_6, ppm	12.0	9.0	7.2	4.6

[1]Nutrient Requirements of Swine (1998).

[2]AAFCO (2000).

Wheat Middlings

Wheat middlings are a common cereal by-product used in commercial swine feed (Cromwell, 2000). The addition of standard wheat middlings to finishing swine diets has the potential to supply energy, protein, and phosphorus as well as fiber to a typical corn-soybean meal diet.

Wheat middlings and wheat shorts are similar in nutritional value and can be confused as the same product. They both consist of portions of flour, bran, aleurone layer, and the germ from the flour milling process. While their protein levels are generally similar, wheat shorts are specified to have a lower crude fiber and fat level.

There are several factors that can influence the final nutrient content of wheat middlings. First, differences in wheat type, weight grade, and wheat processing specifications can impact what components of the kernel can be used for wheat middlings. Secondly, wheat middling nutrient concentration can vary depending on the objectives of the milling process. The nutrient concentration of wheat middlings is related to the level of flour that remains after processing or is incorporated back into the final product. Thus, wheat middlings with a higher level of flour will have a greater feeding value compared to middlings where the majority of flour has been removed. Thus, consideration must be given to nutrient composition, method of processing, quality, and cost when formulating diets with wheat middlings.

When comparing wheat middlings to other cereal grains, middlings are higher in fat, fiber, and minerals (NRC, 1998; Table 1.2) than wheat, corn, sorghum, and soybean meal, however, they also have lower energy than these ingredients with low CP compared to soybean meal (NRC, 1998). Lysine and threonine are also the most limiting amino acids in diets containing wheat middlings for growing-finishing pigs (Quant et al, 2008).

Table 1.2 Comparison of cereal grain nutrient content.[1]

Item	Wheat middlings	Wheat[2]	Corn	Sorghum	SBM
DM, %	89	88	89	89	90
CP, %	15.9	13.5	8.3	9.2	47.5
Crude fat, %	4.2	2.0	3.9	2.9	3.0
ME, kcal/kg	3,025	3,210	3,420	3,340	3,380
ADF, %	10.7	4.0	2.8	8.3	5.4
NDF, %	35.6	13.5	9.6	18	8.9
Ca, %	0.12	0.06	0.03	0.03	0.34
P, %	0.93	0.37	0.28	0.29	0.69

[1]Nutrient Requirements of Swine (1998).

[2]Hard red winter wheat grain.

Erikson et al. (1985) evaluated the digestibility of diets containing wheat middlings compared to corn-soybean meal diets formulated to similar DE and ME concentrations. They found substituting up to 60% middlings for corn and soybean meal did not affect the apparent protein digestibility of the diet. Apparent biological value and net protein value were maximized with a 20% inclusion of dietary middlings but greater levels of dietary middlings resulted in a linear decrease of these variables. This is in contrast with Just (1982) who reported swine diets with increased fiber can result in decreased nutrient digestibility and ME utilization due to increased nutrients transferred to the hindgut.

Boyd et al. (2010) conducted a study to determine the net energy (NE) estimate for a chemically defined source of wheat middlings. The middlings were defined as 22.7% starch, 16.5% CP; 5.4% fat; 9.0% crude fiber; 34.0% NDF; and 4.8% ash. Treatments consisted of a control corn-soybean meal-based diet with four blended wheat middling diets to make treatments of 4.5, 9.0, 13.5, or 18.0% middlings. The NE values for the treatment diets were calculated as

2.480, 2.467, 2.454, 2.440, and 2.427 Mcal/kg, respectively. As middlings increased, the NE value decreased slightly, however, Boyd et al. (2010) reported no differences for ADG (1.15 kg/d ± 0.02), ADFI (3.33 kg/d ± 0.05), and G:F (0.345 ± 0.01) among treatments and that wheat middlings has approximately 87.9% the energy of corn. This is similar to the NRC (1998) which as the ME at 88.5% of corn.

Growing and Finishing Pig Performance

Numerous studies have been conducted to determine the effects of wheat by-products on growth and carcass traits in diets for growing and finishing swine. A summary of studies listing amount of dietary wheat by-products fed and resulting performance as percent of those pigs fed a control diet with no wheat by products are listed in Table 1.3. A regression analysis of increasing wheat by-products' impact on growth performance is listed in Table 1.4.

Patience et al. (1977) conducted a growth study with 44, 10-week old pigs (initial BW 31 kg to final BW of 70 kg) testing dietary wheat short inclusions on growth performance. The grow-finish pigs were fed Canadian wheat shorts processed from hard red spring wheat. The dietary energy was decreased with increasing dietary wheat shorts (0, 9.7, 19.3, 29.0, 38.6, 48.3, 58.0, 67.6, 77.3, 86.9, and 96.9 %, respectively). They reported numerically decreased ADG for pigs fed above 19.3% wheat shorts with a linear reduction in G:F as dietary wheat shorts increased. Patience et al. (1977) concluded a maximum of 19.3% wheat shorts can be included in growing diets before decreasing growth performance.

Young (1980) used a factorial arrangement of treatments that included 4 levels of wheat shorts (0, 32.2, 64.4, and 96.6% of the diet), 2 levels of L·lysine HCL addition (0 or 0.11%), and 2 physical forms of the diet (meal or pelleted). Young (1980) reported a linear ($P < 0.05$) decrease in ADG from 50 to 90 kg with increasing dietary wheat shorts. Also, G:F worsened as dietary wheat shorts increased. Young (1980) found overall, pigs fed wheat short diets with a supplement of 0.11% L·lysine HCl vs. no supplement experienced a 6.25% increase in ADG along with 5.88% increase in G:F. In this study, supplementing synthetic lysine was reported to make the greatest improvement in diets with the highest inclusion rates of wheat shorts. Young (1980) also observed improvements in ADG and G:F when wheat shorts diets were pelleted, with the greatest improvement reported in the highest inclusion rate diets.

Erikson et al. (1985) conducted 2 experiments to evaluate the effects of wheat middlings on grow-finish pig growth and carcass characteristics. The first experiment used 96 pigs (initial BW of 60 kg to final BW of 90 kg) in which wheat middlings were added (0, 20, 40, 60%) to diets replacing both corn and soybean meal on an equal lysine basis. Average daily gain and G:F decreased linearly with increasing wheat middlings; however, there were no differences in ADFI.

Erikson et al. (1985) also evaluated the effects of replacing corn with wheat middlings (0, 10, 20, or 30%) on an equal weight-basis in finishing diets for pigs weighing 69.7 to 90 kg. They reported no difference in ADG among treatments, but a linear increase in ADFI was observed as wheat middlings increased. Due to the increased ADFI and no change in ADG, they reported poorer G:F as wheat middlings increased. Erikson et al. (1985) suggested different growth responses to dietary wheat middlings among trials may be due to different dietary lysine levels. In this experiment, wheat middlings merely replaced an equal weight of corn as it was incorporated into the diet. Thus, as wheat middlings increased from 0 to 30%, dietary lysine was increased as well from 0.79 to 0.92% in the grower diets. On the other hand, in the previously mentioned trial, all diets were formulated to contain the same amount of dietary lysine (0.75%) with wheat middlings replacing both corn and soybean meal on an equal lysine basis. The higher levels of dietary lysine, when replacing corn with wheat middlings on an equal weight basis, may have prevented some of the decreased ADG reported when dietary wheat middlings were added on an equal lysine basis.

Cromwell et al. (1992) observed pigs fed increasing wheat middlings (10, 20, 40, and 60 %) resulted in decreased (-0.01, -0.04, -0.05, -0.10 kg/d) ADG. This resulted in an average of 2.82% reduced ADG with every 10% added wheat middlings.

Feoli et al. (2006) used pigs weighing from 64 kg to a final BW of 122 kg, and reported a linear decrease in ADG (0.94, 0.92, 0.89 kg/d, respectively) when pigs were fed 0, 15, and 30% dietary wheat middlings. A linear decrease in G:F (0.330, 0.310, 0.304) was also reported with no difference in ADFI (2.86, 2.96, 2.91 kg/d).

Barnes et al. (2011a) conducted a trial with 288 pigs (46.5 to 135 kg BW) to measure the effect on performance when pigs were fed 0, 10, or 20% wheat middlings in a corn-soybean meal-based diet also containing 30% dried distillers grains with solubles (DDGS). In agreement with previous studies, they observed pigs fed increasing wheat middlings had decreased ADG and poorer G:F, with no differences among treatments in ADFI.

While most research with wheat middlings did not maintain similar dietary energy concentrations, Shaw et al. (2002) used 64 barrows (65 to 107 kg BW) and included 30% wheat middlings along with additional choice white grease (CWG) to keep ME value constant to the corn-soybean meal-based diet. They reported no differences in growth performance. Likewise, Barnes et al. (2011b) used 288 pigs (42 to 144 kg BW) in a 2 × 3 factorial, comparing diets with and without 20% dietary wheat middlings along with 0, 2.5, or 5% added CWG. While feeding 20% wheat middlings without added CWG worsened ADG and G:F by 6 and 7%, respectively; adding 5% CWG to the diet containing 20% wheat middlings resulted in similar ADG and G:F to the control diet without wheat middlings or added CWG. Barnes et al. (2011b) also noted pigs had improved performance because of added CWG in diets regardless of whether or not diets contained wheat middlings.

Fahrenholz et al. (1988) conducted 2 experiments evaluating environmental factors' impact on animal performance when fed increasing wheat mill run. The objective was to determine the optimal levels of wheat mill run in finishing pig diets during hot and cold weather. Both experiments included wheat mill run at 0, 15, 30, or 45% of the diet. Experiment 1 used 128 pigs (initially 43 kg BW) during the winter, and resulted in pigs fed the control diet with no wheat mill run having greater ADG than pigs fed wheat mill run (0.90 vs. 0.83, 0.81, and 0.80 kg/d, respectively). For G:F, pigs fed 15% dietary wheat mill run were not different than pigs fed the control diet, however, when wheat mill run was increased beyond 15% of the diet, there was decreased G:F. Experiment 2 used 160 pigs (initial BW 44 kg) during the summer and found no decrease in ADG until pigs were fed 30% wheat mill run. In this trial, there was a linear decrease in G:F with increasing dietary mill run. In agreement with other trials, both of these experiments found no difference in feed intake due to level of dietary wheat mill run inclusion.

In a summary of all research evaluating growth performance of dietary wheat middlings, wheat shorts, and wheat mill run fed to growing and finishing pigs, the majority of research experiments reported a linear decrease in ADG and G:F with no change in ADFI (Figures 1.3, 1.4, and 1.5). We conducted regression analysis of the data to estimate the percentage response in pig performance with increasing wheat by-products. Because of similarity in wheat shorts, mill run, and wheat middlings, all data was combined into a single analysis. The regression analysis revealed that each 10% inclusion of wheat by-products resulted in 1.5% decrease in

ADG and a 2.0% decrease in G:F. Additionally, the regression analysis revealed ADFI increased slightly (0.4% per 10%) in order to compensate for the reduced dietary energy.

Pelleting Wheat By-Products

Various processing techniques, such as pelleting of wheat by-products, have also been investigated in poultry and swine diets. There has been much research pertaining to effects of processing techniques (such as pelleting and regrinding) of wheat middlings and its effects on poultry performance. Saunders et al. (1969) discovered protein digestibility was improved for chicks if wheat shorts were re-ground three times. Cave et al. (1965) noted pelleted wheat shorts improved ME in diets for chicks. Other research resulted in no improvement in ME observed in pelleted chick diets, thus the response to pelleting has not been constant in poultry (Bayley et al., 1968).

In swine, Patience et al. (1977) evaluated variation in digestibility of wheat shorts with production processes of autoclaving, pelleting, extruding, and regrinding. They evaluated whether these techniques could increase the availability of energy and N from a control mash finishing pig diet containing increasing wheat shorts. They found pelleting wheat shorts increased DE compared to the control with no wheat shorts and all treatments with increasing dietary wheat shorts in mash form. Patience et al. (1977) suggest differences in the literature, could be because pelleting brings out the greatest improvement in poorer quality material. Also, no treatments enhanced phosphorus availability and although pelleting and re-grinding tended to improve the apparent digestibility of N, it was not different from the control mash diet.

Young (1980) noted pelleted diets including wheat shorts, resulted in an overall 4.7% improvement in ADG and 5.9% improvement in G:F, with the larger improvements seen when the highest amounts of wheat shorts were included into diets (64.4% or greater). However, they also reported pelleting diets did not influence the DE or protein digestibility of wheat short diets. Thus, there is potential for improvement in growth performance with pelleting wheat by-products in diets for grow-finish pigs; however, more research in this area is needed.

Wheat by-products and effects on carcass traits

While dietary wheat by-products often impact pig growth performance, they have also been shown to affect carcass traits. The majority of studies measuring carcass yield reported at least a numerical decrease in yield in pigs fed wheat by-products.

Barnes et al. (2011a) reported a decrease in yield when pigs were fed 10 and 20% wheat middlings. Agreeing with this data, Feoli et al. (2006) also reported a reduction in carcass yield when wheat middlings were included in diets at 15 and 30%. Because of the high fiber content of wheat middlings, it has been reported to affect pig gut fill. Just (1982) reported a 0.34 kg increase in gut fill per 1% increased dietary fiber for pigs that had been withdrawn (approximately 12 hours) from feed before time of slaughter. If those pigs had been fed on the same day as they were killed, the gut fill would have been greater.

Young (1980) evaluated other possible causes for the decrease in carcass yield when wheat shorts were included in finishing pig diets. Young (1980) obtained a shrunk weight of pigs in order to reduce the influence of gut fill on carcass yield. Calculations of ADG and G:F based on the shrunk weight revealed a further decline in the performance of pigs fed increasing wheat shorts. Just (1982) concluded that the live weights of pigs fed high fiber diets should be adjusted for gut fill to obtain a similar carcass weight.

Shaw et al. (2002) and Barnes et al. (2011b) maintained similar dietary energy by adding CWG to diets containing wheat middlings, in order to evaluate if growth performance and carcass yield were improved. Both studies were able to preserve similar growth performance when compared to the corn-soybean meal-based diet; however, they still both reported a reduction in carcass yield with pigs fed wheat middlings.

Patience et al. (1977) and Erikson et al. (1985) reported a positive increase in yield when feeding 10% wheat shorts or wheat middlings; however, when feeding greater concentrations of dietary wheat shorts, Patience et al. (1977) reported a linear decrease in yield. It isn't completely clear why these researchers found increased carcass yield when feeding low levels of wheat middlings. Differences in diet form could account for some of the reported differences. Measuring yield from a final weight at the farm versus a final weight at the packing plant after transit could account for some variations in yield values between trials as well.

Just et al. (1983) performed a series of studies in Europe evaluating the effects of fiber in growing pig diets and reported decreased backfat, protein deposition, and loin depth as fiber levels increased. Barnes et al. (2011b) reported feeding 20% wheat middlings in grow-finish swine diets also resulted in decreased backfat and loin depth.

Increasing wheat middlings by 10% of the diet decreases carcass yield approximately 0.06% with a linear decrease in yield as dietary wheat by-products increased (Figure 1.6). Thus, impact on yield and carcass lean must be taken into consideration when contemplating adding dietary wheat by-products.

Bulk Density

One factor of concern when including wheat by-products into pig diets is lowered bulk density. The definition of bulk density is the weight per unit volume. According to Cromwell et al. (2000), bulk density of wheat middlings is affected by the amount of bran or flour that is present in the product. A typical density range for wheat middlings has been estimated by

Cromwell et al. (2000) to be between 288 to 384 g/L. Wheat middlings sample bulk density can vary depending on source and even within batch.

Lighter wheat middlings with a lower bulk density typically consists of more bran material, which results in a higher fiber, protein, and P content than heavier midds. Heavy (higher bulk density) wheat middlings typically contain more of the endosperm portion of the kernel. Cromwell et al. (1992) theorized pigs fed wheat middlings with a light bulk density (more bran material) resulted in poorer growth performance when compared to the pigs fed wheat middlings with a heavier bulk density (more endosperm material). Both groups of pigs were negatively affected with added dietary wheat middlings regardless of ingredient bulk density. However, pigs fed heavier middlings had improved ADG and G:F when compared to those pigs fed the diets with lighter wheat middlings. When pigs were fed the heavy or higher quality wheat middlings, growth performance was not substantially affected up to 20% dietary middlings and performance was only modestly reduced when 40% middlings were fed.

Cromwell et al. (2000) corroborated these findings by reporting the variability among sources and laboratories in analysis of wheat middlings. According to Cromwell et al. (1992) light wheat middlings typically weigh 288 to 320 g/L, whereas heavy middlings weigh 352 to 384 g/L. Cromwell et al. (2000) observed that the average bulk density of wheat middlings was around 320 g/L. Additionally, this study revealed bulk density was negatively correlated with CP ($r = -0.61$), lysine ($r = -0.59$), P ($r = -0.54$), and NDF ($r = -0.81$). This data clearly demonstrated the wide variation among wheat middlings sources.

Shaw et al. (2002) evaluated the effects of feeding wheat middlings with a bulk density of 287 g/L to early and late finishing pigs. While they did observe numerical decreases in growth performance for early finishing pigs; there was no difference in overall performance between pigs fed the corn-soybean meal-based diet and those fed 30% dietary wheat middlings with added CWG.

Both experiments by Barnes et al. (2011a,b) reported adding dietary wheat middlings decreased diet bulk density; however, added CWG had no effect on bulk density. The high NDF levels and low bulk density of diets containing both DDGS and wheat middlings may have limited the pigs' ability to consume enough feed to overcome the lower energy level in the wheat middling diets.

Summary

Across 11 studies, regression analyses of performance data with increasing dietary wheat middlings, wheat shorts, or mill run added in corn-soybean meal-based diets resulted in a linear decrease in ADG and G:F as wheat by-products were increased in the diet. In the majority of the studies reviewed, feed intake was not affected; however, there appears to be a slight increase in ADFI as wheat by-products are increased in order to compensate for lower dietary energy. The majority of studies measuring carcass traits also reported at least a numerical decrease in carcass yield, which also resulted in a linear decrease of carcass yield as wheat by-products were increased in the diet when analyzed with regression analysis. The decrease in yield can be due to both increased gut fill and decreased leanness in pigs fed higher fiber diets. Because much variation exists among wheat middlings samples, bulk density of wheat middlings has been reported to be a tool for quickly estimating the potential nutritional value. Consideration must be given to nutrient composition, method of processing, quality, and price of wheat middlings, wheat shorts, or wheat mill run when contemplating incorporating these ingredients into grow-finish swine diets.

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Table 1.3 Performance of finishing pigs fed wheat by-products compared to corn-soybean meal-based diets.

Reference	Wheat By-product used	Response vs. pigs fed the control diet (%) ADG	ADFI	G:F	Yield	ME value est. of diet (kcal/kg)
Patience et al., 1977	Shorts					
9.7%		93.2	89.8	103.2	101.4	99.00
19.3%		103.7	100.6	103.2	98.4	96.45
29.0%		90.3	90.4	100.0	97.8	95.23
38.6%		93.2	89.8	103.2	98.9	93.99
48.3%		91.8	91.8	100.0	97.2	92.71
58.0%		88.7	100.0	88.9	97.4	91.40
67.6%		100.0	103.5	96.6	96.9	90.06
77.3%		87.1	98.6	88.9	95.0	88.61
86.9 %		90.3	101.4	89.0	94.9	87.20
96.6%		90.3	108.7	80.0	92.8	86.01
Young et al., 1980	Shorts					
32.3%		97.4	97.4	96.6	97.9	96.04
64.4%		91.7	109.6	69.6	92.4	91.76
96.6%		74.2	107.7	75.0	88.6	87.34
Erickson et al., 1985; Exp.1[1]	Middlings					
10%		96.3	103.5	91.9	101.6	---
20%		97.5	102.8	94.6	100.3	---
30%		98.8	112.5	84.1	100.5	---
Erickson et al.,1985; Exp. 2[2]	Middlings					
20%		94.1	98.9	95.3	100.6	---
40%		94.1	102.1	91.8	100.3	---
60%		90.1	99.3	90.8	101.8	---
Fahrenholz et al., 1988;	Mill run					

Exp. 1						
15%		91.2	94.4	96.8	---	99.98
30%		88.8	101.4	86.9	---	99.97
45%		87.5	100.8	86.3	---	99.95
Fahrenholz et al., 1988;	Mill run					
Exp. 2						
15%		98.2	105.4	92.9	---	99.99
30%		89.7	104.2	85.4	---	99.97
45%		86.3	107.4	78.0	---	99.95
Cromwell et al., 1992	Middlings					
10% light wheat midds		98.3	103.2	95.4	---	---
20% light wheat midds		94.8	101.0	93.3	---	---
40% light wheat midds		93.5	101.0	91.8	---	---
60% light wheat midds		86.2	98.6	86.9	---	---
10% heavy wheat midds		96.0	96.9	99.4	---	---
20% heavy wheat midds		100.0	99.2	99.4	---	---
40% heavy wheat midds		93.6	95.3	97.6	---	---
60% heavy wheat midds		87.8	102.9	85.6	---	---
Shaw et al., 2002;	Middlings					
30% [3]		95.2	97.8	100.9	---	100.00
30% [4]		103.5	100.3	103.4	99.3	100.00
Feoli et al., 2006	Middlings					
15%		97.0	103.4	99.3	99.9	98.41
30%		93.3	101.6	91.4	99.9	96.74
Barnes et al., 2011; Exp 1	Middlings					
10%		96.7	100.3	97.1	99.1	98.87
20%		95.3	99.2	96.3	98.3	97.85
Barnes et al., 2011; Exp 2	Middlings					
20%		93.5	99.1	93.2	99.4	98.12

[1]Equal weight formulation

[2] Equal lysine formulation

[3]Early finishing (average BW= 78.8 kg at end of phase)

[4]Late finishing (average BW= 106.6 kg at end of phase)

Table 1.4 Prediction of finishing pig performance fed wheat by-products compared to corn-soybean meal-based diets through regression analysis[1]

Level in the diet, %	ADG	ADFI	G:F	Yield
0	100.0	100.0	100.0	100.0
10	97.7	99.7	97.9	99.7
20	96.1	100.3	95.6	99.0
30	94.5	101.0	93.3	98.4
40	92.9	101.7	91.0	97.7
50	91.4	102.4	88.7	97.0
60	89.8	103.1	86.4	96.3
70	88.2	103.8	84.1	95.7
80	86.6	104.4	81.8	95.0
90	85.1	105.1	79.5	94.3

[1]Wheat by-products consist of wheat middlings, wheat shorts, and wheat mill run.

Figure 1.3 Predicted ADG of finishing pigs fed increasing dietary wheat middlings, wheat shorts, or wheat mill run from regression analysis using the model [Y= 99.233 – 0.154X, with X = % wheat by-product fed].

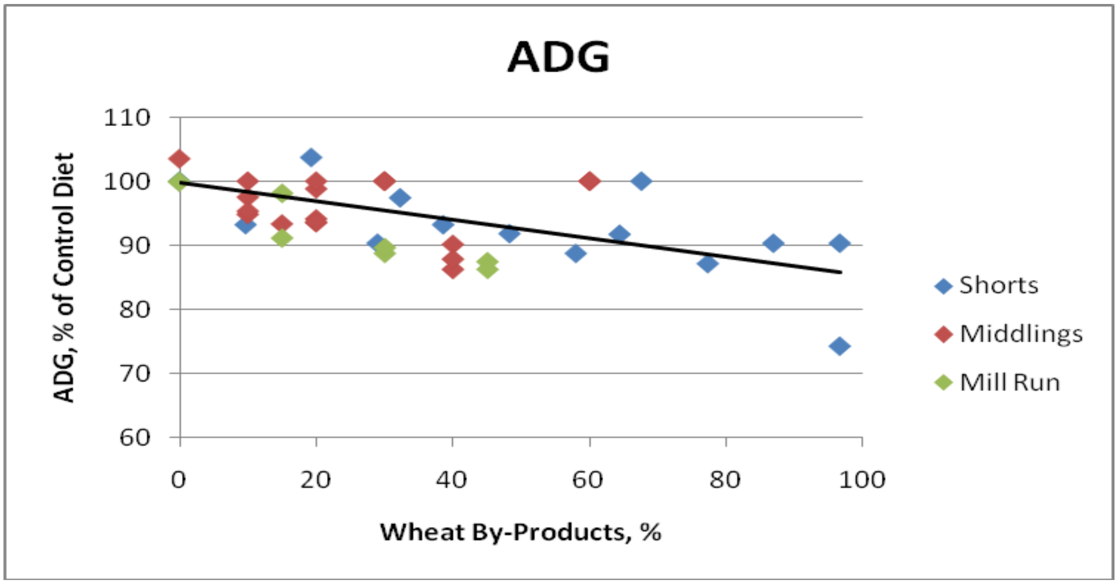


Figure 1.4 Predicted ADFI of finishing pigs fed increasing dietary wheat middlings, wheat shorts, or wheat mill run from regression analysis using the model [Y= 99.158 + 0.0437X with X= % wheat by-product fed].

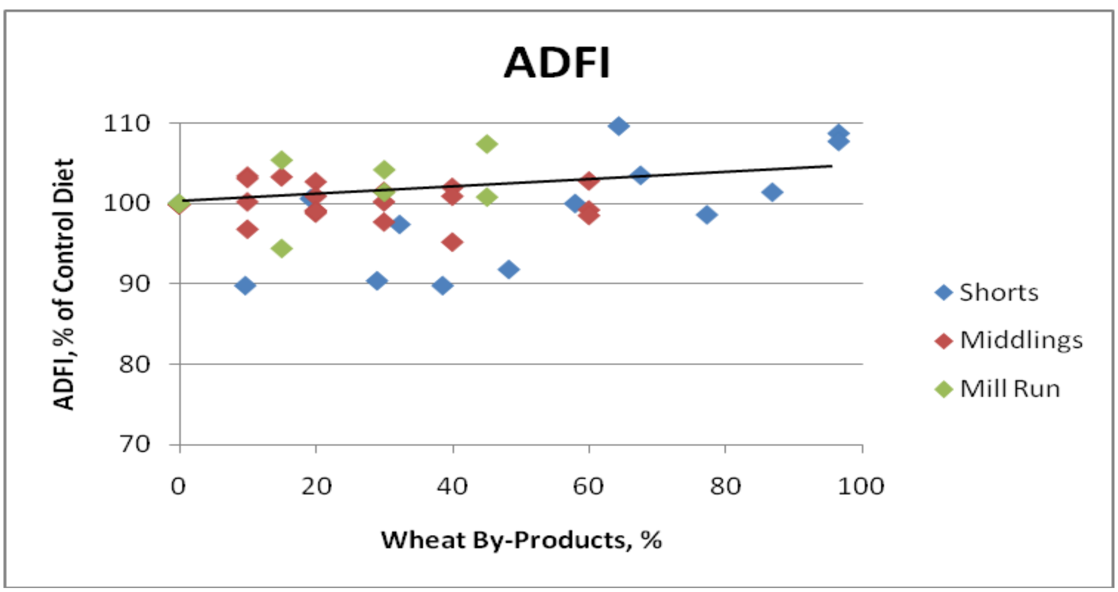


Figure 1.5 Predicted G:F of finishing pigs fed increasing dietary wheat middlings, wheat shorts, or wheat mill run from regression analysis using the model [Y= 99.976 - 0.1992X, with X= % wheat by-product fed].

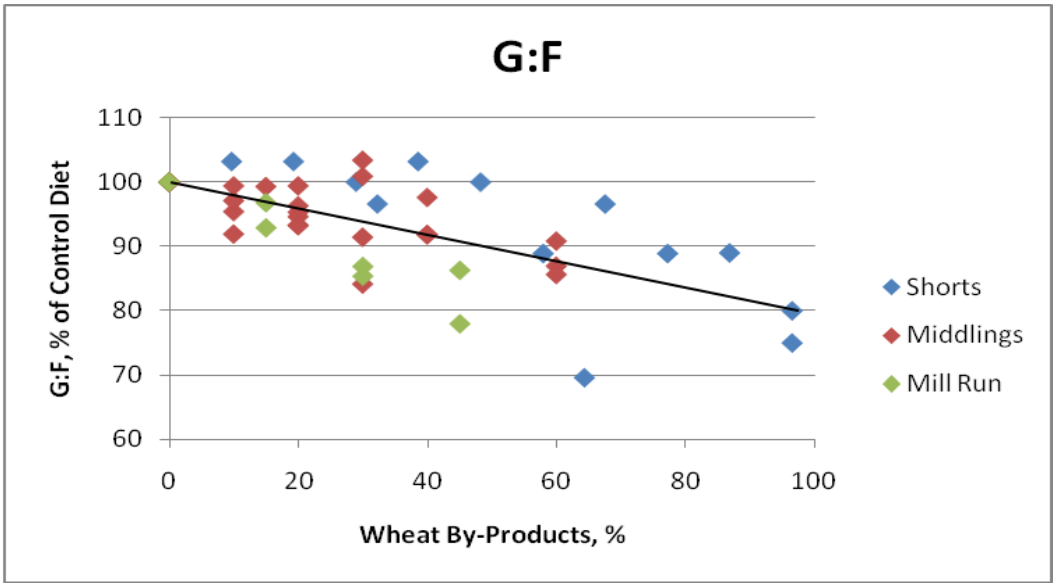
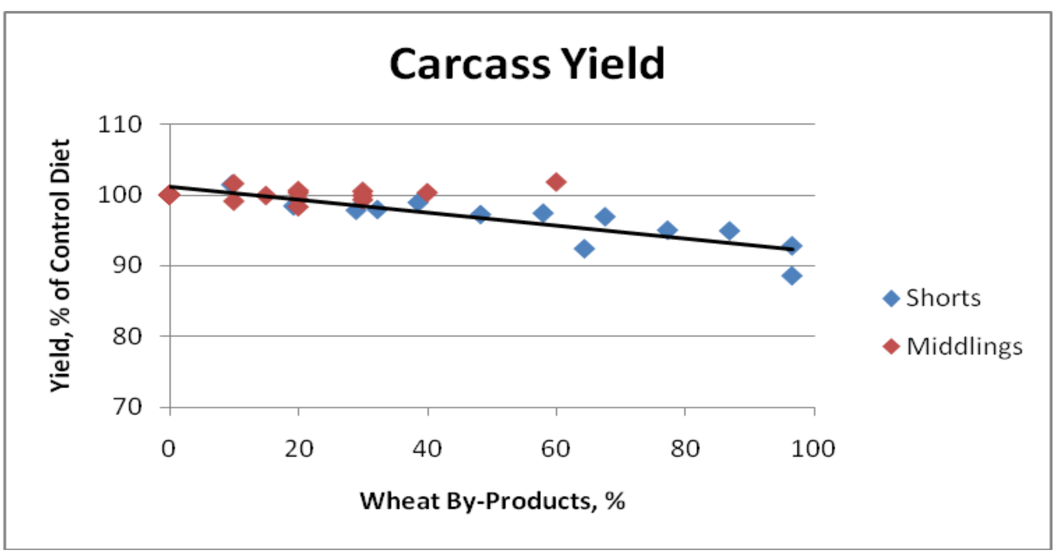


Figure 1.6 Predicted carcass yield of finishing pigs fed increasing dietary wheat middlings, wheat shorts, or wheat mill run from regression analysis using the model [Y= 100.4 -0.0678X, with X= % wheat by-product fed].



Chapter 2 - Effects of xylanase in finishing pig diets varying in dietary energy and fiber on growth performance, carcass characteristics, and nutrient digestibility

ABSTRACT

A total of 576 pigs (TR4 × 1050: PIC Hendersonville, TN; initially 48.1 kg BW) were used in a 75-d trial to evaluate effects of xylanase (Porzyme 93010; Dansico Animal Nutrition, St. Louis, MO) in finishing pig diets varying in dietary energy and fiber on growth performance, carcass characteristics, and nutrient digestibility. Pens of pigs were balanced by initial BW and gender then randomly allotted to 1 of 6 dietary treatments in a 2 × 3 factorial (with or without xylanase and 3 dietary energy levels) with 8 pigs per pen and 12 replications per treatment. The 6 treatments consisted of corn-soybean meal-based diets with added dried distillers grains with solubles (DDGS), wheat middlings (Midds), and choice white grease (CWG) arranged to make low (3.30 Mcal ME per kg of diet; 30% DDGS, 12.5% Midds, and 0% CWG), medium (3.38 Mcal ME per kg of diet; 15% DDGS, 6.25% Midds, and 1.2% CWG), and high energy diets (3.45 Mcal ME per kg of diet; 0% DDGS, 0% Midds, and 2.4% CWG) with or without xylanase (0 or 4,000 units xylanase per kg of diet). Diets were formulated to contain increasing dietary CWG to maintain uniform dietary crude fat levels in all diets. Diets were fed in meal form in 4 phases. There were no significant xylanase × energy interactions for any growth response criteria measured. However, there was a tendency ($P = 0.06$) for an enzyme by energy density interaction for both loin depth and NDF digestibility. Digestibility of NDF increased as xylanase

was supplemented in the diet and there was a tendency for differing loin depth with the medium and high dietary energy treatments with or without xylanase supplementation. Overall (d 0 to 75), pigs fed diets with xylanase had poorer ADG (P < 0.03) compared to pigs fed diets without xylanase. There were no differences in any other growth response criteria between pigs fed diets with or without xylanase. Increasing dietary energy increased (linear; P < 0.001) ADG and G:F with no affect on ADFI. For carcass traits, increasing dietary energy increased (linear; P < 0.01) yield, HCW, backfat depth, and reduced (linear; P < 0.001) FFLI and jowl fat iodine value. Apparent digestibility of ADF improved (P < 0.002) with the addition of dietary xylanase; however, there were no differences in any other nutrient digestibility criteria. Also, as dietary energy increased, there was an increase (linear; P < 0.02) in apparent digestibility of DM, N, fat, GE, ADF, and NDF. In summary, feeding pigs diets with increasing energy levels resulted in improved performance over those fed low energy diets. While ADF digestibility was increased with xylanase supplementation, growth performance, carcass characteristics and other nutrient digestibility values were not improved.

Key words: energy, growth, finishing pig, xylanase

INTRODUCTION

During fermentation of corn in order to produce dried distillers grains with solubles (DDGS) and milling of wheat to produce wheat middlings (Midds), the majority of the starch is fermented or separated from the kernel. Thus, remaining components, such as fiber, increase in concentration. Since both Midds and DDGS have higher crude fiber content than the grains in their original form, both contain more arabino-xylans as well. Arabinoxylans are hydrophilic non-starch polysaccharides (NSP) found in grain as minor constituents in the cell wall that act as anti-nutritional factors (Finnie et al., 2006; Diebold et al., 2004). Because swine do not digest

NSP efficiently due to their lack of specific digestive enzymes, the dietary energy content of most grain by-products is lower than the parent grain. It is under these conditions that exogenous enzymes like xylanase may be beneficial when added to diets to increase nutrient availability.

Xylanase is a carbohydrase, which is able to break some insoluble bonds that monogastric animals are otherwise unable to digest (Sugimoto and Van Buren, 1970). Xylanase has been shown to improve feed utilization and decrease cost of gain (Partridge, 2001). It has also been successful in increasing nutrient digestibility of swine diets (Barrera et al., 2004; Thacker et al., 2004; Nortey et al., 2008). Because corn is highly digestible and low in fiber, xylanase has not consistently shown improvements in growth performance when used in corn-based diets (Kim et al., 2003). However, xylanase may be more beneficial in corn-soybean meal-based diets that contain ingredients such as DDGS and Midds.

Therefore, the objective of this study was to evaluate xylanase in corn-soybean meal-based diets varying in dietary energy and fiber on growth performance, carcass characteristics and nutrient digestibility of grow-finish pigs.

MATERIALS AND METHODS

General

The Institutional Animal Care and Use Committees at Kansas State University and Dansico Animal Nutrition (St. Louis, MO) approved protocols used in this experiment. This experiment was conducted at the Kansas State University Swine Teaching Research Center.

The facility was a totally-enclosed, environmentally-controlled, mechanically-ventilated barn. It had 2 identical rooms containing 40 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

Two groups of finishing pigs were used to complete this experiment. The first group of pigs was fed from April through June 2010, while the second group of pigs was fed from May through July 2010. Both groups were fed four phase diets with the same time duration for each phase.

A total of 576 pigs (TR4 × 1050: PIC Hendersonville, TN; initially 48.1 kg BW) were used in a 75-d experiment. Pens of pigs were allotted in a completely randomized design to 1 of 6 dietary treatments in a 2 × 3 factorial with 8 pigs per pen (4 barrows and 4 gilts) and 12 replications per treatment. The 6 treatments consisted of corn-soybean meal-based diets with DDGS, Midds, and CWG to make low (3.30 Mcal ME per kg of diet; 30% DDGS, 12.5 % Midds, and 0% CWG), medium (3.38 Mcal ME per kg of diet; 15% DDGS, 6.25% Midds, and 1.2% CWG), and high energy diets (3.45 Mcal ME per kg of diet; 0% DDGS, 0% Midds, and 2.4 % CWG) with or without xylanase (0 or 4,000 units xylanase per kg of diet; Porzyme 93010, St. Louis, MO). Diets were formulated to contain increasing dietary CWG in order to maintain uniform dietary crude fat levels in all diets. Diets were fed in meal form and pigs were fed in 4 phases from approximately 48 to 66, 66 to 84, 84 to 101, and 101 to 123 kg BW for phases 1 to 4, respectively (Tables 2.1 and 2.2). 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, 17, 35, 52, and 75 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 75, pigs were weighed and transported (approximately 204 km) to a commercial processing plant (Triumph Foods Inc., St. Joseph, MO). Each pig had been individually tattooed according to pen number to allow for data retrieval by pen and carcass data collection at the packing plant. 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 iodine value using the equation of Cocciardi et al. (2009).

Digestibility and Chemical Analysis

Fecal samples were collected on d 7 of phase 3 (d 42 of trial) via rectal massage from at least 4 pigs per pen. All phase 3 diets contained 0.5% chromic oxide as the digestibility marker. Samples of feces were stored in a freezer (-20° C) until they were then thawed and homogenized within each pen. Fecal samples were then dried at 50º C in a forced-air oven and ground for analysis of bomb calorimetry and chromium concentration.

Gross energy of diets and ground fecal samples were determined with an adiabatic bomb calorimeter (Parr Instruments, Moline, IL). Diets and ground fecal samples were also analyzed for chromium concentration with an atomic absorption spectrometer (Williams et al., 1962 and Perkin-Elmer, 1971).

Samples of corn, soybean meal, DDGS (Abengoa; York, NE), and Midds (Archer-Daniels-Midland Co.; Lincoln, NE) were collected at the time of feed manufacturing and a composite sample was analyzed for moisture (AOAC 934.01, 2006), CP (AOAC 990.03, 2006), crude fat (AOAC 920.39 A, 2006), crude fiber (AOAC 978.10, 2006), ash (AOAC 942.05, 2006), Ca (AOAC 965.14/985.01, 2006.), and P (AOAC 965.17/985.01, 2006) at Dansico Animal Health Laboratories (St. Louis, MO). Also, a complete AA profile (AOAC 982.30 Ea,b, chp. 45.3.05, 2006.) at the University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia, MO) was conducted.

In addition, diet samples were collected from each feeder and combined for a single composite sample by treatment for each phase to measure moisture, CP, crude fat, crude fiber, ash, Ca, P, and bulk density (Seedburo Model 8800, Seedburo Equipment, Chicago, IL). Fecal samples were also analyzed for moisture, CP, crude fat, crude fiber, ash, Ca, and P.

Xylanase activity was analyzed at Danisco Animal Nutrition Laboratory (St Louis, MO) in which one unit of xylanase activity (XU) is defined as the amount of xylanase that will liberate 0.5 µmol of reducing sugars (expressed as xylose equivalents) from a cross-linked oat spelt xylan substrate (at pH 5.3 and 50° C) in one minute.

Statistical Analysis

Data were analyzed as a 2 × 3 factorial in 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 polynomial contrasts were conducted to determine effects of increasing dietary energy. Because there were treatment differences in HCW, it was used as a covariate for backfat, loin depth, and FFLI. Results were considered significant at $P \leq 0.05$, and a trend at $P \leq 0.10$.

RESULTS

Chemical analysis

Ingredient samples of corn, DDGS, Midds, and SBM were verified to be similar to those used in formulation (Table 2.3). The minor differences would not be expected to influence the results of the experiment.

Nutrient analysis of the treatment diets showed that for most of the nutrients, the levels were similar to formulated values (Tables 2.4 and 2.5). The only exception was crude fat, where all values were lower than expected, especially for the high energy diets where the greatest level of CWG was added.

Treatment diets containing xylanase were formulated to contain 4,000 units of xylanase activity per kg of diet. Chemical analysis revealed some variation in dietary xylanase activity. On average, most of the treatments tested slightly below formulated levels.

As Midds and DDGS were added to the diets in increasing amounts, dietary bulk density was decreased as expected.

Growth and Carcass

There were no significant xylanase × energy interactions for any growth performance criteria evaluated (Table 2.6). For overall (d 0 to 75) main effects, pigs fed diets with xylanase had poorer ADG ($P < 0.03$) when compared to pigs fed diets without added xylanase (Table 2.7). However, there were no differences between xylanase treatments for ADFI or G:F. Increasing energy improved (linear; $P < 0.001$) ADG and G:F, with no change in ADFI. Due to the improvement in ADG from increasing diet energy, final BW was also increased (linear, $P <$ 0.01).

There were no significant xylanase × energy interactions for any carcass criteria evaluated; however, there was a tendency ($P = 0.06$) for a loin depth interaction which was the result of a numerical increase in the medium energy diet without xylanase and a numerical decrease in the medium energy diet with xylanase. Adding xylanase to the diet did not influence carcass characteristics. Pigs fed diets with increased energy had increased (linear; $P < 0.01$) yield, HCW, and backfat depth. Furthermore, pigs fed diets with increased energy had lower (linear; $P < 0.001$) FFLI and jowl fat iodine value. In addition, dietary energy did not affect loin depth.

There were no significant xylanase × energy interactions observed for apparent digestibility (Table 2.8); however there was a tendency ($P = 0.06$) for a NDF digestibility interaction which was the result of a large increase in NDF digestibility for the low energy diet supplemented with xylanase but very small differences between both the medium or high energy diets when xylanase was added. For the main effects, the addition of xylanase improved ($P <$ 0.002) apparent total tract digestibility of ADF (Table 2.9); however, there were no differences in any other nutrient digestibility criteria evaluated. As dietary energy increased, there was an increase ($P < 0.02$) in apparent digestibility of DM, N, fat, GE, ADF, and NDF.

DISCUSSION

With the inclusion of dietary Midds and because the distillation process increases the proportion of NSP in DDGS, it is theorized that dietary enzymes may be more effective when Midds and DDGS are added to the diet. However, our study showed that other than improved digestibility of ADF, supplementing diets of grow-finish pigs with xylanase did not improve nutrient digestibility, growth performance, or carcass characteristics.

Past research has reported varying results in growth performance when feeding diets supplemented with exogenous enzymes. It has been noted by Stein et al. (2007) that because corn is low in fiber and highly digestible, enzymes have had varying affects in predominately corn diets. Agreeing with the current study, Jones et al., (2010) used the same xylanase product and reported no overall differences in performance between nursery pigs fed 30% DDGS diets with or without enzyme.

In addition, there have been numerous studies evaluating xylanase supplementation with multiple feed ingredients. Van Lunen and Shulze (1996) reported xylanase supplementation improved ADG and G:F by 9.2 and 5.3% in wheat-Midds-soybean meal-based diets. Mavromichalis et al. (2000) supplemented xylanase in wheat-soybean meal-based finishing pig diets and reported improved ADG in 1 of 2 studies conducted. In a third study, they reported no response to xylanase in wheat-based nursery diets. In addition, xylanase did not improve performance of finishing pigs in another study with rye- or barley-based diets (Thacker et al., 1991).

Causes of variation in xylanase research can include factors such as enzyme source, amount of enzyme used, ingredient variety, environment under which the ingredient was grown, stored, and processed, the age of the animal, interaction with other dietary ingredients, and health status (Bedford and Schulze; 1998). Furthermore, while the underlying structure of most xylans is similar, in practice the variety is enormous due to differences in xylan backbone structural size and types and degrees of substitutions from the xylan backbone (Bastawde, 1992; Sunna and

Antranikan, 1997). Therefore, Barrera et al. (2004) suggested variation seen between trials testing xylanase may be partially due to different arabinoxylans that exist in the diets.

In the current study, there was an increase in ADF total tract apparent digestibility when xylanase was added to the diet, with no difference in all other nutrient digestibility criteria. While past research has also demonstrated improved digestibility of nutrients when feeding xylanase in swine diets, the improved digestibility often does not translate to improved growth performance. Feeding xylanase increased nutrient digestibility with addition of enzymes to diets with DDGS (Opapeju et al., 2006; Sigfridson and Haraldsson, 2007) or wheat by-products (Barrera et al., 2004; Feoli et al., 2008; Woyengo et al., 2008) without improving growth performance. This suggests that xylanase can improve digestibility, but not to the extent to consistently improve growth performance.

In order to achieve a more consistent and affective growth response, more research is needed to investigate the mechanisms by which xylanase can make NSP's more available to the pig. Because poultry and pigs differ in their digestive tract physiology, they may respond differently to enzyme supplementation. One theory of the mode of action for carbohydrases, relates to the fact that some of the cell wall components of certain cereal grains (such as wheat, barley, and rye) dissolve in the digestive tract and interact to form high molecular weight, viscous aggregates (Bedford and Schulze; 1998). It was suggested by Burnett (1966) that NSP's such as beta-glucan and xylan can reduce the nutritional value of cereal grains by increasing the intestinal fluid viscosity. This increase in viscosity is theorized to interfere with the digestive process by reducing enzyme-substrate association and the rate at which their products approach the mucosal surface for absorption (White et al., 1983). Almirall et al. (1995) reported a decrease in viscosity of digesta in the gastrointestinal tract when supplementing carbohydrases such as xylanase and beta-glucanase, thereby, increasing utilization of high-fiber diets in poultry. However, it has been suggested that this issue may affect pigs to a lesser degree because pig's digesta has naturally higher water content and therefore a lower starting viscosity (Partridge, 2001).

Thacker et al. (2004) suggested carbohydrases, such as beta-glucanase and xylanase, failed to improve growth performance in finishing pigs, because, unlike in poultry, beta-glucan and xylan are already extensively degraded in the intestinal tract of pigs even in the absence of supplemental enzymes (Graham et al., 1989). The DE content measured with the fecal analysis method, such as in the current study, provides no information on the relative disappearance of energy in the small vs. large intestine, which does affect the efficiency of energy utilization (Just et al., 1983). Thus, if xylan digestion occurs in the swine's large intestine where pigs are unable to fully utilize the increased energy, the potential beneficial effects of xylanase (such as increased growth rate and improved G:F) are greatly reduced (Jacela et al., 2009; Thacker 2000).

Just (1982) and Turlington and Stahly (1984) conducted a series of experiments evaluating effects of increasing dietary fiber in swine diets on net energy value. They reported that higher dietary crude fiber, similar to the medium and low energy treatments in the current study, reduced digestibility of all of the nutrients except for soluble carbohydrates, as well as increased the proportion of nutrients in the hindgut. Furthermore, Just (1982) concluded ME utilization is decreased and there is an increase in non-absorbed nutrients that are excreted from the body when fiber content is increased.

The results from the current study support Just (1982) and Turlington and Stahly (1984) with decreased digestibility of DM, N, fat, GE, ADF, and NDF as dietary energy decreased. Just (1982) suggested decreased nutrient digestibility may be partially due to an increased passage rate of nutrients through the digestive tract. With increasing dietary fiber, the volume of feed and NDF increase; therefore, decreasing the retention time of digesta in the digestive tract.

Just (1982) further suggested a proportion of CP, and thus N, disappears in the hind gut as dietary fiber increases. Because more nutrients are transferred to the hindgut, increased microbial activity occurs. The microbes synthesize their own protein and AA's; however, most of these are excreted through feces. Therefore, ileal digestibility may be a more accurate measure of the amount of protein utilized by the body compared to apparent total tract digestibility.

The growth response to energy concentration with differing amounts of DDGS, Midds, and CWG, agrees with previous data from Barnes et al. (2011), reporting that as dietary energy increased (3.27, 3.39, 3.50 Mcal per kg of diet), ADG and G:F linearly improved, while feed intake remained similar. In their research, increasing Midds also reduced ADG and G:F. Feoli et al. (2006) reported similar results with increasing Midds (0, 15, or 30%) in finishing pig diets with leading to decreased ADG and G:F, and no difference in ADFI. The high NDF levels in diets containing both DDGS and Midds may have limited the pigs' ability to consume enough feed to overcome the lower energy level of the diet.

As for carcass data, the lack of affect of xylanase on carcass traits is consistent with other trials. Feoli et al. (2006) reported no differences in carcass traits whether xylanase was included in a corn-based diet, with or without dietary DDGS and Midds. Barrera et al. (2004) and Mavromichalis et al. (2000) also reported no difference in carcass traits when xylanase was added to wheat-based diets.

Increased DDGS and Midds in low energy diets reduced carcass yield, backfat, and HCW. This is consistent with Barnes et al. (2011), in that increased levels of dietary Midds and DDGS also resulted in reduced yield, and reduced backfat with a lighter HCW. The yield response could be a result of increased dietary bulk density which could lead to increased gut fill, and therefore a reduction in yield. The results of lower carcass yield in pigs fed high fiber diets was not unexpected and similar results have been reported in past studies (Turlington and Stahly, 1984; Linneen et al., 2008; Barnes et al., 2011). Turlington and Stahly (1984) reported increased gut fill and increased colon contents with increased NDF levels in finishing pig diets.

In the current study, CWG was added in the medium and high energy diets in order to maintain a uniform crude fat level to that of the low energy diet. This was done to remove any influence dietary crude fat may have on the effect of the xylanase. In the current study, jowl fat iodine value was highest in the low energy treatments. This was seen because as dietary crude fiber was increased with the addition of DDGS and Midds, the diet's fat composition became more unsaturated compared to the higher energy diets where a greater contribution of the dietary fat came from CWG, which is more saturated. Therefore, when dietary fat shifted from saturated to unsaturated, it resulted in an increase in jowl fat iodine value, which is a measure of degree of unsaturation in carcass fat (Jacela et al. 2011). Increased jowl fat iodine value when feeding increasing dietary DDGS and CWG agrees with previous data (Barnes et al., 2011). Benz et al. (2010) and Whitney et al. (2006) also observed a linear increase in fat iodine value as DDGS increased in the diet.

While digestibility of ADF was increased with xylanase supplementation, growth performance, carcass characteristics and other nutrient digestibility values were not improved. As expected, pigs fed diets with increasing dietary energy had improved performance compared with pigs fed low energy diets. Due to the lack of response to xylanase, more research is needed in order to further explain its mode of action and how it can potentially affect finishing pig performance.

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FIGURES AND TABLES

Table 2.1 Phase 1 and phase 2 diet composition (as-fed basis)[1]

	Phase 1			Phase 2		
	Energy			Energy		
Item	Low	Medium	High	Low	Medium	High
Ingredient, %						
Corn	42.20	57.83	73.17	45.11	60.97	76.42
Soybean meal, 46.5% CP	12.82	17.24	21.68	10.02	14.27	18.70
DDGS[2]	30.00	15.00	---	30.00	15.00	---
Wheat middling	12.50	6.25	---	12.50	6.25	---
Choice white grease	---	1.20	2.45	---	1.20	2.45
Monocalcium phosphate, 21% P	---	0.05	0.50	---	---	0.40
Limestone	1.25	1.23	0.98	1.23	1.23	1.00
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.15	0.15	0.15	0.13	0.13	0.13
Trace mineral premix[4]	0.15	0.15	0.15	0.13	0.13	0.13
L·Lys HCl	0.39	0.33	0.27	0.37	0.31	0.25
DL-Met	---	0.01	0.05	---	---	0.03
L-Thr	---	0.04	0.07	---	0.04	0.07
Phytase[5]	0.09	0.09	0.09	0.09	0.09	0.09
Xylanase premix[6]	0.10	0.10	0.10	0.10	0.10	0.10
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible (SID) AA						
Lys, %	0.95	0.95	0.95	0.86	0.86	0.86
Met:lys, %	32	30	31	34	31	30
Met and cys:lys, %	67	61	58	71	63	58
Thr:lys, %	62	62	62	64	64	64
Trp:lys, %	17	17	17	17	17	17
Total lys, %	1.11	1.08	1.06	1.01	0.99	0.96
CP, %	20.1	18.4	16.7	19.0	17.2	15.5
SID Lys:ME, g/Mcal	2.88	2.81	2.75	2.60	2.54	2.49
ME, kcal/kg	3,301	3,377	3,451	3,305	3,379	3,451
Ca, %	0.56	0.56	0.56	0.54	0.54	0.54
P, %	0.54	0.46	0.46	0.52	0.43	0.43
Available P, %	0.35	0.27	0.27	0.35	0.26	0.25
Crude fat, %	5.6	5.6	5.6	5.6	5.6	5.6
Crude fiber, %	4.5	3.5	2.5	4.5	3.4	2.4

[1]Dietary treatment fed in meal form from 45 to 64 kg BW for phase 1 and from 64 to 82 for phase 2.

[2]Corn distillers dried grains with solubles (Abengoa; York, NE).

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

[5]Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided 510 FTU/kg of complete feed with 0.10 % available P released in Phase 1 and 2.

[6]Premix was a mixture of Porzyme 93010 (Danisco Animal Nutrition, St Louis, MO) with ground corn and provided 4,000 units of xylanase per kg of complete feed. For non-xylanase treatments, the premix was replaced by corn.

Table 2.2 Phase 3 and phase 4 diet composition (as-fed basis)[1]

	Phase 3			Phase 4		
	Energy			Energy		
Item	Low	Medium	High	Low	Medium	High
Ingredient, %						
Corn	46.90	62.60	78.12	49.79	65.59	81.12
Soybean meal, 46.5% CP	7.81	12.22	16.64	5.51	9.84	14.27
DDGS[2]	30.00	15.00	---	30.00	15.00	---
Wheat middling	12.50	6.25	---	12.50	6.25	---
Choice white grease	---	1.20	2.45	---	1.20	2.45
Monocalcium phosphate, 21% P	---	---	0.35	---	---	0.30
Limestone	1.23	1.20	1.03	1.23	1.20	1.03
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.10	0.10	0.10	0.08	0.08	0.08
Trace mineral premix[4]	0.10	0.10	0.10	0.08	0.08	0.08
L·Lys HCl	0.34	0.28	0.22	0.29	0.24	0.18
DL-Met	---	---	0.03	---	---	0.02
L-Thr	---	0.02	0.05	---	---	0.03
Phytase[5]	0.09	0.09	0.09	0.09	0.09	0.09
Xylanase premix[6]	0.10	0.10	0.10	0.10	0.10	0.10
Chromic oxide	0.50	0.50	0.50	---	---	---
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis						
Standardized ileal digestible (SID) AA						
Lys, %	0.78	0.78	0.78	0.69	0.69	0.69
Met:lys, %	37	32	30	40	35	31
Met and cys:lys, %	75	67	60	82	73	63
Thr:lys, %	66	65	65	71	66	66
Trp:lys, %	17	17	18	18	18	18
Total lys, %	0.93	0.90	0.88	0.83	0.81	0.78
CP, %	18.1	16.4	14.6	17.2	15.5	13.7
SID Lys:ME, g/Mcal	2.37	2.32	2.27	2.09	2.04	1.99
ME, kcal/kg	3,053	3,125	3,189	3,071	3,143	3,211
Ca, %	0.53	0.53	0.53	0.52	0.52	0.52
P, %	0.51	0.42	0.41	0.51	0.42	0.39
Available P, %	0.35	0.25	0.23	0.34	0.25	0.22
Crude fat, %	5.7	5.7	5.7	5.8	5.8	5.8
Crude fiber, %	4.4	3.4	2.4	4.4	3.4	2.3

[1]Dietary treatment fed in meal form from 82 to100 kg BW for phase 3 and from 100 to 122.5 kg for phase 4.

[2]Corn distillers dried grains with soluble (Abengoa; York, NE).

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

[5]Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided 510 FTU/kg of complete feed with 0.10 % available P released in Phase 3 and 4.

[6]Premix was a mixture of Porzyme 93010 (Danisco Animal Nutrition, St Louis, MO) with ground corn and provided 4,000 units of xylanase per kg of complete feed. For non xylanase treatments, the premix was replaced by corn.

Table 2.3 Analyzed composition of dietary ingredients on an as-fed basis[1, 2]

Item, %	Corn	DDGS[3]	Midds	SBM
DM	83.1	90.3	86.9	88.4
CP	7.8 (8.5)[4]	26.9 (27.7)	15.6 (15.9)	46.1 (46.5)
Crude fat	4.1 (3.9)	9.3 (10.7)	4.7 (4.2)	1.3 (1.5)
Crude fiber	2.2 (2.2)	6.3 (7.3)	8.4 (7.0)	3.8 (3.9)
Ash	1.5	4.5	6.2	6.5
Ca	0.04 (0.03)	0.06 (0.2)	0.4 (0.1)	0.3 (0.3)
P	0.3 (0.3)	0.8 (0.8)	1.1 (1.0)	0.6 (0.7)
Phytic acid	0.8	0.7	3.2	1.7
Bulk density, g/L	556.8	644.8	278.0	477.6
Indispensable AA				
Arg	0.41	1.20	1.02	3.36
His	0.22	0.71	0.39	1.19
Ile	0.30 (0.28)	1.01 (1.01)	0.44 (0.53)	2.15 (2.16)
Leu	0.93 (0.99)	3.11 (3.17)	0.91 (1.06)	3.59 (3.66)
Lys	0.29 (0.26)	0.82 (0.78)	0.66 (0.57)	2.95 (3.02)
Met	0.17 (0.17)	0.51 (0.55)	0.22 (0.26)	0.62 (0.67)
Phe	0.39	1.28	0.54	2.33
Thr	0.29 (0.29)	1.00 (1.06)	0.50 (0.51)	1.68 (1.85)
Trp	0.05 (0.06)	0.19 (0.21)	0.14 (0.20)	0.68 (0.65)
Val	0.39 (0.39)	1.33 (1.35)	0.67 (0.75)	2.31 (2.27)
Dispensable AA				
Ala	0.56	1.77	0.72	1.97
Asp	0.54	1.61	1.08	5.05
Cys	0.18 (0.19)	0.53 (0.57)	0.30 (0.32)	0.63 (0.74)
Glu	1.43	3.55	2.45	8.29
Gly	0.34	1.09	0.79	1.94
Pro	0.60	1.91	0.80	2.30
Ser	0.34	1.10	0.54	2.03
Tyr	0.25	0.93	0.37	1.68

[1]Samples of corn, dried distillers grains with solubles (DDGS), wheat middlings (MIDDS) and soybean meal (SBM) were collected at the time of feed manufacturing and a composite sample was analyzed at Dansico Animal Nutrition lab (St. Louis, MO).

[2]Corn, Midds (Archer-Daniels-Midland Co.; Lincoln, NE), and SBM nutrient and amino acid values from NRC, 1998.

[3]DDGS (Abengoa; York, NE), amino acid values from Stein (2007).

[4]Values in parenthesis were used in diet formulation.

Table 2.4 Chemical analysis and bulk density of phase 1 and 2 diets (as-fed basis)

	Phase 1						Phase 2					
Xylanase[1]:	-	-	-	+	+	+	-	-	-	+	+	+
Item Energy:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
DM, %	87.4	86.8	86.0	87.8	86.8	86.0	87.4	86.9	86.4	87.5	86.9	86.7
CP, %	20.0	18.0	16.4	20.0	17.7	15.9	18.1	17.0	15.0	18.4	17.1	15.3
Crude fat, %	5.3	5.4	4.2	5.8	5.1	4.2	5.4	4.7	4.0	2.8	4.5	4.1
Crude fiber, %	3.9	3.2	2.3	4.3	3.1	1.9	4.1	3.2	1.7	4.4	3.2	1.9
Ash %	4.9	4.9	3.7	5.0	4.9	4.0	4.6	4.6	3.6	4.7	4.3	3.7
Ca, %	0.67	0.67	0.65	0.75	0.69	0.68	0.60	0.71	0.69	0.66	0.72	0.60
P, %	0.55	0.46	0.44	0.57	0.44	0.45	0.58	0.44	0.41	0.58	0.45	0.38
ADF, %	6.0	4.4	2.6	6.1	4.4	3.07	6.4	4.3	2.3	7.1	4.8	2.4
NDF, %	19.4	14.8	8.5	19.7	13.8	8.7	22.8	14.5	8.4	20.6	15.0	7.7
XU,[2,3] U/kg	---	---	---	3,261	2,029	1,938	---	---	---	3844	3,343	5,642
Bulk density,[4] g/L	518	567	618	516	570	622	502	565	636	515	580	636

[1]Porzyme 93010 (Danisco Animal Nutrition, St Louis, MO).

[2]XU=xylanase activity units.

[3]One unit of xylanase activity is defined as amount of xylanase that will liberate 0.5 µmol of reducing sugars from a cross linked oat spelt xylan (at pH 5.3 and 50°C) substrate in one minute.

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

Table 2.5 Chemical analysis and bulk density of phase 3 and 4 diets (as-fed basis)

	Phase 3						Phase 4					
Xylanase[1]:	-	-	-	+	+	+	-	-	-	+	+	+
Item Energy:	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
DM, %	87.0	86.5	85.9	87.0	86.7	86.0	88.0	87.0	86.5	87.4	87.1	86.3
CP, %	17.2	16.2	14.2	18.3	16.1	14.8	16.9	14.8	12.6	16.6	14.9	13.0
Crude fat, %	5.4	5.4	4.3	5.5	4.7	3.8	5.4	4.6	4.4	5.1	4.5	3.7
Crude fiber, %	3.8	3.0	1.8	4.2	2.9	1.8	3.8	2.9	1.9	3.6	2.7	1.9
Ash, %	5.1	4.5	3.8	4.9	4.3	4.0	5.3	4.3	3.4	4.5	3.9	3.4
Ca, %	0.77	0.59	0.54	0.66	0.67	0.59	0.87	0.66	0.59	0.66	0.67	0.58
P, %	0.54	0.42	0.40	0.53	0.43	0.40	0.54	0.39	0.37	0.54	0.42	0.42
ADF, %	6.0	4.4	2.7	6.6	4.48	2.9	6.2	4.2	2.3	6.3	4.6	2.7
NDF, %	19.3	13.5	8.3	19.0	13.9	9.4	18.7	13.9	8.3	20.5	14.3	9.0
XU[2,3],U/kg	---	---	---	4,787	3,879	3,211	---	---	---	3,745	3,279	6,198
Bulk density,[4]g/L	530	566	620	517	570	626	510	545	609	519	561	610

[1]Porzyme 93010 (Danisco Animal Nutrition, St Louis, MO).

[2]XU=xylanase activity units.
[3]One unit of xylanase activity is defined as amount of xylanase that will liberate 0.5 µmol of reducing sugars from a cross linked oat spelt xylan (at pH 5.3 and 50°C) substrate in one minute.
[4]Diet samples collected from each feeder during each phase and combined and then sub-sampled for analysis.

Table 2.6 Interactive effects of dietary xylanase and energy on finishing pig growth performance and carcass characteristics[1]

Xylanase[2]:	-	-	-	+	+	+		Probability, $P <$
Energy:	Low	Medium	High	Low	Medium	High	SEM	Xylanase × Energy
Initial wt, kg	48.1	48.1	48.1	48.1	48.1	48.1	1.06	1.00
D 0 to 75								
ADG, kg	0.963	1.000	1.014	0.956	0.971	1.003	0.008	0.44
ADFI, kg	2.92	2.89	2.88	2.85	2.86	2.88	0.030	0.60
G:F	0.330	0.346	0.352	0.335	0.340	0.348	0.003	0.18
Final wt, kg	121.0	123.5	124.8	120.2	121.2	124.0	1.33	0.84
Carcass characteristics								
Yield, [3]%	72.1	73.5	73.4	72.7	72.4	73.4	0.43	0.14
HCW, kg	87.3	90.7	91.6	87.4	87.9	91.0	1.12	0.40
Backfat depth,[4] mm	19.6	20.8	21.9	19.6	20.5	21.5	0.59	0.88
Loin depth,[4] mm	59.3	60.1	58.9	59.5	58.4	60.4	0.67	0.06
FFLI,[4,5]	51.1	50.5	49.7	51.2	50.5	50.0	0.37	0.81
Jowl fat iodine value	76.0	72.7	69.2	75.5	72.2	69.1	0.36	0.78

[1]576 pigs (TR4 × 1050: PIC Hendersonville, TN) were used in a 75-d study with 8 pigs per pen and 12 pens per treatment.

[2]Porzyme 93010 (Danisco Animal Nutrition, St. Louis, MO).

[3]Percentage yield was calculated by dividing HCW by live weight obtained before transport to the packing plant.

[4]Data analyzed by using HCW value as a covariate.

[5]FFLI= fat-free lean index.

Table 2.7 Main effects of dietary xylanase and energy level on finishing pig growth performance and carcass characteristics[1]

	Xylanase[2]		Energy			Xylanase	Energy	Probability, $P <$			
										Energy	
	-	+	Low	Medium	High	SEM	SEM	Xylanase	Energy	Linear	Quadratic
Initial wt, kg	48.1	48.1	48.1	48.1	48.1	0.62	0.75	1.00	1.00	0.98	0.99
D 0 to 75											
ADG, kg	0.992	0.976	0.959	0.985	1.009	0.004	0.005	0.03	<0.001	<0.001	0.99
ADFI, kg	2.90	2.86	2.89	2.88	2.88	0.014	0.019	0.17	0.95	0.89	0.77
G:F	0.342	0.341	0.332	0.343	0.350	0.001	0.002	0.65	<0.001	<0.001	0.68
Final wt, kg	123.1	121.8	120.6	122.4	124.4	0.59	0.84	0.26	0.04	0.01	0.85
Carcass characteristics											
Yield,[3] %	73.0	72.9	72.4	73.0	73.4	0.24	0.29	0.66	0.03	0.01	0.93
HCW, kg	89.9	88.8	87.3	89.3	91.3	0.53	0.67	0.22	0.002	<0.001	0.93
Backfat depth,[4] mm	20.8	20.5	19.6	20.6	21.7	0.44	0.56	0.49	<0.001	<0.001	0.84
Loin depth,[4] mm	59.4	59.5	59.4	59.2	59.7	0.32	0.43	0.98	0.81	0.74	0.58
FFLI,[4,5]	50.4	50.6	51.1	50.5	49.9	0.28	0.31	0.53	0.002	<0.001	0.94
Jowl fat iodine value	72.6	72.3	75.7	72.5	69.1	0.24	0.26	0.14	<0.001	<0.001	0.48

[1]576 pigs (TR4 × 1050: PIC Hendersonville, TN) were used in a 75-d study with 8 pigs per pen and 12 pens per treatment.

[2]Porzyme 93010 (Danisco Animal Nutrition, St Louis, MO).

[3]Percentage yield was calculated by dividing HCW by live weight obtained before transport to the packing plant.

[4]Data analyzed by using HCW value as a covariate.

[5]FFLI=fat-free lean index.

Table 2.8 Interactive effects of dietary xylanase and energy on finishing pig apparent total tract digestibility[1]

	Xylanase[2]:	-	-	-	+	+	+		Probability, $P <$
									Xylanase ×
Item, %	Energy:	Low	Medium	High	Low	Medium	High	SEM	Energy
DM		72.5	78.5	82.6	74.6	78.7	83.2	1.35	0.59
N		69.6	72.5	76.9	72.3	70.4	77.8	1.81	0.26
Fat		42.4	52.0	49.9	45.7	49.8	50.9	2.68	0.49
GE		69.1	75.6	81.3	72.1	75.9	81.1	1.29	0.36
ADF		60.4	68.0	60.9	66.6	68.8	68.3	2.08	0.17
NDF		39.7	50.9	56.2	49.1	48.4	58.0	2.65	0.06

[1]Fecal samples were collected on d 7 of phase 3 (d 42 of trial) via rectal message from at least 4 pigs/pen.

[2]Porzyme 93010 (Danisco Animal Nutrition, St Louis, MO).

Table 2.9 Interactive effects of dietary xylanase and energy on finishing pig apparent total tract digestibility[1]

								Probability, $P <$			
	Xylanase[2]		Energy			Xylanase	Energy			Energy	
Item, %	-	+	Low	Medium	High	SEM	SEM	Xylanase	Energy	Linear	Quadratic
DM	77.9	78.8	73.5	78.6	82.9	1.07	1.14	0.22	< 0.0001	< 0.0001	0.84
N	73.0	73.5	71.0	71.4	77.4	1.32	1.45	0.67	< 0.0001	< 0.0001	0.02
Fat	48.2	48.8	44.2	50.9	50.4	1.90	2.11	0.72	0.005	0.006	0.07
GE	75.3	76.4	70.6	75.8	81.2	0.82	0.95	0.29	< 0.0001	< 0.0001	0.72
ADF	63.1	67.9	63.5	68.4	64.6	1.35	1.56	0.002	0.02	0.52	0.008
NDF	49.0	51.8	44.5	49.6	57.1	1.61	1.91	0.16	< 0.0001	< 0.0001	0.50

[1]Fecal samples were collected on d 7 of phase 3 (d 42 of trial) via rectal message from at least 4 pigs/pen.

[2]Porzyme 93010 (Danisco Animal Nutrition, St Louis, MO).

Chapter 3 - Effects of dietary wheat middlings, dried distillers grains with solubles, and choice white grease on growth performance, carcass characteristics, and carcass fat quality of finishing pigs

Abstract

Two experiments were conducted to evaluate the effects of wheat middlings (Midds), dried distillers grains with solubles (DDGS), and choice white grease (CWG) in combinations on growth, carcass traits, and carcass fat quality of finishing pigs. In Exp. 1, 288 pigs (initially, 46.6 kg BW) were used in an 84-d experiment with pens of pigs randomly allotted to 1 of 4 treatments with 8 pigs per pen and 9 pens per treatment. Treatments included a corn-soybean meal-based control diet, the control with 30% DDGS, or a diet with 30% DDGS plus 10% or 20% Midds. Diets were fed in 4 phases and formulated to constant standardized ileal digestible (SID) lys:ME within phase. Overall (d 0 to 84), pigs fed increasing Midds had decreased (linear; $P \leq 0.02$) ADG and G:F. There were no differences in ADFI. Feeding 30% DDGS did not influence growth performance. For carcass traits, increasing Midds decreased (linear; $P < 0.01$) carcass yield and HCW, but also decreased (quadratic; $P < 0.02$) backfat depth and increased (quadratic; $P < 0.01$) FFLI. Feeding 30% DDGS decreased ($P < 0.03$) carcass yield and backfat depth ($P < 0.01$), but increased FFLI ($P < 0.02$) and jowl fat iodine value ($P < 0.001$). In Exp. 2, 288 pigs (initially, 42.3 kg BW) were used in an 87-d experiment with pens of pigs randomly allotted to 1 of 6 dietary treatments with 8 pigs per pen and 6 pens per treatment. Treatments were arranged in a 2 × 3 factorial with main effects of Midds (0 or 20%) and CWG (0, 2.5, or 5%) with all diets containing 15% DDGS. Diets were fed in 4 phases and formulated to constant SID Lys:ME within phase. There were no CWG × Midds interactions. Overall, (d 0 to 87), feeding 20% dietary Midds decreased ($P < 0.01$) ADG and G:F. Pigs fed diets with increasing CWG had improved ADG (quadratic, $P < 0.03$) and G:F (linear, $P < 0.01$). Dietary Midds or CWG did not affect ADFI. For carcass traits, feeding 20% Midds decreased ($P < 0.05$) carcass yield, HCW, backfat depth, and loin depth, while increasing ($P < 0.001$) jowl fat iodine value. Pigs fed CWG also had decreased (linear, $P < 0.05$) FFLI and increased (linear, $P < 0.01$) jowl fat iodine value. In conclusion, feeding Midds reduced pig growth performance, carcass yield, and increased jowl fat iodine value. While increasing diet energy with CWG can help mitigate negative effects on live performance; it did not eliminate negative impacts of Midds on carcass yield, HCW, and jowl fat iodine value.

Key words: growth, finishing pig, wheat middlings

Introduction

Feed costs represent 60 to 75% of the total cost of pork production. With increased use of corn in ethanol production, ingredient costs have increased. Thus, feed ingredient alternatives to corn and soybean meal are becoming more frequently used in swine diets. While these ingredients are used with the intent of lowering feed costs, it is important to know their impact on growth and carcass traits.

Wheat middlings are a common cereal by-product used in commercial pig feed (Cromwell, 2000). The addition of Midds to finishing diets has potential to supply energy, CP, P, and fiber when incorporated into typical corn-soybean meal diets. Wheat middlings have higher CP and fiber than corn (NRC, 1998).

Dried distillers grains with solubles are corn by-products from ethanol production. They have approximately 3 times the crude fat, CP, and fiber content as corn. Also, DDGS have a higher P bioavailability compared to corn (Pedersen et al., 2007). Stein and Shurson (2009) reported no negative impact on growth performance when up to 30% DDGS were added to finishing pig diets.

In addition, DDGS have similar DE and ME concentrations to corn (Pedersen et al., 2007) while Midds have a lower ME concentration and thus, reduced gains and feed efficiency can be expected when added to corn-soybean meal diets (Shaw et al., 2002). Including a dietary energy source such as CWG when Midds are fed may mitigate these negative effects, but there is limited information on the effect of this combination on growth performance and no information on the impact on carcass fat iodine value. Also, there is no published data on the impact of Midds in diets containing DDGS.

Therefore, our objective was to determine effects of dietary Midds, DDGS, and CWG in combinations in corn-soybean meal-based diets on growth performance, carcass characteristics, and carcass fat quality of grow-finish pigs.

Materials and Methods

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

Two experiments involving a total of 576 pigs (TR4 ×1050; PIC Hendersonville, TN) were used. Both experiments were 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 40 pens (2.4 × 3.1 m) with adjustable gates facing the alleyway, allowing for 0.93 sq m per pig. Each pen was equipped with a single-sided, dry self-feeder with 2 eating spaces (Farmweld; Teutopolis, IL) located 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 a automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of delivering and recording diets as specified on an individual pen basis. The equipment provided pigs ad libitum access to food and water.

Experiment 1

Two hundred and eighty-eight pigs (initially 46.6 ± 1.0 kg BW) were used in an 84-d experiment to evaluate the effects of DDGS and increasing dietary Midds on growing-finishing pig growth performance, carcass traits, and carcass fat quality. Pens of pigs were allotted in a complete randomized design to 1 of 4 treatments with 8 pigs per pen (4 barrows and 4 gilts) and 9 pens per treatment. Treatments included a corn-soybean meal-based control diet, the control with 30% DDGS, or the diet with 30% DDGS plus 10% or 20% Midds. Diets were in meal form. Pigs were fed in 4 phases from approximately 46 to 67, 67 to 84, 84 to 101, 101 to 131 kg BW for phases 1 to 4, respectively (Tables 1 and 2). Treatment diets were formulated to constant standardized ileal digestible (SID) Lys:ME within each phase. Diets were formulated to meet all requirement estimates suggested by NRC (1998).

Pigs were weighed by pen on d 0, 20, 36, 52, and 84 to determine 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 84, pigs were weighed and transported (approximately 204 km) to Triumph Foods Inc. (St. Joseph, MO). Pigs had been individually tattooed according to pen number to allow for data retrieval by pen and carcass data collection at the packing plant. Hot carcass weights were measured immediately after evisceration, and each carcass was evaluated for percentage yield, backfat, and loin depth. Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the 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. Also, jowl samples were collected and analyzed by Near Infrared Spectroscopy (NIR; Bruker MPA; Multi Purpose Analyzer) for iodine value using the equation of Cocciardi et al. (2009).

Chemical analysis

Samples of Midds (Archer-Daniels-Midland Co.; Lincoln, NE) and DDGS (Hawkeye Gold, Menlo, IA) were collected at the time of feed manufacturing and combined into a single composite sample that was analyzed for moisture (AOAC 934.01, 2006), CP (AOAC 990.03, 2006), crude fat (AOAC 920.39 A, 2006), crude fiber (AOAC 978.10, 2006), ash (AOAC 942.05, 2006), Ca (AOAC 965.14/985.01, 2006.), and P (AOAC 965.17/985.01, 2006) at Ward Laboratories (Kearney, NE). Composite samples of Midds and DDGS were also analyzed for complete amino acid profile (AOAC, 2006.) at University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia, MO).

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).

Experiment 2

Two hundred eighty-eight pigs (initially 42.3 ± 1.0 kg BW) were used in an 87-d study to determine the effects of Midds and CWG on growth performance, carcass characteristics, and carcass fat quality of finishing pigs. Pens of pigs were randomly allotted to 1 of 6 dietary treatments with 8 pigs per pen (4 barrows and 4 gilts) and 6 pens per treatment. Dietary treatments were arranged in a 2 × 3 factorial with the main effects of added Midds (0 or 20%)

and CWG (0, 2.5, or 5%). Dietary treatments were corn-soybean meal-based with 15% DDGS and were fed in 4 phases (Tables 3 and 4). All diets were fed in meal form and balanced to a similar SID Lys:ME within each phase.

Wheat middlings (Archer-Daniels-Midland Co.; Lincoln, NE) and DDGS (Abengoa; York, NE) samples were collected at the time of feed manufacturing and a composite sample was analyzed for nutrient content as described for Experiment 1. Also, diet samples were collected from each feeder and combined for a single composite sample by treatment for each phase to measure bulk density as described for Experiment 1.

Pigs and feeders were weighed on d 0, 21, 41, 60, and 87 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 87, all pigs were weighed and transported (approximately 204 km) to Triumph Foods Inc. (St. Joseph, MO). Pigs were tattooed and carcass data was collected and analyzed as described in Experiment 1.

Statistical analysis

For Exp.1 and 2, data were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC) with pen as the experimental unit. Because there were differences in HCW, it was used as a covariant for backfat, loin depth, and FFLI. In Exp. 1, linear and quadratic polynomial contrasts were conducted to determine effects of increasing dietary Midds. A single degree of freedom contrast was used for comparing pigs fed the control diet to pigs fed the diet containing 30% DDGS without Midds. In Exp. 2, the main effects of the different treatment regimens of Midds and added CWG, and their interaction were tested. Linear and quadratic contrasts were used to determine the effects of increasing dietary CWG. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results

Chemical analysis

Analysis of nutrients of DDGS and Midds were verified to be generally similar to values used in formulation (Tables 5 and 6) and we do not believe the differences would have impacted the results or data interpretation of the experiments.

Bulk density tests showed adding dietary DDGS and Midds decreased diet bulk density, but adding CWG had no effect (Tables 7 and 8).

Experiment 1

Overall (d 0 to 84), pigs fed increasing Midds had decreased (linear; $P \leq 0.02$) ADG and (linear; $P \leq 0.01$) G:F (Table 9). There were no differences in ADFI. There was a tendency for decreased (linear; $P < 0.07$) final BW as Midds increased. Feeding 30% DDGS did not influence growth performance. For carcass traits, increasing Midds decreased (linear; $P < 0.01$) carcass yield and HCW and tended to decrease (linear; $P < 0.06$) loin depth. Pigs fed Midds also had decreased (quadratic; $P < 0.02$) backfat depth and increased (quadratic; $P < 0.01$) FFLI.

While feeding 30% DDGS did not affect growth performance, it resulted in decreased carcass yield ($P < 0.03$) and backfat depth ($P < 0.01$), with increased FFLI ($P < 0.02$) and jowl fat iodine value ($P < 0.001$).

Experiment 2

There were no CWG × Midds interactions observed (Table 10). Overall, (d 0 to 87), feeding 20% dietary Midds decreased ($P < 0.01$) ADG and G:F (Table 11). Pigs fed diets with increasing CWG had increased ADG (quadratic, $P < 0.03$) and G:F (linear, $P < 0.01$) Feed intake was not affected by the addition of 20% dietary Midds or added CWG. Pigs fed diets containing 20% Midds had decreased ($P < 0.01$) final BW; while there was a trend for increased final BW ($P < 0.09$) as dietary CWG increased.

For carcass traits, feeding 20% Midds decreased carcass yield ($P < 0.04$), HCW ($P < 0.003$), backfat depth ($P < 0.04$), and loin depth ($P < 0.001$). Furthermore, feeding 20% Midds increased jowl fat iodine value ($P < 0.001$). In addition, pigs fed CWG had a tendency for increased (linear, $P < 0.06$) backfat depth, increased (linear, $P < 0.01$) jowl fat iodine value, and decreased (linear, $P > 0.05$) FFLI.

Discussion

Both of the current experiments found that pigs fed diets with varying levels of Midds had decreased ADG and G:F with no change in ADFI. These results are similar to those of Feoli et al. (2006) and Cromwell et al. (1992) who also reported decreased ADG and G:F when Midds were increased in the diet with no change in feed intake. The increase in NDF content in diets containing both Midds and DDGS may have limited the pigs' ability to consume enough feed to overcome the lower energy concentration in Midds diets.

Interestingly, adding 5% CWG to the diet containing 20% Midds resulted in similar ADG and G:F to the diet without Midds or added CWG. The ME level of the high-fat, 20% Midds diet would suggest that pigs fed this diet should have resulted in improved G:F, indicating that the diet ME may have been overestimated in the Midds diets, or other factors may have prevented further improvement.

Past research by Just (1982) evaluated effects of increasing dietary fiber on net energy value and growth performance of growing swine. Just (1982) reported increasing NDF in swine diets reduced digestibility of all of the nutrients except soluble carbohydrates, and increased the proportion of nutrients in the hindgut. Turlington and Stahly (1984) observed an increase in gut fill and colon contents ($P < 0.05$) when dietary fiber was increased. Furthermore, Just (1982) reported decreased ME utilization and increased excretion of non-available nutrients when NDF content increased in the diet. Increased crude fiber can increase the amount of energy excreted through urine N.

Some theories for reduced ME utilization in high fiber diets is thought to be due to the increased proportion of nutrients transferred to the hindgut. Increased crude fiber can increase the passage rate of nutrients through the digestive tract and decrease digestion in the small intestine. Therefore, a larger proportion of carbohydrates are fermented in the hindgut, making volatile fatty acids (acetic acid, butyric acid, propionic acid, etc.), which most likely have a lower metabolic efficiency when compared to glucose absorbed in the small intestine. Furthermore, the additive effects of increased heat from fermentation, increased gas production, and increased protein excretion from urea can result in decreased energy utilization. This may help explain why the pigs fed the diet with 5% added CWG to 20% Midds (3,501, 3,508, 3,510, and 3,514 kcal/kg ME in each phase, respectively) had similar growth performance and final BW to those pigs fed the diet with no added fat and no Midds with a lower ME value (3,344, 3,351, 3,353, and 3,358 kcal/kg ME in each phase).

Some variation exists in past research as to the optimal inclusion of Midds in finishing diets. Shaw et al. (2002) reported that 30% Midds could be included in grow-finish diets before a significant reduction in performance was observed. Other research (Erikson et al. 1985; Cromwell et al., 1992) observed a decrease in performance when as little as 10% Midds was added to the diet. Wheat middling's affect on growth and carcass data of finish pigs can vary depending on nutrient content, as well as its bulk density. One potential difference among trials may be explained by the amount of variation that can occur between Midds sources and even within batch. Differences in wheat type, grade, and wheat processing specifications can impact which components of the wheat kernel are used for Midds. In addition, Midds nutrient concentration can vary depending on the objectives of the milling process (Blasi et al., 1998).

Increased dietary Midds resulted in light bulk density of the diets with CWG having no effect. A decrease in bulk density can indicate increased gut fill due to high fiber content. With variation existing between Midds products, research has been done in order to evaluate Midds quality and in particular, bulk density. Cromwell et al. (2000) suggested bulk density may not only affect gut fill, but it may also be used as a general indicator of Midds quality. They reported bulk density measurement can provide an estimation of the amount of bran and flour present in Midds products. Wheat middlings with a light bulk density will typically consist of more bran material, and thus, a high fiber, protein, and phosphorus content than heavier Midds consisting of starchier endosperm parts of the kernel. This theory agrees with earlier data in which Cromwell et al. (1992) conducted a study with finishing pigs fed diets differing in bulk densities with light (34% NDF, 15.1% CP, and 0.65% Lys) or heavy (30% NDF, 14.0% CP, and 0.58% Lys) Midds at increasing amounts. Feeding light Midds to pigs resulted in poorer growth performance; however, all pig growth performance was negatively affected with added Midds.

In Exp.1, our data agrees with past research reporting that up to 30% DDGS can be included in finishing swine diets without a negative effect on performance (Stein, 2007, Stein and Shurson, 2009). While feeding 30% DDGS did not affect growth performance, it did result in decreased carcass yield and softer fat as indicated by increased jowl fat iodine value. In past research, DDGS has also been reported to increase fat iodine value by Benz et al. (2010) and

Whitney et al. (2006). Whitney et al. (2006) reported belly fat iodine value increased 1.7 g/100 g for every 10% DDGS in grow-finish diets. The increase in iodine value is due to the increased unsaturated fat provided by DDGS. Boyd et al. (1997), Averette-Gatlin et al. (2003), and Weber et al. (2006,) also demonstrated increased dietary unsaturated fat increased carcass iodine value.

The effect of Midds on jowl fat iodine value has not previously been evaluated. In Exp. 2, pigs fed 20% Midds had increased jowl fat iodine value even when DDGS level was held constant at 15%. However, increasing dietary Midds had no affect on jowl fat iodine value in Exp. 1. Bergstrom et al. (2011) reported pigs with slower growth rates and less backfat had increased iodine value, which agrees with the observations in Exp. 2.

In the current study, there was a reduction in carcass yield when dietary DDGS were fed. Other studies have reported decreased yield with the addition of dietary DDGS (Hinson et al., 2007; Xu et al., 2007; Linneen et al., 2008). This may be due to the higher fiber content of DDGS compared to corn. The high fiber content leads to increased gut fill thus increased visceral weight, which is not included into carcass yield measurement (Turlington and Stahly, 1984).

In addition, because of the high fiber content of wheat middlings, it has been reported to affect pig gut fill and thus reduce carcass yield (Shaw et al., 2002). Just (1982) reported a 0.34 kg increase in gut fill per 1% increased dietary fiber for pigs that had been withdrawn from feed (approximately 12 h) before time of slaughter. However, if those pigs had been fed the same day as they were killed, the gut fill would have been greater. Furthermore, Just (1982) reported feeding pigs diets with increased fiber resulted in decreased backfat depth, protein deposition, and loin depth, which agrees with the results of the current studies.

Past research with other wheat milling by-products such as wheat shorts (Patience et al., 1977; and Beames and Natoli, 1969), also reported decreased carcass yield. Young (1980) obtained a shrunk weight of pigs to reduce influence of gut fill on yield in order to evaluate other possibilities of decreased carcass yield in pigs fed wheat shorts. Calculations of ADG and G:F based on the shrunk weight revealed a further decline in the performance of pigs being fed increasing amounts of dietary wheat shorts. Reduction in carcass traits can be attributed to the combination of increased gut fill and visceral weight and decreased BW before slaughter.

In the current study, CWG was added to minimize detrimental effects of dietary Midds on performance and carcass traits. While adding dietary CWG to diets with Midds made it possible to maintain similar growth performance when compared to pigs fed the corn-soybean meal-based diets, a reduction of carcass yield was still seen in all Midds containing diets regardless of dietary fat addition. These results are consistent with Shaw et al. (2002), who included 30% dietary Midds with added CWG to finishing pig (65 to 107 kg BW) diets. Thus, cost of ingredients and impact on yield must be taken into consideration when contemplating adding dietary fat to diets containing Midds. Just (1982) concluded that pigs fed high fiber diets may have similar daily gain; however, live weight should be adjusted for gut fill to obtain a similar carcass weight.

In conclusion, these data indicate that lower dietary energy and decreased bulk density of diets containing Midds reduced pig performance, carcass yield, and increased jowl fat iodine value. Increasing diet energy with CWG helped mitigate some of the negative effect on live performance; however, additional energy from CWG did not eliminate the negative impact of Midds on carcass yield and carcass weight.

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FIGURES AND TABLES

Table 3.1 Phase 1 and 2 diet composition (Exp. 1, as-fed basis)[1]

	Phase 1				Phase 2			
DDGS, %:	0	30	30	30	0	30	30	30
Item / Midds, %:	0	0	10	20	0	0	10	20
Ingredient, %								
Corn	79.96	55.55	48.31	41.04	83.38	58.93	51.68	44.22
Soybean meal, 46.5% CP	17.43	12.12	9.34	6.57	14.29	8.95	6.17	3.48
DDGS	---	30.00	30.00	30.00	---	30.00	30.00	30.00
Wheat middlings	---	---	10.00	20.00	---	---	10.00	20.00
Monocalcium phosphate, 21% P	0.50	---	---	---	0.35	---	---	---
Limestone	0.98	1.28	1.28	1.30	0.95	1.18	1.18	1.30
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.15	0.15	0.15	0.15	0.13	0.13	0.13	0.13
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.13	0.13	0.13	0.13
L·lys HCl	0.29	0.35	0.39	0.43	0.26	0.32	0.36	0.40
DL-Met	0.02	---	---	---	0.01	---	---	---
L-Thr	0.06	---	---	---	0.04	---	---	---
Phytase[4]	0.13	0.05	0.03	0.02	0.13	0.03	0.01	---
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculate analysis								
Standardized ileal digestible (SID) AA, %								
Lys	0.86	0.87	0.86	0.85	0.76	0.76	0.75	0.74
Met:lys	28	34	34	34	29	37	37	37
Met & cys:lys	57	69	69	70	59	75	75	75
Thr:lys	61	64	63	61	61	67	65	64
Trp:lys	17	17	17	17	17	17	17	17
Total lys, %	0.96	1.02	1.01	0.99	0.85	0.91	0.90	0.88
ME, kcal/kg	3,334	3,351	3,314	3,276	3,347	3,358	3,320	3,278
SID Lysine:ME,g/Mcal	2.58	2.58	2.58	2.58	2.27	2.27	2.27	2.27
CP, %	15.2	18.9	18.6	18.3	14.0	17.6	17.4	17.1
Ca, %	0.55	0.55	0.55	0.56	0.50	0.50	0.50	0.55
P, %	0.45	0.45	0.51	0.56	0.41	0.44	0.49	0.55
Available P, %	0.28	0.28	0.28	0.28	0.24	0.24	0.24	0.26

[1]Phase 1 diets were fed from approximately 45 to 63.5 kg; phase 2 diets were fed from 63.5 to 81 kg.

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

[3]Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 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 600,533 FTU/kg.

Table 3.2 Phase 3 and 4 diet composition (Exp. 1, as-fed basis)[1]

	Phase 3				Phase 4			
DDGS, %:	0	30	30	30	0	30	30	30
Item, Midds, %:	0	0	10	20	0	0	10	20
Ingredient, %								
Corn	86.06	61.55	54.29	46.78	88.05	63.61	56.19	47.89
Soybean meal, 46.5% CP	11.80	6.46	3.68	1.00	9.95	4.53	1.84	0.00
DDGS	---	30.00	30.00	30.00	---	30.00	30.00	30.00
Wheat middlings	---	---	10.00	20.00	---	---	10.00	20.00
Monocalcium phosphate, 21% P	0.23	---	---	---	0.18	---	---	---
Limestone	0.98	1.13	1.14	1.29	0.95	1.08	1.15	1.28
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.08
Trace mineral premix[3]	0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.08
L·lys HCl	0.24	0.30	0.34	0.38	0.22	0.29	0.32	0.33
DL-Met	---	---	---	---	---	---	---	---
L-Thr	0.03	---	---	---	0.03	---	---	---
Phytase[4]	0.13	0.02	---	---	0.13	---	---	---
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculate analysis								
Standardized ileal digestible (SID) AA, %								
Lys	0.68	0.68	0.67	0.67	0.62	0.62	0.61	0.61
Met:lys	30	39	39	39	32	42	42	42
Met & cys:lys	62	80	80	81	65	85	85	87
Thr:lys	62	70	68	66	64	72	71	71
Trp:lys	17	17	17	17	17	17	17	17
Total lys, %	0.76	0.82	0.81	0.80	0.70	0.76	0.75	0.74
ME, kcal/kg	3,353	3,417	3,325	3,280	3,358	3,366	3,327	3,283
SID Lys:ME,g/Mcal	2.03	2.03	2.03	2.03	1.85	1.85	1.85	1.85
CP, %	13.0	16.7	16.4	16.1	12.3	15.9	15.7	15.7
Ca, %	0.48	0.48	0.48	0.54	0.45	0.45	0.48	0.53
P, %	0.37	0.43	0.48	0.54	0.35	0.42	0.48	0.53
Available P, %	0.21	0.21	0.23	0.26	0.20	0.20	0.23	0.26

[1]Phase 3 diets were fed from approximately 81 to 99 kg; phase 4 diets were fed from 99 to 122 kg

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

[3] Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 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 600,533 FTU/kg .

Table 3.3 Phase 1 and 2 diet composition (Exp. 2, as-fed basis)[1]

	Phase 1						Phase 2					
Midds, %:	0	0	0	20	20	20	0	0	0	20	20	20
Item CWG, %:	0	2.5	5	0	2.5	5	0	2.5	5	0	2.5	5
Ingredient, %												
Corn	64.85	61.25	57.41	50.46	46.88	43.06	68.00	64.26	60.61	53.48	49.81	46.14
Soybean meal, 46.5% CP	17.73	18.81	20.13	12.17	13.25	14.57	14.76	16.00	17.16	9.28	10.52	11.68
DDGS	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Wheat middlings	---	---	---	20.00	20.00	20.00	---	---	---	20.00	20.00	20.00
Choice white grease	---	2.50	5.00	---	2.50	5.00	---	2.50	5.00	---	2.50	5.00
Monocalcium P, 21% P	0.30	0.30	0.30	---	---	---	0.30	0.30	0.30	---	---	---
Limestone	1.08	1.08	1.08	1.23	1.22	1.20	1.00	1.00	0.98	1.15	1.13	1.13
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[2]	0.15	0.15	0.15	0.15	0.15	0.15	0.13	0.13	0.13	0.15	0.13	0.13
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.13	0.13	0.13	0.15	0.13	0.13
L·lys HCl	0.31	0.32	0.33	0.39	0.40	0.40	0.29	0.30	0.30	0.37	0.37	0.38
L-Thr	0.03	0.03	0.05	0.05	0.06	0.06	0.01	0.01	0.03	0.04	0.04	0.05
Phytase[4]	0.06	0.06	0.06	0.06	0.06	0.06	0.04	0.04	0.04	0.04	0.04	0.04
Total	100.0	100.0	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) AA, %												
Lys	0.93	0.96	0.99	0.91	0.94	0.97	0.84	0.87	0.90	0.82	0.85	0.88
Met:lys	30	29	28	29	29	28	31	30	30	31	30	29
Met & cys:lys	61	59	58	61	59	58	64	62	61	64	63	61
Thr:lys	62	62	62	62	62	62	62	62	62	62	62	62
Trp:lys	17	17	17	17	17	17	17	17	17	17	17	17
Total lys, %	1.06	1.10	1.13	1.03	1.06	1.10	0.97	1.00	1.03	0.94	0.97	1.00
ME, kcal/kg	3,344	3,457	3,571	3,274	3,386	3,501	3,351	3,463	3,578	3,278	3,393	3,508
SID Lys:ME/Mcal	2.78	2.78	2.78	2.78	2.78	2.78	2.51	2.51	2.51	2.51	2.51	2.51
CP, %	18.15	18.36	18.66	17.61	17.82	18.12	17.01	17.27	17.52	16.50	16.77	17.01
Ca, %	0.55	0.55	0.55	0.55	0.55	0.55	0.51	0.51	0.51	0.51	0.51	0.51
P, %	0.47	0.47	0.47	0.52	0.52	0.51	0.46	0.46	0.46	0.51	0.50	0.50
Available P, %	0.28	0.28	0.28	0.28	0.28	0.28	0.25	0.25	0.25	0.25	0.25	0.25

[1] Phase 1 diets were fed from approximately 45 to 63.5 kg. Phase 2 diets were fed from 63.5 to 81.6 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 sulphate, 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) provided600,533 FTU/kg.

Table 3.4 Phase 3 and 4 diet composition (Exp. 2, as-fed basis)[1]

		Phase 3						Phase 4					
	Midds,%:	0	0	0	20	20	20	0	0	0	20	20	20
Item	CWG, %:	0	2.5	5	0	2.5	5	0	2.5	5	0	2.5	5
Ingredient, %													
Corn		70.82	67.30	63.74	56.42	52.94	49.30	73.61	70.20	66.77	59.10	55.66	52.11
Soybean meal, 46.5% CP		12.04	13.04	14.12	6.51	7.48	8.60	9.35	10.27	11.19	3.95	4.87	5.91
DDGS		15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Wheat middlings		---	---	---	20.00	20.00	20.00	---	---	---	20.00	20.00	20.00
Choice white grease		---	2.50	5.00	---	2.50	5.00	---	2.50	5.00	---	2.50	5.00
Monocalcium P, 21% P		0.30	0.30	0.30	---	---	---	0.30	0.30	0.30	---	---	---
Limestone		1.00	1.00	0.98	1.13	1.13	1.13	0.98	0.95	0.95	1.10	1.10	1.10
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[2]		0.10	0.10	0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix[3]		0.10	0.10	0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.08	0.08	0.08
L·lys HCl		0.27	0.27	0.28	0.35	0.35	0.36	0.25	0.25	0.26	0.32	0.33	0.33
L-Thr		0.01	0.02	0.02	0.03	0.04	0.05	---	0.01	0.01	0.02	0.03	0.04
Phytase[4]		0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Total		100.0	100.0	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) AA, %													
Lys		0.75	0.78	0.80	0.74	0.76	0.79	0.67	0.69	0.71	0.65	0.68	0.70
Met:lys		33	32	31	33	32	31	35	34	33	35	34	33
Met & cys:lys		68	66	64	68	66	65	73	71	69	74	71	69
Thr:lys		64	64	64	64	64	64	65	65	65	65	65	65
Trp:lys		17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
Total lys, %		0.87	0.90	0.93	0.85	0.87	0.90	0.78	0.81	0.83	0.76	0.78	0.80
ME, kcal/kg		3,353	3,468	3,580	3,283	3,397	3,510	3,358	3,472	3,585	3,280	3,399	3,514
SID Lys:ME/Mcal		2.24	2.24	2.24	2.24	2.24	2.24	1.99	1.99	1.99	1.99	1.99	1.99
CP, %		15.96	16.14	16.34	15.44	15.60	15.82	14.92	15.07	15.21	14.44	14.59	14.78
Ca, %		0.50	0.50	0.50	0.50	0.50	0.50	0.48	0.48	0.48	0.48	0.48	0.48
P, %		0.45	0.45	0.45	0.50	0.49	0.49	0.44	0.44	0.43	0.49	0.48	0.48
Available P, %		0.23	0.23	0.23	0.23	0.23	0.23	0.22	0.22	0.22	0.22	0.22	0.22

[1]Phase 3 diets were fed from approximately 81.6 to 100 kg; Phase 4 diets were fed from 100 to 122 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 complete diet: 19.8 mg Mn from manganese oxide, 82.6 mg Fe from iron sulfate, 82.6 mg Zn from zinc oxide, 8.3 mg Cu from copper sulfate, 0.15 mg I from calcium iodate, and 0.15 mg Se from sodium selenite.
[3]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.

[4]Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO.) provided 600,533 FTU/kg.

Table 3.5 Analysis of DDGS and Midds (Exp. 1, as-fed basis)[1]

Nutrient,%	DDGS[1]	Midds[2]
DM	90.98	89.72
CP	27.0 (27.7)[3]	14.7 (15.9)
Crude fat	11.0 (10.7)	3.8 (4.2)
Crude fiber	9.7 (7.3)	8.2 (7.0)
ADF	12.8	11.4
NDF	24.1	32.0
Ca	0.32 (0.20)	0.32 (0.12)
P	0.78 (0.77)	1.09 (0.93)
Indispensible Amino acids, %		
Arg	1.24	1.11
His	0.80	0.45
Ile	1.08 (1.03)	0.53 (0.53)
Leu	3.26 (2.57)	1.03 (1.06)
Lys	0.84 (0.62)	0.72 (0.57)
Met	0.53 (0.50)	0.24 (0.26)
Phe	1.38	0.64
Thr	1.03 (0.94)	0.53 (0.51)
Trp	0.21 (0.25)	0.20 (0.20)
Val	1.47 (1.30)	0.77 (0.75)

[1]DDGS (Hawkeye Gold, Menlo, IA) amino acid values from Stein (2007).
[2]Wheat middlings (Archer-Daniels-Midland Co.; Lincoln, NE) nutrient and amino acid values from NRC, 1998.
[3]Values in parentheses indicate those used in diet formulation.

Table 3.6 Analysis of DDGS and Midds (Exp.2, as-fed basis)

Nutrient, %	DDGS[1]	Midds[2]
DM	91.3	90.4
CP	27.7 (27.7)[3]	14.6 (15.9)
Crude fat	11.0 (10.7)	3.9 (4.2)
Crude fiber	9.5 (7.3)	8.4 (7.0)
ADF	11.0	10.2
NDF	27.1	34.0
Ca	0.15 (0.20)	0.14 (0.12)
P	0.80 (0.77)	1.00 (0.93)

[1]Dried distillers grains with solubles from Abengoa; York, NE.
[2]Wheat middlings from Archer-Daniels-Midland Co.; Lincoln, NE.
[3]Values in parenthesis indicate those used in diet formulation.

Table 3.7 Bulk density of experimental diets (Exp.1, as-fed basis)[123]

		Treatments			
	DDGS, % :	0	30	30	30
Bulk density, g//L	Midds, %:	0	0	10	20
Phase 1[4]		---	---	---	---
Phase 2		638	609	554	480
Phase 3		658	621	511	532
Phase 4		645	613	584	528

[1] 576 pigs (TR4 × 1050, PIC Hendersonville, TN; 45.4 kg initial BW) were used in this 84-d study with 8 pigs per pen and 9 pens per treatment.
[2]Bulk density of a material represents the mass per unit volume.
[3]Diet samples collected from each feeder and combined for a single composite sample by treatment and phase.
[4]Phase 1 was d 0 to 20; Phase 2 was d 20 to 36; Phase 3 was d 36 to 52; Phase 4 was d 52 to 84.

Table 3.8 Bulk density of experimental diets (Exp.2, as-fed basis)[123]

		Treatments					
	Midds, % :	0	0	0	20	20	20
Bulk density, g//L	CWG, %:	0	2.5	5.0	0	2.5	5.0
Phase 1[4]		660	639	639	584	557	551
Phase 2		656	635	635	542	538	533
Phase 3		659	659	658	533	525	522
Phase 4		665	663	663	560	551	557

[1] 288 pigs (TR4 × 1050: PIC Hendersonville, TN; 42.3 kg initial BW) were used in this 87-d study with 8 pigs per pen and 6 replications per diet.
[2]Bulk density of a material represents the mass per unit volume.
[3]Diet samples collected from each feeder and combined for a single composite sample by treatment and phase.
[4]Phase 1 was d 0 to 21; Phase 2 was d 21 to 41; Phase 3 was d 41 to 60; Phase 4 was d 60 to 87.

Table 3.9 Effects of Midds and DDGS in finishing diets on growth performance, carcass characteristics, and carcass fat quality (Exp. 1)[1]

						Probability, *P* <		
							Midds	
DDGS, %:	0	30	30	30				
Item, Midds, %:	0	0	10	20	SEM	DDGS[2]	Linear	Quadratic
Initial wt, kg	46.6	46.6	46.6	46.6	0.60	0.97	0.96	1.00
D 0 to 84								
ADG, kg	1.051	1.038	1.005	0.991	0.014	0.51	0.02	0.57
ADFI, kg	3.22	3.11	3.10	3.09	0.046	0.12	0.68	0.95
G:F	0.327	0.333	0.324	0.322	0.003	0.11	0.004	0.32
Final wt, kg	134.9	133.8	131.0	129.8	1.50	0.61	0.07	0.65
Carcass characteristics								
Carcass yield,[3] %	74.2	73.4	72.7	72.1	0.27	0.03	0.003	0.94
HCW, kg	100.1	98.1	95.3	93.6	1.12	0.22	0.008	0.65
Backfat depth,[4] mm	24.8	22.9	24.0	21.9	0.58	0.01	0.24	0.02
Loin depth,[4] mm	61.2	61.5	59.9	60.0	0.56	0.73	0.06	0.17
FFLI[4, 5]	48.2	49.3	48.6	49.8	0.34	0.02	0.29	0.01
Jowl fat iodine value	70.6	76.5	76.0	77.4	0.56	<0.001	0.29	0.19

[1]A total of 288 pigs (TR4 × 1050, PIC Hendersonville, TN) were used in an 84-d trial with 8 pigs per pen and 9 replications per diet.

[2]Contrast control vs. 30% DDGS with 0% Midds diet.

[3]Percentage yield was calculated by dividing HCW by live weight obtained before transport to the packing plant.

[4]Data analyzed by using HCW value as a covariate.

[5]FFLI=fat-free lean index

Table 3.10 Interactions of Midds and CWG on finishing-pig growth performance, carcass characteristics and carcass fat quality (Exp. 2)[1]

	Midds, %:	0	0	0	20	20	20		Probability, *P* <
Item,	CWG, %:	0	2.5	5.0	0	2.5	5.0	SEM	CWG × Midds
Initial wt, kg		42.3	42.4	42.3	42.3	42.3	42.3	1.3	1.00
D 0 to 87									
ADG, kg		1.052	1.049	1.084	0.988	0.983	1.040	0.013	0.64
ADFI, kg		3.06	3.03	3.04	3.07	2.97	3.00	0.046	0.76
G:F		0.344	0.347	0.357	0.322	0.332	0.347	0.004	0.33
Final wt, kg		133.8	135.2	136.9	128.2	128.9	132.8	2.2	0.87
Carcass characteristics									
Carcass yield,[2] %		73.3	73.9	73.4	72.8	72.9	72.8	0.41	0.82
HCW, kg		98.0	99.8	100.5	93.4	94.0	96.7	1.80	0.84
Backfat depth,[3] mm		21.3	22.7	22.2	20.0	20.3	21.8	0.72	0.35
Loin depth,[3] mm		65.4	64.0	64.1	61.6	61.0	62.9	0.69	0.14
FFLI[3,4]		50.6	49.7	50.0	51.1	50.9	50.1	0.42	0.41
Jowl iodine value		71.6	72.4	72.3	73.8	73.7	75.1	0.34	0.12

[1]288 pigs (TR4 × 1050, PIC Hendersonville, TN) were used in an 87-d study with 8 pigs per pen and 6 replications per diet.
[2] Percentage yield was calculated by dividing HCW by live weight obtained before transport to the packing plant.

[3]Data analyzed by using HCW value as a covariate.

[4]FFLI=fat-free lean index.

Table 3.11 Main effects of dietary Midds and CWG on finishing pig growth performance, carcass characteristics and carcass fat quality (Exp. 2)[1]

	Midds, %		CWG, %			Midds	CWG	Main effects		Added CWG	
Item	0	20	0	2.5	5	SEM	SEM	Midds	CWG	Linear	Quadratic
Initial wt, kg	42.3	42.3	42.3	42.3	42.3	0.75	0.92	0.98	1.00	0.98	0.978
D 0 to 87											
ADG, kg	1.062	1.004	1.020	1.016	1.062	0.008	0.009	<0.0001	0.002	0.003	0.03
ADFI, kg	3.04	3.01	3.07	3.00	3.02	0.027	0.033	0.40	0.31	0.29	0.28
G:F	0.349	0.334	0.333	0.339	0.352	0.002	0.003	<0.0001	0.0001	<0.0001	0.32
Final wt, kg	135.3	130.0	131.0	132.1	134.8	1.24	1.52	0.005	0.21	0.09	0.64
Carcass characteristics											
Carcass yield,[2] %	73.5	72.8	73.0	73.4	73.1	0.23	0.29	0.04	0.67	0.86	0.39
HCW, kg	99.5	94.7	95.7	96.9	98.6	1.04	1.27	0.003	0.29	0.12	0.89
Back fat,[3] mm	22.1	20.7	20.6	21.5	22.0	0.42	0.49	0.04	0.16	0.06	0.77
Loin depth,[3] mm	64.5	61.8	63.5	62.5	63.5	0.41	0.47	0.0001	0.22	1.00	0.08
FFLI,[3,4]	50.1	50.7	50.8	50.3	50.0	0.24	0.28	0.11	0.13	0.05	0.65
Jowl iodine value	72.1	74.2	72.7	73.1	73.7	0.20	0.24	<0.0001	0.02	0.005	0.66

[1] 288 pigs (TR4 × 1050: PIC Hendersonville, TN) were used in an 87-d study with 8 pigs per pen and 6 replications per diet.
[2]Percentage yield was calculated by dividing HCW by live weight obtained before transport to the packing plant.
[3]Data analyzed by using HCW value as a covariate.

[4]FFLI=fat-free lean index.

Chapter 4 - Effects of standardized ileal digestible (SID) tryptophan:lysine in diets containing 30% dried distiller grains with solubles (DDGS) on finishing pig performance and carcass traits

ABSTRACT

Two experiments were conducted to determine the effects of standardized ileal digestible (SID) Trp:Lys in grow-finish swine diets containing 30% DDGS. Within each experiment, crystalline Lys and Trp replaced soybean meal to alter the dietary SID Trp:Lys concentration while maintaining minimum ratios of other AA's to Lys. In Exp. 1, 638 pigs (36.3 kg BW) were used in a 105-d trial (6 pens per treatment). Pens of pigs were randomly allotted to 1 of 4 dietary treatments with SID Trp:Lys of 14.0, 15.0, 16.5, and 18.0%. From d 0 to 42, ADG (quadratic, $P < 0.05$) and ADFI (quadratic, $P < 0.07$) increased with no changes in G:F as Trp:Lys increased. Both ADG and ASFI were maximized at Trp:Lys 16.5%. From d 42 to 105, increasing SID Trp:Lys increased (linear; $P < 0.001$) ADG and ADFI. Unlike data from d 0 to 42, the response was linear through the highest SID Trp:Lys of 18.0%. Overall (d 0 to 105), increasing SID Trp:Lys increased (linear; $P < 0.001$) final BW, ADG, ADFI, and HCW. In Exp. 2, 1,214 pigs (66.3 kg initial BW) were used in a 73-d finishing trial (9 pens per treatment). Pens of pigs were randomly allotted to 1 of 5 dietary treatments with SID Trp:Lys of 15.0, 16.5, 18.0 and 19.5, and the 15.0% Trp:Lys diet with L-Trp added to achieve 18.0% SID Trp:Lys. Overall (d 0 to 73), ADG, ADFI, G:F, and final BW improved (linear, $P < 0.03$) as dietary SID Trp:Lys increased through 19.5%. There were no differences in growth performance between the two diets containing 18.0% SID Trp:Lys. For carcass traits, increasing SID Trp:Lys resulted in increased HCW (linear, $P < 0.01$) and a tendency for a decreased quadratic ($P < 0.09$) response in backfat

depth and FFLI, with pigs fed diets containing 16.5 and 18.0% SID Trp:Lys having increased FFLI and lower backfat depth compared to pigs fed 15.0 and 19.5% SID Trp:Lys. Additionally, there was also a tendency for pigs fed the diet with added crystalline Trp to have increased ($P <$ 0.09) backfat depth and decreased FFLI ($P < 0.08$) compared to pigs fed the same SID Trp:Lys without crystalline Trp. The results indicated the optimal SID Trp:Lys was 16.5% from 36.3 to 72.6 kg, but at least 19.5% from 72.6 to 120.2 kg in corn-soybean meal diets containing 30% DDGS.

Key words: DDGS, amino acids, growth

INTRODUCTION

Increased ethanol production from corn in the United States has prompted the increased use of biofuel by-products such as dried distillers grains with solubles (DDGS; Stein and Shurson, 2009) in swine diets. Determining the proper nutritional value and optimum utilization of this alternative feedstuff is critical to maintain performance. Tryptophan can be a concern when feeding corn by-products because corn protein is low in this amino acid. Thus, as the inclusion of dietary DDGS increases in corn-soybean meal diets, Trp becomes the second limiting amino acid because the low Trp concentration of corn is magnified (Stein, 2007).

The majority of research conducted regarding Trp to date, has utilized corn–soybean meal diets, with very little published research regarding Trp:Lys ratio in diets containing DDGS. The optimal Trp:Lys level in diets has not been consistent in published literature. Using Trp and Lys requirements in the NRC (1998), the SID Trp:Lys ratio calculates to 18 to 19% for growing-finishing pigs. Susenbeth (2006) and Quant et al. (2007) reported growing pig (approximately 25 to 50 kg BW) diets required a Trp:Lys ratio of 17%. Additionally, Kendell et al. (2007) found the SID Trp:Lys requirement is no greater that 17% in late finishing (90 to 125 kg) diets. Hinson et al. (2010) reported that 16% Trp:Lys ratio was adequate for diets with 30% DDGS (27 to 117 kg BW pigs). Thus, an improved understanding of the optimum Trp:Lys becomes increasingly important as more DDGS and crystalline AA inclusion in commercial diets continues to increase.

Therefore, the objective of these experiments were to determine the effects of increasing standardized ileal digestible (SID) Trp:Lys in grow-finish pig diets containing 30% DDGS.

MATERIALS AND METHODS

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

Two experiments were conducted to evaluate the effects of increasing SID Trp:Lys ratio in grow-finish pig (Line 1050 × 337; PIC Hendersonville, TN) diets on growth performance and carcass characteristics. Both experiments were conducted in a 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. Each pen (5.5 × 3.0 m) was equipped with a 5-hole stainless steel dry self-feeder (STACO, Inc., Schaefferstown, PA) and a cup waterer for ad libitum access to 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. Prior to the start of each trial, pigs were fed a common corn-soybean meal-based grower diets that contained DDGS and met or exceeded NRC (1998) nutrient estimates.

Experiment 1

A total of 638 pigs (initially 36.3 kg BW) were used in a 105-d growing-finishing trial to evaluate the effects of SID Trp:Lys in diets containing 30% DDGS on growth performance and carcass traits. Pigs were sorted by gender (barrow or gilt) and stocked initially with 26 to 27 pigs per pen. Pens of pigs were randomly allotted to 1 of 4 treatment groups with average pig weight per pen balanced across treatments with 6 pens per treatment (3 pens of gilts and 3 pens of barrows). All diets were fed in meal form and treatments were fed in 4 phases. Dietary treatments included corn-soybean meal-based diets containing 30% DDGS with soybean meal replacing crystalline Lys and Thr to achieve SID Trp:Lys ratios of 14.0, 15.0, 16.5, and 18.0%. In addition, Trp:LNAA and Trp:BCAA were calculated for each treatment by phase (Tables 4.1 and 4.2).. All AAs were formulated to levels at or above their estimates, in order to ensure Trp was first limiting. All dietary treatments were formulated to contain similar dietary ME and SID Lys concentrations within each phase. Additionally, L-Thr was added to the two diets with lowest Trp:Lys.

Diet samples were collected from feeders during every phase. After they were transported to Kansas State University, diet samples were stored in a freezer (-20°C) until a subsample of phase 1 and 2 diets were sent for analysis for AA concentrations. Complete AA and CP analysis were performed by Ajinimoto Heartland LLC (Chicago, IL; AOAC, 2000).

Pens of pigs were weighed and feed disappearance was measured on d 0, 21, 42, 63, 76, 95, and 105 to calculate ADG, ADFI, and G:F. 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 date.

On d 76, the 3 heaviest pigs from each pen (determined visually) were weighed and sold in accordance with the farm’s normal marketing procedure. At the end of the experiment, pigs were individually tattooed according to gender and pen number to allow for carcass data collection and data retrieval by pen.

On d 105, pigs were transported (approximately 290.5 km) to JBS Swift and Company (Worthington, MN) processing plant for data collection. Standard carcass criteria of percent yield, HCW, backfat depth, and loin depth were collected. Hot carcass weights were measured immediately after evisceration, and yield was calculated as HCW divided by BW. Fat depth and loin depth were measured with an optical probe inserted between the 3rd and 4th rib from the last rib (counting from the ham end of the carcass) and 7 cm from the dorsal midline of the hot carcass. Fat-free lean index was calculated according to National Pork Producers Council (2000) procedures.

Experiment 2

A total of 1,214 pigs (initially 66.3 kg) were used in a 73-d finishing trial. Pens were mixed gender and stocked initially with 25 to 28 pigs per pen, maintaining approximately an equal number of barrows and gilts within pens. Pens of pigs were balanced by average BW and randomly allotted to 1 of 5 treatment groups with 9 pens per treatment. All diets were fed in meal form. Pigs were fed common diets from approximately 36 to 66 kg BW. These diets were formulated to contain 30% DDGS with a SID Trp:Lys of 18%. Dietary treatments were fed in 3 phases and included corn-soybean meal-based diets with SID Trp:Lys of 15.0, 16.5, 18.0, 19.5% and the 15.0% diet with added L-Trp to achieve 18.0% SID Trp:Lys. In addition, Trp:LNAA and Trp:BCAA were calculated by phase (Tables 4.3 and 4.4). All dietary treatments were formulated to contain similar dietary ME and SID Lys concentrations within each phase. Similar to the first experiment, all AAs were formulated at or above their estimates in order to ensure Trp was the first limiting AA. The last diet of 15.0% Trp:Lys with the addition of L-Trp to increase the Trp level to 18.0%, was formulated in order to validate that tryptophan was the first limiting amino acid. Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN) was added in phase 3 diets. Hence, increased SID Lys levels were used in the last dietary phase.

Diet samples were collected from the feeders during every phase. After they were transported to Kansas State University, diet samples were stored in a freezer (-20°C) until a subsample of each diet was sent for analysis for amino acid concentrations. Complete amino acid, free Lys, free Thr, and CP analysis was performed by Ajinimoto Heartland LLC (Chicago, IL; AOAC, 2000).

Pens of pigs were weighed and feed disappearance was measured on d 0, 20, 33, 47, 62, and 73 to determine ADG, ADFI, and G:F. Feed intake and G:F were determined from the feed delivery data generated through the automated feeding system and the amount of feed remaining in each pen's feeder on each weigh date.

On d 47 of the experiment, the 3 heaviest pigs from each pen (2 barrows and 1gilt; determined visually) were weighed and sold in accordance with the farm's normal marketing procedure. At the end of the experiment, pigs were individually tattooed according to pen number to allow for carcass data collection and data retrieval by pen.

On d 73, pigs were transported (approximately 290 km) to JBS Swift and Company (Worthington, MN) processing plant. Standard carcass criteria of percentage carcass yield, HCW, backfat depth, and loin depth, with fat-free lean index were calculated. Hot carcass weights were measured immediately after evisceration, and yield was calculated as HCW divided by BW at both the farm and the plant. Carcass trait measurements were collected as in Exp. 1.

Statistical analysis

Both Exp. 1 and Exp. 2 data were analyzed as a completely randomized design with pen as the experimental unit. Analysis of variance was performed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). In both experiments, because there were differences in HCW, it was used as a covariate for backfat depth, loin depth, and fat-free lean index. In Exp. 1, the effect of gender and gender by treatment interactions were tested. Linear and quadratic contrasts were used to determine the effects of treatments with increasing Trp:Lys. Contrast coefficients for Trp:Lys (14.0, 15.0, 16.5, and 18.0%) were determined for unequally spaced treatments by using the IML procedure of SAS. In Exp. 2, contrast coefficients were used to evaluate linear and quadratic responses to Trp:Lys (15.0, 16.5, 18.0, and 19.5%) and to compare the two diets containing 18.0 Trp. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

RESULTS

Chemical Analysis

Diet analysis verified levels of free Lys and Thr, and CP to be similar to dietary formulated values for Exp.1 and Exp. 2. In both of the current studies, AA values for corn and soybean meal were obtained from NRC (1998) with Stein (2007) amino acid values used for DDGS, as DDGS from our source have been thoroughly tested and found to be similar in nutrient profile.

Experiment 1

Gender differences in growth performance were as expected, with barrows having greater ($P < 0.001$) ADG and ADFI than gilts (Table 4.5). Both barrows and gilts had improved ADG as SID Trp:Lys increased; however, the magnitude of the response was slightly greater for gilts than barrows (gender × treatment interaction, $P < 0.05$). Gilt carcasses had lower ($P < 0.001$) backfat depth and greater ($P < 0.001$) FFLI than barrow carcasses.

From d 0 to 42, there was increased ADG (quadratic, $P < 0.05$) and a tendency for increased ADFI (quadratic, $P < 0.07$) with no changes in G:F as Trp:Lys increased. From d 42 to 105, increasing SID Trp:Lys increased (linear, $P < 0.001$) ADG and ADFI. Unlike data from d 0 to 42, where the response plateued at 16.5% Trp:Lys, the response was linear through the highest SID Trp:Lys of 18.0%. There was a tendency for a quadratic effect in G:F ($P < 0.10$) of increasing SID Trp:Lys, with pigs fed 15.0 and 16.5% having numerically worse G:F than pigs fed either 14.0 or 18.0%.

Overall (d 0 to 105), increasing SID Trp:Lys increased (linear, $P < 0.001$) final BW, ADG, and ADFI, but G:F was not influenced ($P > 0.20$). For carcass characteristics, pigs fed increasing SID Trp:Lys had heavier (linear, $P < 0.001$) HCW with no effects on other carcass parameters ($P > 0.11$).

Experiment 2

Overall (d 0 to 73), ADG, ADFI, G:F, and final BW improved (linear, $P < 0.03$) as dietary SID Trp:Lys increased through 19.5% (Table 4.6). There were no differences in growth performance between pigs fed the two diets with 18.0% SID Trp:Lys regardless of whether the ratio was obtained by adding soybean meal or L-Trp. For carcass traits, increasing SID Trp:Lys resulted in increased HCW (linear, $P < 0.01$) and a tendency for a quadratic effect ($P < 0.09$) for backfat depth and FFLI (quadratic, $P < 0.09$), with pigs fed diets containing 16.5 and 18.0% SID Trp:Lys having increased FFLI and lower backfat depth compared to pigs fed 15.0 and 19.5% SID Trp:Lys. Additionally, there was a tendency for pigs fed the diet containing crystalline Trp to have increased ($P < 0.08$) backfat depth and decreased FFLI ($P < 0.10$) compared to pigs fed the same SID Trp:Lys ratio without crystalline Trp.

DISCUSSION

Tryptophan plays a key role in several biological pathways which lead to a variety of end products. In addition to protein synthesis, Trp is closely associated with the kynurenine pathway, which is responsible for a large portion of Trp catabolism as well as regulation of immune responses (Sainio et al., 1996). Furthermore, a smaller proportion of the Trp supply serves as a precursor for serotonin; an important neuromediator associated with the regulation of a variety of biological responses such as appetite, sleep, and stress (Wolf, 1974; Sève, 1999; Kerr et al., 2002).

Serotonin cannot cross the blood brain barrier and therefore, its precursor's Trp or 5-hydroxytryptamine (5–HT) must be transported across the blood brain barrier in order to increase the serotonin levels in the brain. Tryptophan and other large neutral amino acids (LNAA∶ Ile, Leu, Phe, Tyr, and Val) must use the same non-specific L-type amino acid transport system in order to cross the blood brain barrier. Therefore, excess amounts of LNAA compete with Trp for transport across the blood brain barrier, and ultimately decrease hypothalamic serotonin concentrations (Henry et al., 1992; Kerr et al., 2002; LeFloc'h and Sève, 2007). The Trp:Lys in both diets and blood plasma are important for the transport of Trp across the blood brain barrier. An increase in this ratio should indicate increased Trp crossing into the brain (Henry et al, 1992; Sève, 1999; Kerr et al., 2002).

Diet composition can directly affect plasma amino acid concentrations and thus Trp transport across the blood brain barrier. Generally, consumption of carbohydrate–rich diets may indirectly increase plasma Trp levels due to an accompanying release of insulin by the body.

Insulin stimulates uptake of LNAA by the peripheral tissues (therefore reducing plasma LNAA levels), which increases the plasma Trp:LNAA ratio and enables adequate Trp to transport across the blood brain barrier.

Including high levels of dietary DDGS in the current studies, provided approximately 3 times the crude fat, protein, and fiber as corn, with a similar energy value. The high CP of DDGS compared to corn incorporates more LNAA into the diet. Consumption of high dietary levels of DDGS can decrease the Trp:LNAA, and once again, lowering the Trp availability to the brain as a result of the increased competition with LNAAs to cross the blood brain barrier (Lyons and Truswell, 1988; Kerr et al., 2002).

In addition to containing more LNAA's, DDGS are also high in the essential amino acids of Met and Thr, which have also been demonstrated to have negative effects on Trp uptake by the brain (Sainio et al., 1996; Sève, 1999; Kerr et al., 2002). The positive response to the increased Trp:Lys was primarily an increase in voluntary feed intake, with subsequent improvement in ADG, G:F, and final BW. Past research has also reported tryptophan to have an influence on feed intake (Russell et al., 1983; Sève et al., 1991; Batterham et al., 1994). The compounded effects of high CP, Met, and Thr, with a Trp deficient diet may further decrease the plasma Trp:LNAA ratio and consequently feed intake (Henry et al., 1992). Decreased brain Trp concentrations ultimately result in lower concentrations of serotonin in the hypothalamus, and a common side effect from this condition is anorexia (Eder et al., 2003). This would support our data where ADFI was decreased in both experiments as the Trp:Lys decreased in diets with 30% DDGS. Feed intake can be restored to normal levels by feeding a diet adequate in Trp, which is supported by our data.

There has been much research attempting to define the optimal Trp:Lys level in corn-soybean meal diets. Lorschy and Patience (45 to 75 kg BW; 1999) and Jansman and Van Diepen (9 to 24 kg BW; 2005) reported optimum Trp:Lys of 19% and 23.1% SID Trp:Lys, respectively. Both of these requirements being above the calculated SID Trp:Lys of 18% from the NRC (1998) and the requirement conclusions from Susenbeth (2006) and Quant et al. (2009) who reported an optimum Trp:Lys of 17% for finishing pigs. Additionally, Kendall et al. (2007) reported that the optimum SID Trp:Lys ratio was no less than 14.5%, but not greater than 17.0% in late finishing (90 to 125 kg) diets. The gender differences measured in Exp.1 agree with Henry et al. (1992), in that gilts had a greater response in ADG to increased dietary Trp in high protein diets compared to barrows.

Very limited research is available on the optimum Trp:Lys for growing finishing pigs fed DDGS. Ma et al. (2010) conducted three experiments with finishing pigs fed SID Lys levels (0.95%, 0.81%, and 0.73%, respectively), with increasing levels of high protein DDGS (0 to 23.7% HPDDGS) used to titrate six different treatments increasing the SID Trp:lys level. They indicated the optimum SID Trp levels were 0.14, 0.11, and 0.11% for pigs from 45 to 64 kg, 70 to 93 kg, and 95 to 115 kg fed diets containing high level of high protein-DDG. Hinson et al. (2010), also conducted 3 experiments in order to determine the optimum SID Trp:Lys in 27 to 45, 67 to 85, and 96 to 117 kg pigs consuming 30% DDGS. However, they increased crystalline L-Trp in order to increase the dietary SID Trp:Lys ratio. They concluded from their data that 16% Trp:Lys was adequate in finishing pig diets containing 30% DDGS. Data from our first trial agrees with Hinson et al. (2010) in that Trp:Lys of approximately 16 to 16.5% was sufficient in growing pig diets, however, 16% Trp:Lys did not meet the requirement of finishing pigs above 73 kg BW.

There are certain aspects of Trp requirements to consider when formulating diets. The DDGS level in the diet will affect the LNAA level and, therefore, levels of DDGS below 30% may not require as high amounts of dietary Trp. Ratios of Trp:LNAA reaching approximately 3.1% or below may start to impact growth performance. Additionally, withdrawing DDGS at the end of the finishing period, in order to reduce the negative impact of DDGS on carcass yield and fat quality, has been shown to be effective (Xu et al., 2009). Thus, lowering dietary DDGS during the late finishing period may prevent excess LNAAs competing with Trp to cross the blood brain barrier.

Additionally, the SID Lys and SBM level should be taken into consideration when formulating finishing diets with high levels of DDGS. Paylean was added in the last phase of the second trial and when doing so, no response to increased Trp:Lys was reported in that phase. When adding Paylean, the SBM level is increased and therefore, the amino acid profile is shifted. Therefore, diets with increased levels of SID Lys or SBM, such as Ma et al. (2010), may not see the same effect to increasing SID Trp:Lys.

Data from these experiments indicate grow-finish pigs fed 30% DDGS require16.5% Trp:Lys from 36 to 70 kg and at least 19.5% Trp:Lys for pigs approximately 70 to 130 kg BW. Additionally, feeding L-Trp resulted in similar growth performance to pigs fed a diet formulated to the same SID Trp:Lys without L-Trp. More research is needed to fully evaluate the role of large natural amino acids on the optimum Trp:Lys in grow-finish diets containing high levels of DDGS.

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FIGURES AND TABLES

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

	Phase 1				Phase 2			
	Trp:Lys, %				Trp:Lys, %			
Item	14.0	15.0	16.5	18.0	14.0	15.0	16.5	18.0
Ingredient, %								
Corn	57.34	55.79	53.23	50.79	59.49	57.93	55.72	53.46
Soybean meal, 46.5% CP	10.30	11.96	14.69	17.26	8.19	9.85	12.22	14.60
DDGS[2]	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Limestone	1.15	1.14	1.12	1.10	1.17	1.16	1.14	1.12
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
VTM premix[3]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
L-Thr	0.07	0.04	---	---	0.06	0.04	---	---
Liquid Lys, 60%	0.68	0.61	0.50	0.39	0.64	0.57	0.47	0.37
Phytase[5]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis								
Standardized ileal digestible (SID) AA, %								
Lys	0.95	0.95	0.95	0.95	0.87	0.87	0.87	0.87
Ile:lys	60	63	67	72	61	64	69	73
Leu:lys	174	178	185	191	184	189	195	202
Met:lys	30	31	32	34	32	33	34	35
Met & cys:lys	61	63	66	68	65	66	69	72
Thr:lys	62	62	62	65	64	64	63	67
Trp:lys	14.0	15.0	16.5	18.0	14.0	15.0	16.5	18.0
Val:lys	74	77	82	86	77	80	84	89
Trp:LNAA	3.2	3.3	3.4	3.6	3.0	3.1	3.4	3.5
Trp:BCAA	4.5	4.7	4.9	5.2	4.3	4.5	4.7	5.0
Total lys, %	1.10	1.11	1.11	1.12	1.02	1.02	1.03	1.03
ME, kcal/kg	3,362	3,362	3,362	3,362	3,362	3,362	3,362	3,362
SID lys:ME, g/Mcal	2.83	2.83	2.83	2.83	2.59	2.59	2.59	2.59
CP, %	17.87	18.49	19.52	20.50	17.07	17.69	18.58	19.49
Ca, %	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
P, %	0.44	0.45	0.46	0.47	0.44	0.44	0.45	0.46
Available P, %	0.32	0.32	0.32	0.32	0.28	0.28	0.28	0.28

[1]Phase 1 diets were fed from approximately 36 to 54 kg; Phase 2 diets were fed from 54 to 73 kg.
[2]Dried distillers grains with solubles from Vera-Sun (Aurora, SD).
[3]Provided per kg of premix: 4,509,409 IU vitamin A; 701,464 IU vitamin $D_{3;}$ 24,050 IU vitamin E; 1,402 mg vitamin K; 12,025 pantothenic acid; 18,037 mg niacin; 3,006 mg vitamin B_2 and 15,031 mg vitamin B_{12}, 40,084 mg Mn from manganese oxide, 90,188 mg Fe from iron sulfate, 100,209 Zn from zinc oxide, 10,021 mg Cu from copper sulfate, 501 mg I from Ethylenediamin dihydroiodide, and 300 mg Se from sodium selenite.
[4]OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 2,700 FTU per kg of diet.

Table 4.2 Phase 3 and 4 diet composition (Exp. 1; as-fed basis)[1]

	Phase 3				Phase 4			
	Trp:Lys, %				Trp:Lys, %			
Item	14.0	15.0	16.5	18.0	14.0	15.0	16.5	18.0
Ingredient,%								
Corn	61.99	60.64	58.53	56.51	64.43	63.20	61.43	59.51
Soybean meal, 46.5% CP	5.79	7.22	9.47	11.61	3.41	4.71	6.61	8.63
DDGS[2]	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Limestone	1.14	1.14	1.12	1.10	1.15	1.14	1.12	1.11
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
VTM premix[3]	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
L-Thr	0.05	0.03	---	---	0.05	0.03	---	---
Liquid Lys, 60%	0.59	0.53	0.43	0.34	0.54	0.48	0.40	0.32
Phytase[4]	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis								
Standardized ileal digestible (SID) AA, %								
Lys	0.78	0.78	0.78	0.78	0.69	0.69	0.69	0.69
Ile:lys	63	66	71	75	65	69	73	78
Met:lys	34	35	36	38	37	38	39	40
Met & cys:lys	69	71	74	76	75	77	79	82
Thr:lys	66	66	66	70	69	69	69	73
Trp:lys	14.0	15.0	16.5	18.0	14.0	15.0	16.5	18.0
Val:lys	80	83	88	93	85	88	93	98
Trp:LNAA	2.9	3.0	3.1	3.3	2.7	2.8	2.9	3.1
Trp:BCAA	4.1	4.3	4.5	4.7	3.8	4.0	4.2	4.4
Total lys, %	0.92	0.92	0.93	0.94	0.83	0.83	0.83	0.84
ME, kcal/kg	3,364	3,364	3,364	3,364	3,364	3,364	3,364	3,364
SID lys:ME, g/Mcal	2.32	2.32	2.32	2.32	2.05	2.05	2.05	2.05
CP, %	16.16	16.69	17.54	18.36	15.25	15.74	16.45	17.23
Ca, %	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
P, %	0.43	0.43	0.44	0.45	0.42	0.42	0.43	0.44
Available P, %	0.24	0.24	0.24	0.24	0.23	0.23	0.23	0.23

[1]Phase 3 diets were fed from approximately 73 to 91 kg; Phase 4 diets were fed from 91 to 109 kg.
[2] Dried distillers grains with solubles from Vera-Sun (Aurora, SD).
[3]Provided per kg of premix: 4,509,409 IU vitamin A; 701,464 IU vitamin D_3; 24,050 IU vitamin E; 1,402 mg vitamin K; 12,025 pantothenic acid; 18,037 mg niacin; 3,006 mg vitamin B_2 and 15,031 mg vitamin B_{12}, 40,084 mg Mn from manganese oxide, 90,188 mg Fe from iron sulfate, 100,209 Zn from zinc oxide, 10,021 mg Cu from copper sulfate, 501 mg I from Ethylenediamin dihydroiodide, and 300 mg Se from sodium selenite.
[4]OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 2,700 FTU per kg of diet.

Table 4.3 Common diets and Phase 1 diet composition (Exp. 2; as-fed basis)[1]

Item	Common diets		Phase 1 Trp:Lys, % 15.0	16.5	18.0	19.5	15.0 to 18.0 with L-Trp
Ingredient, %							
Corn	51.50	54.09	60.71	58.66	56.58	54.51	60.68
Soybean meal, 46.5% CP	16.42	13.84	7.05	9.26	11.46	13.67	7.05
DDGS[2]	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Limestone	1.12	1.14	1.14	1.12	1.10	1.08	1.14
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35
VTM premix[3]	0.10	0.10	0.09	0.09	0.09	0.09	0.09
L-Thr	---	---	0.03	---	---	---	0.03
L-Trp	---	---	---	---	---	---	0.02
Biolys[4]	0.50	0.47	0.63	0.52	0.41	0.30	0.63
Phytase[5]	0.01	0.01	0.003	0.003	0.003	0.003	0.003
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis							
Standardized ileal digestible (SID) AA, %							
Lys	0.95	0.87	0.78	0.78	0.78	0.78	0.78
Ile:lys	71	72	66	71	75	80	66
Met:lys	33	35	35	36	37	39	35
Met & cys:lys	68	71	71	74	77	79	71
Thr:lys	65	66	65	66	70	74	65
Trp:lys	18.0	18.0	15.0	16.5	18.0	19.5	18.0
Val:lys	85	88	84	88	93	98	84
Trp:LNAA	3.5	3.4	3.0	3.1	3.3	3.4	3.6
Trp:BCAA	5.1	4.9	4.3	4.5	4.7	4.9	5.1
Total lys, %	1.12	1.03	0.92	0.93	0.94	0.94	0.92
ME, kcal/kg	3,364	3,364	3,369	3,366	3,366	3,364	3,369
SID lys:ME, g/Mcal	2.82	2.59	2.32	2.32	2.32	2.32	2.32
CP, %	20.55	19.55	17.09	17.84	18.61	19.38	17.11
Ca, %	0.51	0.51	0.48	0.48	0.48	0.48	0.48
P, %	0.47	0.46	0.43	0.44	0.45	0.46	0.43
Available P, %	0.33	0.27	0.24	0.24	0.25	0.25	0.24

[1]Common diets were fed from 36 to 68 kg; Phase 1 diets were fed from 68 to 91 kg.
[2]Dried distillers grains with solubles from Vera-Sun (Aurora, SD).
[3]Provided per kg of premix: 4,509,409 IU vitamin A; 701,464 IU vitamin D_3; 24,050 IU vitamin E; 1,402 mg vitamin K; 12,025 pantothenic acid; 18,037 mg niacin; 3,006 mg vitamin B_2 and 15,031 mg vitamin B_{12}, 40,084 mg Mn from manganese oxide, 90,188 mg Fe from iron sulfate, 100,209 Zn from zinc oxide, 10,021 mg Cu from copper sulfate, 501 mg I from Ethylenediamin dihydroiodide, and 300 mg Se from sodium selenite.
[4]Biolys® contains 50.7% L-lys (Evonik Degussa GmbH, Hanau, Germany).
[5]OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided 2,700 FTU per kg of diet.

Table 4.4 Phase 2 and 3 diet composition (Exp. 2; as-fed basis)[1]

	Phase 2					Phase 3				
	Trp:Lys, %					Trp:Lys, %				
Item	15.0	16.5	18.0	19.5	15.0 to 18.0 with L-Trp	15.0	16.5	18.0	19.5	15.0 to 18.0 with L-Trp
Ingredient, %										
Corn	63.26	61.48	59.59	57.80	63.24	69.33	66.83	64.47	62.13	69.30
Soybean meal, 46.5% CP	4.58	6.48	8.49	10.39	4.58	13.13	15.79	18.35	20.85	13.14
DDGS[2]	30.00	30.00	30.00	30.00	30.00	15.00	15.00	15.00	15.00	15.00
Limestone	1.13	1.12	1.10	1.08	1.13	1.10	1.12	1.10	1.08	1.10
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
VTM premix[3]	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
DL-met	---	---	---	---	---	0.02	0.01	---	---	0.02
L-Thr	0.02	---	---	---	0.02	0.10	0.07	0.03	---	0.10
L-Trp	---	---	---	---	0.02	---	---	---	---	0.03
Biolys[4]	0.58	0.48	0.38	0.29	0.58	0.65	0.52	0.39	0.27	0.65
Phytase[5]	0.002	0.002	0.002	0.002	0.002	0.01	0.01	0.01	0.01	0.01
Ractopamine HCl[6]	---	---	---	---	---	0.025	0.025	0.025	0.025	0.025
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) AA, %										
Lys	0.69	0.69	0.69	0.69	0.69	0.90	0.90	0.90	0.90	0.90
Ile:lys	68	73	78	83	68	60	65	69	74	60
Met:lys	38	39	40	42	38	30	31	31	32	30
Met & cys:lys	77	80	83	85	77	60	62	64	66	60
Thr:lys	68	69	73	77	68	66	66	65	66	66
Trp:lys	15.0	16.5	18.0	19.5	18.0	15.0	16.5	18.0	19.5	18.0
Val:lys	89	93	98	103	89	73	77	82	87	73
Trp:LNAA	2.8	2.9	3.1	3.2	3.4	3.5	3.7	3.8	3.9	4.2
Trp:BCAA	4.0	4.2	4.4	4.6	4.8	5.1	5.3	5.5	5.7	6.1

Total lys, %	0.83	0.83	0.84	0.84	0.83	1.02	1.03	1.04	1.04	1.02
ME, kcal/kg	3,369	3,369	3,366	3,366	3,369	3,360	3,358	3,355	3,353	3,360
SID lys:ME, g/Mcal	2.05	2.05	2.05	2.05	2.05	2.68	2.68	2.68	2.68	2.68
CP, %	16.11	16.76	17.46	18.12	16.12	16.65	17.54	18.40	19.26	16.67
Ca, %	0.47	0.47	0.47	0.47	0.47	0.49	0.50	0.50	0.50	0.49
P, %	0.42	0.43	0.44	0.45	0.42	0.39	0.40	0.41	0.42	0.39
Available P, %	0.23	0.23	0.24	0.24	0.23	0.21	0.21	0.21	0.21	0.21

[1]Phase 2 diets were fed from 91 to 109 kg; Phase 3 diets were fed from 109 to 127 kg.
[2]Dried distillers grains with solubles from Vera-Sun (Aurora, SD).
[3]Provided per kg of premix: 4,509,409 IU vitamin A; 701,464 IU vitamin $D_{3;}$ 24,050 IU vitamin E; 1,402 mg vitamin K; 12,025 pantothenic acid; 18,037 mg niacin; 3,006 mg vitamin B_2 and 15,031 mg vitamin B_{12}, 40,084 mg Mn from manganese oxide, 90,188 mg Fe from iron sulfate, 100,209 Zn from zinc oxide, 10,021 mg Cu from copper sulfate, 501 mg I from Ethylenediamin dihydroiodide, and 300 mg Se from sodium selenite.
[4]Biolys® contains 50.7% L-Lys (Evonik Degussa GmbH, Hanau, Germany).
[5]Optiphos2000 (Enzyvia LLC, Sheridan, IN) provided 2,700 FTU per kg of diet.
[6]Ractopamine HCL (Paylean, Elanco Animal Health, Greenfield, IN) 9.0 g/ton was added.

Table 4.5 Effects of increasing SID Trp:Lys on growth performance of growing-finishing pigs (Exp. 1)[1]

	SID Trp:Lys, %				TRT	Gender		Gender	Probability, $P<$		
Item	14.0	15.0	16.5	18.0	SEM	Barrows	Gilts	SEM	Gender	Linear	Quadratic
Initial wt, kg	36.2	36.3	36.4	36.3	0.85	36.0	36.6	0.60	0.47	0.96	0.88
d 42 wt, kg	69.0	71.4	73.4	73.3	1.31	71.9	71.6	0.93	0.79	0.03	0.27
Final wt, kg	117.3	120.4	125.0	129.7	1.35	125.2	121.0	0.95	0.01	<0.0001	0.99
d 0 to 42											
ADG, kg	0.781	0.834	0.880	0.876	0.017	0.85	0.83	0.012	0.24	0.001	0.05
ADFI, kg	1.79	2.01	2.04	2.07	0.051	2.01	1.95	0.036	0.28	0.003	0.07
G:F	0.436	0.416	0.432	0.425	0.010	0.43	0.43	0.007	0.80	0.77	0.63
d 42 to 105											
ADG, kg	0.799	0.816	0.852	0.912	0.010	0.87	0.82	0.007	<0.0001	<0.0001	0.18
ADFI, kg	2.59	2.75	2.89	3.02	0.050	2.95	2.67	0.035	<0.0001	<0.0001	0.40
G:F	0.309	0.297	0.295	0.303	0.006	0.30	0.31	0.004	0.11	0.54	0.10
d 0 to 105											
ADG, kg	0.792	0.824	0.864	0.897	0.007	0.86	0.82	0.01	<0.0001	<0.0001	0.43
ADFI, kg	5.22	5.66	5.87	6.05	0.112	5.91	5.49	0.08	0.002	<0.0001	0.15
G:F	0.152	0.146	0.148	0.148	0.003	0.15	0.15	0.002	0.18	0.52	0.20
Carcass characteristics											
Carcass yield[2], %	73.9	73.6	73.8	73.8	0.28	73.5	74.1	0.25	0.10	0.98	0.72
HCW, kg	86.9	88.7	93.4	95.1	1.20	92.7	89.3	1.04	0.02	0.0001	0.60
Backfat depth[3], mm	15.6	16.2	16.9	16.5	0.47	18.5	14.1	0.39	<0.0001	0.23	0.12
Loin depth[3], mm	62.6	61.8	61.3	61.3	1.14	61.3	62.2	0.95	0.41	0.46	0.58
FFLI[3,4]	50.7	50.6	50.6	50.9	0.16	49.8	51.6	0.14	<0.0001	0.37	0.29

[1] A total of 638 pigs (PIC 1050 × 337) were used in a 105-d growing-finishing trial with 26 to 27 pigs per pen and 6 pens per treatment.
[2]Percentage yield was calculated by dividing HCW by live weight obtained prior to transport to the packing plant.
[3]Data analyzed by using HCW value as a covariate.

[4]FFLI=fat-free lean index.

Table 4.6 Effects of increasing Trp:Lys ratio on growth performance and carcass characteristics of finishing pigs (Exp. 2) [1]

	SID Trp:Lys, %						Probability, *P*<		
Item	15.0	16.5	18.0	19.5	L-Trp to 18.0	SEM	Linear	Quadratic	L-Trp to 18.0
Initial wt, kg	66.3	66.4	66.2	66.3	66.4	1.48	0.96	0.99	0.96
Final wt, kg	118.2	120.0	122.7	123.8	121.3	1.76	0.02	0.85	0.57
D 0 to 73									
ADG, kg	0.734	0.756	0.792	0.811	0.776	0.010	<0.0001	0.87	0.25
ADFI, kg	2.42	2.43	2.51	2.53	2.44	0.040	0.03	0.91	0.25
G:F	0.304	0.312	0.316	0.322	0.318	0.004	0.002	0.73	0.72
Carcass characteristics									
Farm yield, %	74.8	74.9	73.8	75.3	74.1	0.40	0.76	0.08	0.59
Carcass yield[2], %	75.3	75.5	75.1	75.0	75.0	0.42	0.52	0.67	0.86
HCW, kg	88.4	89.8	90.6	93.0	89.9	1.26	0.01	0.71	0.67
Backfat depth[3], mm	15.8	15.3	15.0	15.9	16.0	0.45	0.96	0.09	0.08
Loin depth[3], mm	58.6	60.5	58.6	58.9	59.5	0.80	0.80	0.29	0.39
FFLI[3,4]	50.7	51.2	51.2	51.0	50.8	0.21	0.42	0.09	0.10

[1]A total of 1,214 pigs (PIC 1050 × 337) were used in a 73-d finishing trial, with 25 to 28 pigs per pen and 9 pens per treatment.
[2]Percentage yield was calculated by dividing HCW by live weight obtained prior to transport to the packing plant.
[3]Data analyzed by using HCW value as a covariate.

[4]FFLI=fat-free lean index.

Appendix A - Dietary Amino Acid Analysis from SID Tryptophan:Lysine Ratio Experiments

Table A.1 Phase 1 and 2 diet total amino acids analysis (Exp. 1, as-fed basis)[1]

	Phase 1				Phase 2			
	SID Trp:Lys, %				SID Trp:Lys, %			
	14.0	15.0	16.5	18.0	14.0	15.0	16.5	18.0
CP, %	17.9	18.2	19.3	20.0	17.4	18.2	18.0	20.0
Indispensable AA								
Arg	0.94	1.02	1.11	1.06	0.94	1.00	1.02	1.19
His	0.47	0.52	0.54	0.51	0.48	0.52	0.51	0.55
Ile	0.71	0.74	0.76	0.74	0.69	0.73	0.70	0.82
Leu	1.84	1.87	1.95	1.92	1.80	1.88	1.86	2.04
Lys	1.10	1.10	1.13	1.04	1.06	1.07	1.08	1.11
Met	0.33	0.34	0.35	0.36	0.32	0.34	0.34	0.37
Phe	0.89	0.93	0.99	1.28	0.87	0.93	0.93	1.04
Thr	0.72	0.72	0.74	0.74	0.70	0.74	0.73	0.78
Trp	0.18	0.19	0.20	0.22	0.18	0.19	0.20	0.22
Val	0.83	0.87	0.92	0.99	0.81	0.87	0.86	0.97

Dispensable AA								
Ala	1.11	1.14	1.20	1.21	1.09	1.12	1.14	1.21
Asp	1.42	1.51	1.65	1.75	1.38	1.50	1.49	1.76
Cys	0.29	0.30	0.31	0.32	0.29	0.30	0.30	0.33
Glu	3.04	3.19	3.39	3.49	2.98	3.19	3.16	3.59
Gly	0.69	0.74	0.78	0.79	0.67	0.72	0.71	0.80
Pro	1.51	1.53	1.63	1.41	1.27	1.19	1.23	1.36
Ser	0.85	0.89	0.95	0.96	0.83	0.88	0.87	1.00
Tyr	0.55	0.55	0.60	0.65	0.55	0.57	0.57	0.62

[1]Diet samples were analyzed by Ajinimoto Heartland LLC (Chicago, IL).

Table A.2 Phase 1, 2, and 3 total amino acids analysis (Exp. 2, as-fed basis)[1,2]

	Phase 1					Phase 2					Phase 3				
	Trp:Lys, %					Trp:Lys, %					Trp:Lys, %				
Item,%	15.0	16.5	18.0	19.5	L-Trp to 18.0	15.0	16.5	18.0	19.5	L-Trp to 18.0	15.0	16.5	18.0	19.5	L-Trp to 18.0
DM	88.24	88.12	87.52	87.74	88.24	88.74	87.94	87.72	87.82	88.63	88.09	88.40	87.96	87.49	87.57
CP	14.96	N/A	15.99	20.11	14.80	15.10	16.42	16.88	18.32	15.03	14.37	15.57	15.56	15.95	14.77
Indispensable AA															
Arg	0.72	0.82	0.81	1.02	0.75	0.76	0.84	0.87	0.98	0.74	0.80	0.90	0.90	0.95	0.83
His	0.39	0.45	0.41	0.50	0.39	0.40	0.42	0.43	0.47	0.40	0.38	0.41	0.41	0.42	0.38
Ile	0.55	0.61	0.59	0.77	0.56	0.57	0.62	0.63	0.71	0.57	0.56	0.62	0.63	0.64	0.57
Leu	1.52	1.64	1.57	1.91	1.54	1.58	1.66	1.68	1.81	1.55	1.39	1.46	1.46	1.50	1.44
Lys	0.84	0.91	0.82	0.94	0.79	0.86	0.87	0.86	0.89	0.83	0.92	0.95	0.89	0.87	0.93
Met	0.24	0.26	0.25	0.30	0.20	0.25	0.26	0.26	0.29	0.26	0.22	0.23	0.23	0.24	0.24
Phe	0.71	0.79	0.76	0.94	0.75	0.74	0.79	0.81	0.89	0.75	0.70	0.76	0.78	0.80	0.75
Thr	0.57	0.61	0.59	0.73	0.57	0.60	0.62	0.63	0.70	0.57	0.61	0.66	0.63	0.62	0.62
Trp	0.15	0.19	0.17	0.17	0.18	0.16	0.19	0.21	0.25	0.18	0.19	0.16	0.22	0.22	0.20
Val	0.71	0.76	0.74	0.98	0.80	0.76	0.78	0.79	0.88	0.81	0.69	0.74	0.74	0.77	0.71
Free lys	0.33	0.25	0.22	0.17	0.27	0.31	0.27	0.23	0.15	0.30	0.33	0.26	0.18	0.13	0.32
Free thr	0.05	0.03	0.02	0.02	0.05	0.05	0.02	0.02	0.02	0.05	0.10	0.10	0.05	0.03	0.12

Dispensable AA															
Ala	0.95	1.02	0.98	1.16	0.91	0.99	1.04	1.04	1.12	0.95	0.86	0.90	0.89	0.92	0.77
Asp	1.05	1.18	1.17	1.53	1.13	1.10	1.21	1.25	1.42	1.16	1.15	1.30	1.33	1.37	1.36
Cys	0.26	0.28	0.27	0.34	0.27	0.27	0.29	0.29	0.31	0.27	0.24	0.26	0.26	0.27	0.26
Glu	2.40	2.64	2.58	3.21	2.53	2.50	2.68	2.75	3.03	2.57	2.37	2.58	2.60	2.69	2.57
Gly	0.56	0.61	0.60	0.72	0.48	0.59	0.63	0.64	0.71	0.51	0.56	0.61	0.61	0.64	0.44
Pro	0.00	1.22	1.17	1.48	0.60	1.22	1.21	1.24	1.36	0.62	1.03	1.14	1.03	1.10	0.00
Ser	0.69	0.75	0.73	0.92	0.66	0.72	0.76	0.78	0.86	0.67	0.69	0.74	0.74	0.77	0.67
Tyr	0.43	0.48	0.46	0.51	0.46	0.45	0.49	0.49	0.51	0.46	0.42	0.45	0.45	0.45	0.44

[1]Diet samples were analyzed by Ajinimoto Heartland LLC (Chicago, IL).