THE EVALUATION OF SORGHUM DRIED DISTILLER'S GRAINS WITH SOLUBLES IN NURSERY PIG DIETS, ON FINISHING PIG PERFORMANCE AND MEAT QUALITY, AND ON LACTATING SOW PERFORMANCE

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Abstract

Five experiments were conducted to determine the effects of sorghum dried distiller's grains with solubles (DDGS) on nursery pig performance, finishing pig performance and meat quality, and lactating sow and litter performance. Experiment 1 established a nutrient database and evaluated the quality and consistency of five ethanol plants in the Western Plains region. Each sample was analyzed for AA, DM, CP, crude fiber, crude fat, ash, NDF, ADF, Ca, P, trace minerals, GE, and starch. In addition, DE, ME, and NE were calculated. Experiments 2 and 3 evaluated the effects of sorghum DDGS on nursery pig performance. In Exp. 2, pigs fed sorghum- or corn-based diets performed similarly; however, as sorghum DDGS increased ADG decreased (linear, $P < 0.01$). A DDGS×grain source interaction (quadratic, $P = 0.03$) was observed for G:F. In corn-based diets, G:F was identical for pigs fed 0 to 30% DDGS, but worsened in pigs fed 45% DDGS. In sorghum-based diets, G:F was best for those fed 0% DDGS, but worsened at higher levels. In Exp. 3, pigs fed corn- or sorghum-based diets performed similarly; however, pigs fed DDGS gained less ($P < 0.03$) than those fed basal diets. Experiment 4 evaluated the effects of sorghum DDGS in sorghum- or corn-based diets on finishing pig growth performance, carcass characteristics, and fat quality. Increasing sorghum DDGS reduced (linear; $P < 0.01$) ADG and increased (linear; $P < 0.01$) backfat IV. Pigs fed the sorghum-based diet with 30% sorghum DDGS had decreased backfat IV ($P < 0.01$) than those fed the sorghum-based diet with corn DDGS. Experiment 5 evaluated the effects of sorghum DDGS on lactating sow and litter performance. Overall, ADFI increased in corn-based diets when DDGS were added, but decreased in sorghum-based diets resulting in a tendency ($P < 0.08$) for a DDGS × grain source interaction. Pig weaning weights were lower ($P < 0.06$) for sows fed diets containing DDGS compared with those fed the basal diets. Adding sorghum DDGS reduced pig performance, and sow lactation performance; therefore, its inclusion in swine diets needs to be evaluated on an income over feed cost basis.

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Chapter 2 - Nutrient analysis of sorghum dried distiller's grains with solubles from ethanol plants in the western plains region and their effects on nursery pig performance

ABSTRACT

Samples of sorghum dried distiller's grains with solubles (DDGS) were collected and analyzed to establish a nutrient database and evaluate the quality and consistency between and within 5 ethanol plants in KS or TX. Each sample (n=21) was analyzed for AA, DM, CP, crude fiber, crude fat, ash, NDF, ADF, Ca, P, Zn, Mn, Cu, Fe, GE, and starch. Mean values (DM) were: 0.88% Lys, 10.49% crude fat, 34.21% CP and 4,722 kcal/kg GE. The standard deviations among sorghum DDGS plants were similar to that within plants for most nutrients. Results of these analyses were used to formulate diets for 2 nursery trials.

Two experiments were conducted to determine the effects of sorghum DDGS (29.0% CP; 7.2% crude fat) added to corn- or sorghum-based diets on nursery pig growth performance. In Exp. 1, 360 nursery barrows (6.8 kg and 26 d of age) were allotted to 1 of 8 dietary treatments with 5 pigs per pen and 9 pens per treatment in a 34-d study. Treatments were arranged in a 2 × 4 factorial with main effects of grain source (corn vs. sorghum) and sorghum DDGS (0, 15, 30, or 45%). The diets were formulated to 1.30% and 1.25% standardized ileal digestibility (SID) Lys in phases 2 and 3, respectively but were not balanced for energy. There were no differences among pigs fed sorghum- or corn-based diets for ADG and ADFI; however, as sorghum DDGS increased from 0 to 45% of the diet, ADG decreased (linear, $P < 0.01$). As sorghum DDGS increased in corn-based diets, G:F was identical for pigs fed 0, 15, and 30% DDGS, but worsened in pigs fed 45% DDGS (grain source × DDGS interaction $P < 0.05$). In sorghum-based diets, G:F was best for those fed 0% DDGS, but worsened in pigs fed 15, 30, or 45% DDGS. In Exp. 2, 180 nursery pigs (10.7 kg and 38 d of age) were used in a 21-d study with 6 pigs per pen and 5 pens per treatment. Treatments were arranged in a 2 × 3 factorial with main effects of grain source (corn vs. sorghum) and DDGS (0 vs. 30% corn DDGS; 28.9% CP; 9.8% crude fat, or 30% sorghum DDGS; 25.7% CP; 8.7% crude fat). Diets were formulated to 1.27% SID and were not balanced for energy. Overall, pigs fed sorghum- or corn-based diets had similar ADG.

Pigs fed sorghum or corn DDGS had similar ADG. Pigs fed diets with 30% DDGS gained less ($P < 0.03$) than pigs fed basal diets. These results suggest sorghum can be a suitable replacement for corn in nursery pig diets, however, increasing sorghum DDGS decreased ADG.

Key Words: corn, dried distiller's grains with solubles, nursery pigs, nutrient analysis, sorghum

INTRODUCTION

Dried distiller's grains with solubles (DDGS) are a by-product of ethanol production commonly added to swine diets to lower feed costs. However, concern about consistency and quality variation among ethanol plants presents challenges to swine nutritionists in using DDGS in diet formulation. Dried distiller's grains with solubles also tend to have low Lys and Trp concentrations, limiting the inclusion rate (Spiehs et al., 2002). Quality of DDGS depends upon crop selection, fermentation type, and drying temperature and duration (Spiehs et al., 2002). While most of the information gathered to date has focused on corn DDGS, little information exists regarding sorghum DDGS from the Great Plains region.

Producers from Texas to South Dakota have grown sorghum for many years due to its ability to thrive in drought conditions. This large production of sorghum accompanied by the rapid increase in demand for grain for ethanol production has resulted in greater availability of sorghum DDGS in this geographical area.

Sorghum has an energy value of 96% that of corn and can be a complete replacement for corn in swine diets (Carter et al., 1989); however in many recent trials, low-tannin sorghum with proper feed processing and diet formulation has been shown to result in equal pig performance to corn-based diets (Shelton et al., 2004; Issa, 2009; Benz et al., 2011). Although a large amount of information is known about the nutritional value of sorghum grain, little is known about the ethanol by-product, sorghum DDGS. With an increased amount of sorghum DDGS available, more research needs to be conducted to determine its impact on pig growth performance. Thus, the objectives of these studies were to determine the nutrient content of Great Plains sorghum DDGS and to compare corn-vs. sorghum-based diets to determine the effects of increasing sorghum DDGS on nursery pig growth performance.

MATERIALS AND METHODS

General

All practices and procedures used in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. Experiment 1 was conducted at the Kansas State University Segregated Early Weaning Facility. Experiment 2 was conducted at the Kansas State University Swine Teaching and Research Center, Manhattan.

Sorghum nutrient analysis

A total of 21 samples of sorghum DDGS were collected from 5 plants in the Western Plains Region (KS=4, TX=1) between May and June 2010. Four of the plants contributed 4 individual samples, while 1 plant contributed 5 individual samples. Of the 5 ethanol plants, 3 produced pure sorghum DDGS while 2 produced a DDGS mixture of either 60 or 70% sorghum with 40 or 30% corn. The 21 samples were then divided into subsamples for proximate and mineral composition analyses (Ward Laboratories, Kearney, NE; AOAC 975.44, 2006), AA analysis (University of Missouri-Columbia, Columbia, MO; AOAC, 2006), and particle size analysis (Kansas State University). Gross energy of the samples was determined with an adiabatic bomb calorimeter (Parr Instruments, Moline, IL). Digestible energy, ME, and NE values on a DM basis were then calculated using the following equations:

- DE kcal/kg = -174 + (0.848 × GE) + {2 × [100-(CP + EE + Ash +NDF)]} - (16 × ADF); Ewan (1989)
- ME kcal/kg = (1 × DE) - (0.68 × CP); Noblet and Perez (1993)
- NE kcal/kg = (0.726 × ME) + (13.3 × EE) + (3.9 × starch) - (6.7 × CP) - (8.7 × ADF); Noblet et al. (1994)

Descriptive statistics (Microsoft Excel 2007; Microsoft Corp., Redmond, WA) were used to calculate the mean of each plant as well as the samples within each DDGS type. Also descriptive statistics were used to calculate the standard deviation from samples within each plant, within all samples of each DDGS type, and across plants.

Experiment 1

A total of 360 nursery barrows (1050, PIC, Hendersonville, TN) with an initial BW of 6.8 kg were used in a 34-d growth study to determine the effects of increasing sorghum DDGS on growth performance. Pigs were weaned at approximately 19 d of age at weaning and fed a common pelleted starter diet for 7 d. At weaning, pigs were allotted to pens by initial BW to achieve the same average weight for all pens. Pigs were randomly allotted to 1 of 8 treatments on d 7 post-weaning. Thus, d 7 post-weaning is d 0 of the experiment. There were 5 pigs per pen and 9 pens per treatment. Each pen (1.5 × 1.5 m) had metal slatted floors, one 5-hole self-feeder, and a nipple waterer. Throughout the study, the pigs had ad libitum access to feed and water.

Treatments were arranged in a 2 × 4 factorial with main effects of grain source (corn vs. sorghum) and sorghum DDGS (0, 15, 30, or 45%). The diets were formulated using sorghum and corn nutrient values derived from NRC (1998; Table 1.1). Standardized ileal digestibility (SID) values for the sorghum DDGS were derived from Urriola et al. (2009). The SID values for the corn DDGS were derived from Stein et al. (2007). Other nutrient values for the sorghum DDGS were derived from previous analysis of sorghum DDGS samples collected from the ethanol plant where the sorghum DDGS were used for this study (White Energy, Russell, KS). The sorghum grain used in this study was a red pericarp variety, and the corn grain used was #2 Yellow dent. The corn DDGS used were golden brown, and the sorghum DDGS were slightly darker than the corn DDGS in visual color. Pigs were fed either corn-soybean meal- or sorghum-soybean meal-based diets containing increasing sorghum DDGS (0, 15, 30, or 45%) in 2 phases (d 0 to 14 and d 14 to 34; Tables 1.2 and 1.3, respectively). All pigs and feeders were weighed on d 0, 14, and 34 to determine response criteria for ADG, ADFI, and G:F.

Experiment 2

A total of 180 nursery pigs (Line 327 × 1050, PIC, Hendersonville, TN) with an initial BW of 10.7 kg were used in a 21-d trial to determine the effects of grain and DDGS source on growth performance. At weaning, pigs were approximately 21 d of age and fed a common mash starter diet for 17 d. Similar to Exp. 1, the pigs were allotted to pens by initial BW to achieve the same average weight for all pens at weaning. Pigs were randomly allotted to 1 of 6 dietary treatments on d 17 post-weaning. Thus, d 17 post-weaning is d 0 of the experiment. There were 6 pigs per pen and 5 pens per treatment. Each pen (1.2 × 1.5 m) had woven wire flooring, one 3-hole, dry self-feeder and nipple waterer to provide ad libitum access to feed and water.

The dietary treatments were arranged in a 2 × 3 factorial with main effects of grain source (corn vs. sorghum) and DDGS (none, 30% corn DDGS, or 30% sorghum DDGS). The corn, sorghum, and sorghum DDGS nutrient values were the same as those used in Exp. 1. The sorghum DDGS used in this study was from the same plant and batch as the ones used in Exp. 1. Dietary treatments were fed for 21 d (Table 1.4). Similar to Exp. 1, all pigs and feeders were weighed on d 0, d 7, d 14, and d 21 to determine the response criteria for ADG, ADFI, and G:F.

Statistical Analysis

Data were analyzed as a completely randomized design with pen as the experimental unit in both experiments. Both experiments were analyzed using the MIXED procedure in SAS (SAS Institute, Inc., Cary, NC). For Exp. 1, contrasts were used to make comparisons between the 1) linear and quadratic interactions of DDGS × grain source, 2) corn- and sorghum-based diets, and 3) linear and quadratic effects of increasing DDGS. In Exp. 2, contrasts were used to make comparisons between the 1) interaction of DDGS × grain source, 2) corn- vs. sorghum-based diets, and 3) effects of none vs. 30% DDGS. Differences among treatments were considered significant with P-values ≤ 0.05 and trends if P-values > 0.05 and ≤ 0.10.

RESULTS AND DISCUSSION

Nutrient analysis

All nutrient values are presented on a DM basis (Tables 1.5, 1.6, 1.7 and 1.8). For the pure sorghum samples, the average DM was 89.5% with a standard deviation of 0.96% (Table 1.5). The average CP was 34.2% with a standard deviation of 3.78%. The CP in DDGS from Kansas ethanol plants was consistently between 31% and 33%, with CP from the Texas plant considerably greater at 39.1%. This could be due to the lower percentage of solubles present in the Texas DDGS sample. The Texas sample had a much lower particle size, again suggesting fewer solubles added back to the DDGS. In comparison, values from Feoli (2008) showed the average DM value for sorghum DDGS was 88.3% with the CP value of 34.1% on a DM basis (Feoli, 2008). The NRC (1998) reported the CP (converted to DM at 89%) to be 10.34% for sorghum grain. The CP of DDGS is generally 3 times higher than the CP of the grain from which it originated, thus values for the DDGS sampled in this study are generally close to this correlation.

The average crude fat content of pure sorghum DDGS was 10.49% with the standard deviation of 1.10%. The sorghum-corn DDGS samples were slightly greater in crude fat, which might be a result of the corn blended with the sorghum before fermentation. According to Feoli (2008), the average value for crude fat in sorghum DDGS was 8.61%, lower than the reported values in the present study (10.49%).

The average ADF was 26.43% with the standard deviation of 4.96%, and the average NDF was 35.07% with the standard deviation of 5.34% for the pure sorghum DDGS samples. The sorghum-corn DDGS samples had average ADF and NDF values of 22.07% (2.28) and 36.73% (1.46), respectively. Because NDF is more digestible than ADF, the sorghum-corn samples might be considered to have slightly greater digestibility than the pure sorghum DDGS samples. Stein (2007) reported the ADF and NDF of corn DDGS to be 13.48% and 44.94%, respectively. The average values for the sorghum grain (NRC, 1998) were lower for both ADF (9.33%) and NDF (20.22%) compared to the DDGS in the present study, which was expected, due to the concentration of ADF and NDF in DDGS compared to the grain from which it originated.

For AA, the average Lys content in the pure sorghum DDGS was 0.88%, while the sorghum-corn DDGS samples had a value of 0.87% (Table 1.6). Feoli (2008) reported pure sorghum DDGS had 0.97% Lys while Stein (2007) reported corn DDGS had 0.88% Lys. For sorghum grain, the NRC (1998) published a Lys value of 0.22% as fed. The average Trp and Thr values for the pure sorghum DDGS were 0.26% and 1.04%, respectively. Tryptophan was greater in concentration than Feoli (2008) value of 0.17%, but similar to Stein (2007) corn DDGS value of 0.24%. In DDGS, regardless of cereal grain source, Trp is considered limiting and generally restricts the amount of crystalline Lys that can be added to the diet. Average Met content was 0.55% for the pure sorghum DDGS and sorghum-corn DDGS samples. The samples' values were slightly lower than Feoli's (2008) sorghum DDGS of 0.59% and Stein (2007) corn DDGS value of 0.62%.

For pure sorghum DDGS, Arg (1.17%), His (0.67%), and Phe (1.48%) average values were lower than Feoli's (2008) reference values (1.35%, 0.85%, and 1.90%, respectively) for sorghum DDGS and Stein's (2007) corn DDGS reference values (1.30%, 0.81%, and 1.51%, respectively).

Dietary phosphorus concentration is important because of its cost in the diet as well as its role in land base requirements for manure application. Both corn and sorghum DDGS contain relatively high concentrations of P, which are highly available to the pig, resulting in a decreased requirement of dietary inorganic phosphorus. The average P content of the pure sorghum DDGS was 0.72%, while the content of the sorghum-corn DDGS samples was 0.74% (Table 1.7).

The average ash concentration in the pure sorghum DDGS samples was 4.42% with the Kansas region ethanol plants (5.02% and 4.93%) being greater than the Texas ethanol plant (3.32%) in this study. The composite means and standard deviations for Ca, K, Mg, S, Na, Zn, Mn, Cu, and Fe were all profiled to determine the amounts present in each sample.

The GE for the pure sorghum DDGS samples was 4,722 kcal/kg with a standard deviation of 94.2, while the GE for sorghum-corn DDGS samples was 4,825 kcal/kg with a standard deviation of 62.1 (Table 1.8). The GE values for the sorghum-corn DDGS samples were greater than those of the pure DDGS samples, which was expected because corn has a greater energy content than sorghum grain. In comparison, Feoli (2008) reported a GE value of 4,921 kcal/kg for sorghum DDGS while Stein (2007) reported 5,434 kcal/kg for corn DDGS. The calculated DE, ME, and NE for the pure sorghum DDGS samples were 3,439 kcal/kg (120.3), 3,206 kcal/kg (138.8), and 2,025 kcal/kg (174.7), respectively. The NRC (1998) reported sorghum grain values for DE at 3,799 kcal/kg, ME at 3,752 kcal/kg, and NE at 2,533 kcal/kg on a DM basis. The DE, ME, and NE for the sorghum-corn DDGS samples were 3,592 kcal/kg (37.7), 3,370 kcal/kg (43.0), and 2,216 kcal/kg (71.0), respectively (Table 1.8). The difference in energy content between sorghum grain and sorghum DDGS is wider than we would have expected. Research has shown that corn and corn DDGS have similar energy values (Pederson et al., 2007). Also, the energy value standard deviations of the pure DDGS samples were approximately double those of the sorghum-corn DDGS samples, meaning there was a larger variation in energy content within samples for the pure DDGS compared to the sorghum-corn DDGS samples.

Particle size of the pure sorghum DDGS samples varied from 447 to 843 µ, with an average of 670 µ. There was considerable range in average particle size between plants, which may have been influenced by the amount of solubles added back to the mash during drying. The average of the sorghum-corn DDGS samples was 632 µ. Particle size and DM are generally considered the two biggest contributors to the flow ability of both corn and sorghum DDGS, in which a greater moisture content and lower particle negatively affect flow ability.

The nutrient and calculated energy values established from this study for pure sorghum DDGS and sorghum-corn DDGS mixtures can now be used by swine nutritionists to more accurately formulate diets. Routine analysis of sorghum DDGS is essential to update nutrient specifications, as variability among geographic regions, crop-growing conditions, and plant manufacturing processes will influence DDGS composition.

Experiment 1

From d 0 to 14, grain source did not influence ADG or ADFI; however, ADG was reduced (linear, $P < 0.05$) as sorghum DDGS increased in the diet due to a tendency ($P = 0.07$) for decreased ADFI (interactive effects, Table 1.9; main effects, Table 1.10). A DDGS × grain source interaction (linear, $P = 0.05$) was observed for G:F. In corn-based diets, increasing sorghum DDGS had no effect on G:F, whereas increasing DDGS in sorghum-based diets tended to worsen G:F, leading to a trend (quadratic, $P = 0.09$) for poorer G:F as DDGS increased.

During phase 2 (d 14 to 34), there were no differences in ADG among pigs fed corn- or sorghum-based diets; however ADFI increased ($P < 0.04$), and G:F worsened ($P < 0.01$) for pigs fed sorghum-based diets. Increasing sorghum DDGS in the corn- and sorghum-based diets decreased ADG (linear, $P < 0.01$), worsened G:F (linear, $P < 0.01$), and had no effect on ADFI.

Overall (d 0 to 34), a quadratic DDGS × grain source interaction ($P = 0.03$) was observed for G:F. As sorghum DDGS increased in corn-based diets, G:F was identical for pigs fed 0, 15, and 30% DDGS, but worsened for those fed 45% DDGS. In sorghum-based diets, G:F was best for those fed 0% DDGS, but worsened in pigs fed 15, 30, or 45% DDGS. No differences in ADG and ADFI were found among pigs fed the corn- and sorghum-based diets; however, G:F worsened ($P < 0.05$) in the pigs fed sorghum-based diets. Increasing DDGS resulted in poorer ADG (linear, $P < 0.01$) and tended to decrease ADFI (linear, $P < 0.07$). Similar to the response for ADG, increasing DDGS resulted in decreased (linear, $P < 0.01$) final BW.

Experiment 2

Overall (d 0 to 21) there was no grain source × DDGS interaction observed for ADG, ADFI, and G:F (Table 1.11). Pigs fed diets containing either corn or sorghum DDGS had similar growth performance with no differences in final BW.

As observed in Exp. 1, ADG and ADFI were similar among pigs fed corn- or sorghum-based diets; however, no difference was observed for G:F in pigs fed corn-based diets compared with those fed sorghum-based diets (Table 1.12). Increasing DDGS from 0 to 30% reduced ($P < 0.03$) ADG, numerically worsened G:F ($P = 0.14$), and had no effect on ADFI.

Grain sorghum has been shown to be a suitable replacement for corn in nursery pig diets. In both experiments, increasing sorghum DDGS in the diet reduced ADG in a linear manner and numerically decreased ADFI. In Exp. 1, G:F was approximately 5% poorer in pigs fed sorghum-based diets vs. pigs fed corn-based diets, which is similar to the energy content differences between the two grains.

Although increasing sorghum DDGS in the diet reduced ADG, increasing sorghum DDGS in the corn-based diets worsened G:F only when fed at the 45% level. Increasing sorghum DDGS in sorghum-based diets reduced G:F in a linear manner. In Exp. 1, the quadratic reduction of G:F in pigs fed 45% DDGS agrees with the results observed by Senne et al. (1996) when diets containing 0, 15, 30, 45, or 60% sorghum DDGS were fed to weanling pigs. However, Feoli et al. (2008) reported pigs fed corn-based diets with 30% corn or sorghum DDGS had reduced ADG and poorer G:F than those fed the corn-based basal diets. Furthermore, pigs fed the corn-based diet with 30% sorghum DDGS had poorer ADG and G:F than those fed the corn-based diet with 30% corn DDGS. These results agree with Exp. 1 and 2 in regards to a decrease in nursery pig growth performance for corn- or sorghum-based diets with 30% corn or sorghum DDGS. Differences between Senne et al. (1995, 1996) and Feoli et al. (2008) findings could be due to the added fat present in the treatment structuresfor the experiments conducted by Senne et al. (1995, 1996) to make diets isocaloric. However, these differences could also be due to differences in DDGS quality or diet formulation.

As dietary sorghum DDGS increased, the linear decrease in ADG was expected due to a reduction of energy. While DDGS have a greater concentration of GE than corn or sorghum grains, the digestibility of this energy is considerably less (Pedersen et al., 2007). In a series of 11 experiments, Pedersen et al. (2007) determined the apparent total tract digestibility (ATTD) of GE to be 90.4% for corn and 76.8% for corn DDGS. Feoli (2008) reported DE values for sorghum DDGS of 3,466 kcal/kg.

In summary, the economic value of ADG and G:F must be evaluated when considering adding sorghum DDGS to nursery diets. The decrease in pig growth performance will need to be offset by a reduction in diet cost when using sorghum DDGS; therefore, its inclusion needs to be evaluated on an income over feed cost basis.

LITERATURE CITED

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FIGURES AND TABLES

Table 2.1 Formulated and analyzed nutrient composition of ingredients (as-fed basis)

	Sorghum		Corn		Sorghum DDGS		Corn DDGS	
Item	Formulated[1]	Analyzed[2]	Formulated[1]	Analyzed[2]	Formulated[1]	Analyzed[2]	Formulated[3]	Analyzed[2]
DM, %	89.00	86.12	89.00	86.22	88.64	89.64	88.50	89.00
CP, %	10.34	9.56	9.33	8.58	27.70	29.04	27.70	25.70
Crude fat, %	3.26	2.40	4.38	2.73	9.35	7.17	10.70	8.71
Crude fiber, %	---	2.03	---	2.00	8.25	5.28	---	5.62
Ash, %	---	1.50	---	1.51	4.45	4.24	---	4.23
Amino acids, %								
Cys	0.17	0.13	0.19	0.14	0.44	0.44	0.57	0.43
Ile	0.37	0.28	0.28	0.22	1.13	1.04	1.01	0.88
Leu	1.21	0.95	0.99	0.76	2.93	2.94	3.17	2.65
Lys	0.22	0.21	0.26	0.22	0.78	0.73	0.78	0.86
Met	0.17	0.12	0.17	0.13	0.42	0.39	0.55	0.47
Thr	0.31	0.24	0.29	0.22	0.86	0.85	1.06	0.87
Trp	0.10	0.06	0.06	0.05	0.22	0.15	0.21	0.18
Val	0.36	0.37	0.39	0.32	1.38	1.34	1.35	1.21

[1]Diets prepared using the formulated values derived from the NRC 1998, Nutrient requirements of swine 10th Ed. National Academy Press, Washington DC.
[2]Values represent the mean of 1 sample analyzed in duplicate.
[3]Experiment 2 diets were prepared using the formulated values derived from Stein (2007).

Table 2.2 Composition of diets, (d 0 to 14, Exp. 1, as-fed basis)[1]

	Corn				Sorghum			
	Sorghum dried distiller's grains with solubles (DDGS), %							
Item	0	15	30	45	0	15	30	45
Ingredient, %								
Corn	56.63	44.86	33.10	21.18	---	---	---	---
Sorghum	---	---	---	---	60.05	47.50	35.05	22.40
Soybean meal (46.5% CP)	25.38	22.34	19.31	16.29	21.76	19.54	17.17	14.95
Sorghum DDGS	---	15.00	30.00	45.00	---	15.00	30.00	45.00
Spray dried whey	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Select menhaden fish meal	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Monocalcium P (21% P)	0.90	0.50	0.15	---	0.85	0.50	0.13	---
Limestone	0.65	0.85	1.00	1.08	0.70	0.85	1.05	1.10
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lys HCl	0.24	0.28	0.32	0.36	0.38	0.39	0.40	0.41
DL-met	0.15	0.13	0.11	0.09	0.19	0.16	0.14	0.11
L-thr	0.11	0.09	0.08	0.06	0.14	0.12	0.10	0.08
Total	100	100	100	100	100	100	100	100
Calculated analysis								
Standardized ileal digestible amino acids, %								
Lys	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30
Ile:Lys	61	64	67	70	60	64	67	70
Met:Lys	37	36	36	36	39	38	38	37
Met & Cys:Lys	60	60	60	60	60	60	60	60
Thr:Lys	63	63	63	63	63	63	63	63
Trp:Lys	17	17	17	17	17	17	17	17
Val:Lys	68	72	76	80	66	71	75	79
Total Lys, %	1.43	1.46	1.49	1.51	1.41	1.44	1.47	1.50
CP, %	21.4	23.1	24.9	26.6	20.6	22.5	24.4	26.3
ME, kcal/kg	3,305	3,234	3,164	3,089	3,258	3,199	3,137	3,073
Ca, %	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
P, %	0.75	0.72	0.71	0.73	0.73	0.71	0.70	0.73
Available P, %	0.46	0.46	0.46	0.51	0.46	0.46	0.46	0.51

[1]Diets were fed in meal form from d 0 to 14 of the experiment, which began 7 d after weaning.
[2]Vitamin premix provided per kg of complete feed: 11,023 IU of vitamin A, 1,377 IU of vitamin D, 44.1 IU of vitamin E, 4.4 mg of vitamin K, 0.04 mg of vitamin B_{12}, 50.0 mg of niacin, 27.6 mg of pantothenic acid, and 8.3 mg of riboflavin.
[3]Trace mineral premix provided per kg of complete feed: 16.5 mg of Cu from $CuSO_4 \cdot 5H_2O$, 0.30 mg of I as $C_2H_2(NH_2)_2 \cdot 2HI$, 165 mg of Fe as $FeSO_4H_2O$, 39.7 mg of Mn as $MnSO_4 \cdot H_2O$, 0.30 mg of Se as Na_2SeO_3, and 165 mg of Zn as $ZnSO_4$.

Table 2.3 Composition of diets, (d 14 to 34, Exp. 1, as-fed basis)[1]

	Corn				Sorghum			
	Sorghum dried distiller's grains with solubles (DDGS),%							
Item	0	15	30	45	0	15	30	45
Ingredient, %								
Corn	64.23	51.27	38.45	25.63	---	---	---	---
Sorghum	---	---	---	---	65.10	52.00	38.90	25.95
Soybean meal (46.5% CP)	31.67	29.91	28.00	26.08	30.78	29.17	27.56	25.79
Sorghum DDGS	---	15.00	30.00	45.00	---	15.00	30.00	45.00
Monocalcium P (21% P)	1.63	1.25	0.88	0.50	1.58	1.20	0.85	0.48
Limestone	0.85	1.03	1.20	1.38	0.88	1.05	1.20	1.38
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lys HCl	0.36	0.36	0.35	0.37	0.39	0.38	0.38	0.38
DL-met	0.17	0.13	0.10	0.06	0.20	0.15	0.11	0.07
L-thr	0.15	0.12	0.08	0.04	0.15	0.12	0.08	0.04
Total	100	100	100	100	100	100	100	100
Calculated analysis								
Standardized ileal digestible amino acids, %								
Lys	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Ile:Lys	59	63	67	72	60	64	68	72
Met:Lys	35	33	32	31	36	34	33	31
Met & Cys:Lys	57	57	57	57	57	57	57	57
Thr:Lys	62	62	62	62	62	62	62	62
Trp:Lys	17	17	17	17	17	17	17	17
Val:Lys	65	71	77	83	66	72	78	83
Total Lys, %	1.38	1.40	1.43	1.46	1.37	1.40	1.43	1.46
CP, %	20.7	22.9	25.1	27.2	20.9	23.0	25.2	27.3
ME, kcal/kg	3,298	3,225	3,155	3,084	3,247	3,186	3,126	3,064
Ca, %	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
P, %	0.74	0.72	0.71	0.69	0.73	0.72	0.71	0.69
Available P, %	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42

[1]Diets were fed in meal form from d 14 to 34 of the experiment.
[2]Vitamin premix provided per kg of complete feed: 11,023 IU of vitamin A, 1,377 IU of vitamin D, 44.1 IU of vitamin E, 4.4 mg of vitamin K, 0.04 mg of vitamin B_{12}, 50.0 mg of niacin, 27.6 mg of pantothenic acid, and 8.3 mg of riboflavin.
[3]Trace mineral premix provided per kg of complete feed: 16.5 mg of Cu from $CuSO_4 \cdot 5H_2O$, 0.30 mg of I as $C_2H_2(NH_2)_2 \cdot 2HI$, 165 mg of Fe as $FeSO_4H_2O$, 39.7 mg of Mn as $MnSO_4 \cdot H_2O$, 0.30 mg of Se as Na_2SeO_3, and 165 mg of Zn as $ZnSO_4$.

Table 2.4 Composition of diets, (d 0 to 21, Exp. 2, as-fed basis)[1]

	Grain source					
	Corn			Sorghum		
	DDGS source and level, %					
	None	Sorghum	Corn	None	Sorghum	Corn
Item	0	30	30	0	30	30
Ingredient, %						
Corn	64.85	41.30	40.75	---	---	---
Sorghum	---	---	---	68.45	43.80	43.15
Sorghum DDGS	---	30.00	---	---	30.00	---
Corn DDGS	---	---	30.00	---	---	30.00
Monocalcium P (21% P)	1.20	0.45	0.50	0.12	0.40	0.45
Limestone	0.93	1.30	1.30	0.98	1.35	1.35
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15
L-lys HCl	0.37	0.45	0.43	0.51	0.55	0.53
DL-met	0.16	0.13	0.04	0.22	0.17	0.06
L-thr	0.13	0.11	0.05	0.18	0.13	0.08
Phytase[4]	0.08	0.08	0.08	0.08	0.08	0.08
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestibility of amino acids, %						
Lys	1.27	1.27	1.27	1.27	1.27	1.27
Ile:Lys	60	66	65	59	65	64
Met:Lys	35	35	31	39	37	32
Met & Cys:Lys	60	60	60	60	60	60
Thr:Lys	62	62	62	63	62	62
Trp:Lys	17	17	17	17	17	17
Val:Lys	67	75	75	65	73	74
Total Lys, %	1.40	1.45	1.46	1.38	1.44	1.45
CP, %	20.6	24.1	24.1	19.8	23.6	23.6
ME, kcal/kg	3,307	3,166	3,294	3,256	3,133	3,263
Ca, %	0.70	0.70	0.70	0.70	0.70	0.70
P, %	0.65	0.61	0.61	0.63	0.59	0.59
Available P, %	0.42	0.42	0.42	0.42	0.42	0.42

[1]Diets were fed in meal form from d 0 to 21 of the experiment.
[2]Vitamin premix provided per kg of complete feed: 11,023 IU of vitamin A, 1,377 IU of vitamin D, 44.1 IU of vitamin E, 4.4 mg of vitamin K, 0.04 mg of vitamin B_{12}, 50.0 mg of niacin, 27.6 mg of pantothenic acid, and 8.3 mg of riboflavin.
[3]Trace mineral premix provided per kg of complete feed: 16.5 mg of Cu from $CuSO_4 \cdot 5H_2O$, 0.30 mg of I as $C_2H_2(NH_2)_2 \cdot 2HI$, 165 mg of Fe as $FeSO_4H_2O$, 39.7 mg of Mn as $MnSO_4 \cdot H_2O$, 0.30 mg of Se as Na_2SeO_3, and 165 mg of Zn as $ZnSO_4$.
[4]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 510 FTU/kg, with release of 0.1% available P.

Table 2.5 Proximate analysis of sorghum dried distiller's grains with solubles (DDGS) from ethanol plants located in the Western Plains region (DM basis)

		Nutrient, %[7]								
Sample Origin	No. of samples	DM	CP	Fat	Ash	NFE	Crude Fiber	ADF	NDF	Starch
Pure samples[1]										
1	4	88.64	31.23	10.55	5.02	43.93	9.28	22.45	30.43	4.58
		(0.75)	(0.84)	(0.26)	(0.16)	(0.84)	(0.57)	(1.29)	(0.78)	(0.44)
2	4	89.35	32.28	11.73	4.93	40.95	10.10	23.90	33.18	4.75
		(0.35)	(0.66)	(0.21)	(0.07)	(0.75)	(0.22)	(1.49)	(1.44)	(0.61)
3	4	90.49	39.13	9.20	3.32	36.00	12.35	32.95	41.60	3.58
		(0.60)	(1.43)	(0.24)	(0.28)	(0.42)	(0.93)	(0.31)	(3.41)	(0.49)
Average	12	89.49	34.21	10.49	4.42	40.29	10.58	26.43	35.07	4.30
		(0.96)	(3.78)	(1.10)	(0.82)	(3.47)	(1.48)	(4.96)	(5.34)	(0.72)
SD among plants	3	0.93	4.29	1.26	0.96	4.00	1.59	5.69	5.82	0.63
Sorghum-corn samples										
1[2]	5	90.26	32.00	11.10	3.64	41.62	11.64	20.38	36.38	3.42
		(0.27)	(1.08)	(0.26)	(0.07)	(1.62)	(0.66)	(1.32)	(1.66)	(0.38)
2[3]	4	90.29	33.55	11.60	4.58	39.40	10.88	24.18	37.18	3.55
		(0.38)	(1.20)	(0.34)	(0.15)	(1.269)	(0.46)	(0.90)	(1.25)	(0.17)
Average	9	90.27	32.69	11.30	4.06	40.63	11.30	22.07	36.73	3.48
		(0.30)	(1.34)	(0.40)	(0.51)	(1.82)	(0.68)	(2.28)	(1.46)	(0.29)
SD among plants	2	0.03	1.10	0.35	0.67	1.57	0.54	2.68	0.56	0.09
Feoli, 2008[4]	sorghum DDGS	88.30	34.14	8.61	4.08	45.07	8.10	---	---	---
Stein, 2007[5]	corn DDGS	89.00	30.90	10.11	---	---	---	13.48	44.94	8.20
NRC, 1998[6]	sorghum grain	89.00	10.34	3.26	---	---	---	9.33	20.22	---

[1]Pure samples contain 100% sorghum DDGS.
[2]Sorghum-corn sample contained 60% sorghum and 40% corn.
[3]Sorghum-corn sample contained 70% sorghum and 30% corn.
[4]Feoli, C. Use of corn- and sorghum-based distiller's dried grains with solubles in diets for nursery and finishing pigs. *Dissertation*. Retrieved September 17, 2010 from K-State Electronic Theses, Dissertations, and Reports: 2004-Present.
[5]Stein, H. 2007. Dried distiller's grains with solubles (DDGS) in diets fed to swine. In: Swine Focus-#001. Pp. 1-8.
[6]NRC, 1998. Nutrient requirements of swine, 10th ed. Natl. Acad. Press, Washington, D.C.
[7]( ) Values in parenthesis represent the standard deviation of the mean.

Table 2.6 Essential AA concentrations for sorghum dried distiller's grains with solubles (DDGS) from ethanol plants located in the Western Plains region (DM basis)

		Amino acid, %[8]									
Sample origin	No. of samples	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val
Pure DDGS samples[1]											
1	4	1.15	0.62	1.28	3.31	0.88	0.47	1.30	0.98	0.25	1.56
		(0.05)	(0.03)	(0.08)	(0.21)	(0.04)	(0.03)	(0.08)	(0.06)	(0.01)	(0.09)
2	4	1.18	`0.67	1.32	3.61	0.93	0.62	1.41	1.02	0.25	1.63
		(0.04)	(0.02)	(0.02)	(0.08)	(0.03)	(0.21)	(0.03)	(0.03)	(0.01)	(0.03)
3	4	1.18	0.73	1.52	4.60	0.83	0.57	1.74	1.14	0.28	1.83
		(0.08)	(0.06)	(0.14)	(0.44)	(0.06)	(0.04)	(0.16)	(0.09)	(0.02)	(0.16)
Average	12	1.17	0.67	1.37	3.84	0.88	0.55	1.48	1.04	0.26	1.67
		(0.06)	(0.06)	(0.14)	(0.63)	(0.06)	(0.13)	(0.22)	(0.09)	(0.02)	(0.15)
SD among plants	3	0.02	0.05	0.13	0.67	0.05	0.08	0.23	0.08	0.01	0.14
Sorghum-corn DDGS samples											
1[2]	5	1.23	0.74	1.25	3.69	0.89	0.55	1.44	1.04	0.25	1.56
		(0.03)	(0.02)	(0.03)	(0.10)	(0.01)	(0.01)	(0.03)	(0.02)	(0.01)	(0.03)
2[3]	4	1.20	0.72	1.37	3.91	0.85	0.77	1.50	1.05	0.24	1.69
		(0.04)	(0.03)	(0.07)	(0.25)	(0.02)	(0.17)	(0.09)	(0.05)	(0.01)	(0.09)
Average	9	1.22	0.73	1.30	3.79	0.87	0.55	1.47	1.05	0.24	1.62
		(0.04)	(0.03)	(0.08)	(0.20)	(0.03)	(0.16)	(0.07)	(0.04)	(0.01)	(0.09)
SD among plants	2	0.02	0.02	0.08	0.16	0.03	0.16	0.04	0.01	0.002	0.09
Feoli, 2008[4]	sorghum DDGS	1.35	0.85	1.58	4.56	0.97	0.59	1.90	1.18	0.17	1.91
Stein, 2007[5,6]	corn DDGS	1.30	0.81	1.13	3.56	0.88	0.62	1.51	1.20	0.24	1.52
NRC, 1998[7]	Sorghum grain	0.43	0.26	0.42	1.38	0.25	0.19	0.56	0.35	0.11	0.52

[1]Pure samples contained 100% sorghum DDGS.
[2]Sorghum-corn sample contained 60% sorghum and 40% corn.
[3]Sorghum-corn sample contained 70% sorghum and 30% corn.
[4]Feoli, C. Use of corn- and sorghum-based distiller's grains with solubles in diets for nursery and finishing pigs. *Dissertation.* Retrieved September 17, 2010 from K-State Electronic Theses, Dissertations, and Reports: 2004-Present.
[5]Stein, H. Dried distiller's grains with solubles (DDGS) in diets fed to swine. 2007. In: Swine Focus-#001. pp. 1-8.
[6]Assumed DM of 89.0% for nutrient calculations.
[7]NRC, 1998 Nutrient requirements of swine 10th ed. Natl. Acad. Press, Washington D.C.
[8]( ) Values in parenthesis represent the standard deviation of the mean.

Table 2.7 Mineral composition of dried distiller's grains with solubles (DDGS) from ethanol plants located in the Western Plains region (DM basis)

		Mineral[5]									
Sample origin	No. of samples	Ca, %	P, %	K, %	Mg, %	S, %	Na, %	Zn, ppm	Mn, ppm	Cu, ppm	Fe, ppm
Pure samples[1]											
1	4	0.11	0.84	1.15	0.39	0.77	0.14	37.95	44.25	7.83	119.25
		(0.01)	(0.02)	(0.04)	(0.01)	(0.02)	(0.01)	(1.24)	(0.96)	(0.25)	(11.87)
2	4	0.07	0.87	1.17	0.42	0.54	0.12	45.58	42.75	6.53	117.00
		(0.01)	(0.02)	(0.01)	(0.01)	(0.05)	(0.01)	(0.79)	(1.89)	(0.196)	(10.23)
3	4	0.07	0.45	0.54	0.23	0.42	0.18	42.55	35.75	7.00	136.50
		(0.01)	(0.04)	(0.03)	(0.03)	(0.09)	(0.05)	(9.20)	(12.87)	(0.42)	(18.70)
Average	12	0.08	0.72	0.95	0.35	0.57	0.15	42.03	40.92	7.12	124.55
		(0.02)	(0.02)	(0.31)	(0.09)	(0.16)	(0.04)	(5.86)	(7.83)	(0.62)	(15.66)
SD among plants	3	0.02	0.24	0.36	0.10	0.18	0.03	3.84	4.54	0.66	10.67
Sorghum-corn samples											
1[2]	5	0.05	0.68	0.81	0.28	0.57	0.04	41.00	21.60	4.82	92.60
		(0.03)	(0.02)	(0.01)	(0.01)	(0.04)	(0.01)	(0.78)	(1.52)	(0.52)	(6.91)
2[3]	4	0.06	0.82	1.07	0.37	0.47	0.11	57.88	43.50	7.05	12.25
		(0.01)	(0.02)	(0.03)	(0.01)	(0.01)	(0.01)	(1.58)	(2.52)	(0.44)	(14.86)
Average	9	0.06	0.74	0.93	0.32	0.53	0.07	48.50	31.33	5.81	106.22
		(0.02)	(0.07)	(0.14)	(0.05)	(0.06)	(0.04)	(8.96)	(11.69)	(1.26)	(19.18)
SD among plants	2	0.01	0.09	0.18	0.07	0.07	0.05	11.93	15.49	1.58	21.67
NRC, 1998[4]	Sorghum grain	0.03	0.33	0.39	0.17	0.09	0.01	16.85	17.05	5.68	51.14

[1]Pure samples contained 100% sorghum DDGS.
[2]Sorghum-corn sample contained 60% sorghum and 40% corn.
[3]Sorghum-corn sample contained 70% sorghum and 30% corn.
[5]NRC, 1998 Nutrient requirements of swine, 10th ed. Natl. Acad. Press, Washington D. C.
[5]( ) Values in parenthesis represent the standard deviation of the mean.

Table 2.8 Energy concentration and particle size of sorghum dried distiller's grains with solubles (DDGS) from ethanol plants located in the Western Plains region (DM basis)

		Energy, kcal/kg[10]				Particle size, μ	
Sample Origin	No. of samples	GE	DE[1]	ME[2]	NE[3]	Mean	Std. deviation
Pure Samples[4]							
1	4	4,680 (76.21)	3,481 (65.5)	3,269 (61.0)	2,127 (44.9)	843 (111.6)	1.78 (0.01)
2	4	4,765 (40.43)	3,520 (54.8)	3,300 (58.7)	2,146 (59.7)	721 (23.6)	1.73 (0.03)
3	4	4,722 (142.48)	3,316 (121.1)	3,050 (118.3)	1,802 (81.4)	447 (65.9)	2.06 (0.05)
Average	12	4,722 (94.2)	3,439 (120.3)	3,206 (138.8)	2,025 (174.7)	670 (186.0)	1.86 (0.16)
SD among plants	3	42.4	108.0	136.2	193.4	202.7	0.18
Sorghum-corn Samples							
1[5]	5	4,792 (52.93)	3,597 (34.3)	3,380 (38.1)	2,253 (68.3)	662 (44.0)	1.82 (0.03)
2[6]	4	4,858 (57.80)	3,585 (45.9)	3,357 (51.2)	2,170 (45.7)	594 (91.9)	1.78 (0.07)
Average	9	4,825 (62.10)	3,592 (37.7)	3,370 (43.0)	2,216 (71.0)	632 (73.8)	1.80 (0.05)
SD among plants	2	46.53	8.8	16.3	59.0	48.5	0.03
Feoli, 2008[7]	Sorghum DDGS	4,921	3,466	---	---	---	---
Stein, 2007[8]	Corn DDGS	5,434	4,140	3,898	---	---	---
NRC, 1998[9]	Sorghum grain	---	3,799	3,752	2,533	---	---

[1]DE= -174 + (0.848 × GE) + {2 × [100 - (CP + EE + Ash + NDF)]} - (16 × ADF).
[2]ME= (1 × DE) - (0.68 × CP).
[3]NE = (0.726 × ME) + (13.3 × EE) + (3.9 × starch) - (6.7 × CP) - (8.7 × ADF).
[4]Pure samples contained 100% sorghum DDGS.
[5]Sorghum-corn sample contained 60% sorghum and 40% corn.
[6]Sorghum-corn sample contained 70% sorghum and 30% corn.
[7]Feoli, C. Use of corn and sorghum-based distiller's grains with solubles in diets for nursery and finishing pigs. *Dissertation*. Retrieved September 17, 2010 from K-State Electronic Theses, Dissertations, and Reports: 2004-Present.
[8]Stein, H. 2007. Dried distiller's grains with solubles (DDGS) in diets fed to swine. In: Swine Focus-#001. pp. 1-8.
[9]NRC, 1998. Nutrient requirements of swine, 10th ed. Natl. Acad. Press, Washington, D.C.
[10]() Values in parenthesis represent the standard deviation of the mean from all individual samples.

Table 2.9 Effects of sorghum dried distiller's grains with solubles (DDGS) on nursery pig performance (Exp. 1)[1]

	Grain source									Probability, P <				
	Corn				Sorghum									
	Sorghum DDGS, %									DDGS × grain source			DDGS	
Item	0	15	30	45	0	15	30	45	SED	Linear	Quadratic	Corn vs. sorghum[2]	Linear	Quadratic
Initial BW, kg	6.9	6.8	6.8	6.8	6.8	6.8	6.8	6.8	0.38	0.60	0.83	0.82	0.63	0.91
d 0 to 14														
ADG, g	313	302	294	282	336	308	286	288	20.93	0.49	0.46	0.53	0.01	0.49
ADFI, g	465	464	441	412	442	469	440	433	28.72	0.33	0.90	0.98	0.07	0.28
G:F	0.672	0.655	0.673	0.686	0.758	0.661	0.650	0.670	0.04	0.04	0.23	0.47	0.18	0.05
d 14 to 34														
ADG, g	610	602	586	534	600	585	603	563	23.70	0.16	0.70	0.70	0.01	0.15
ADFI, g	962	947	928	891	964	984	992	950	39.12	0.26	0.62	0.04	0.14	0.29
G:F	0.636	0.636	0.632	0.600	0.623	0.596	0.608	0.592	0.01	0.57	0.07	0.01	0.01	0.37
d 0 to 34														
ADG, g	488	478	466	430	491	471	472	449	20.39	0.51	0.57	0.60	0.01	0.47
ADFI, g	757	748	728	694	749	772	765	736	31.53	0.24	0.67	0.14	0.07	0.23
G:F	0.644	0.641	0.641	0.620	0.656	0.612	0.617	0.610	0.01	0.27	0.03	0.05	0.01	0.47
Final BW, kg	23.6	23.1	22.6	21.4	23.5	22.8	22.9	22.3	1.77	0.39	0.51	0.53	0.01	0.61

[1]A total of 360 nursery barrows (Line 1050, PIC, Hendersonville, TN); initially 6.8 kg and 7 d post-weaning) were used in a 34-d growth trial to evaluate the effects on growth performance of grain source and increasing sorghum DDGS on pig performance. There were 5 pigs per pen and 9 pens per treatment.

[2]Contrast compares the mean of pigs fed sorghum-based diets with DDGS (0, 15, 30, or 45%) with the mean of pigs fed the corn-based diets (0, 15, 30, or 45% DDGS).

Table 2.10 Main effects of grain source and sorghum dried distiller's grains with solubles (DDGS) on nursery pig performance (Exp. 1)[1]

	Grain source			Sorghum DDGS, %					Probability, $P <$		
										DDGS level	
Item	Corn	Sorghum	SED	0	15	30	45	SED	Grain source	Linear	Quadratic
Initial BW, kg	6.8	6.8	0.19	6.9	6.8	6.8	6.8	0.27	0.82	0.63	0.91
d 0 to 14											
ADG, g	298	304	10.47	325	305	290	285	14.80	0.53	0.01	0.49
ADFI, g	446	446	14.36	453	467	440	422	20.31	0.98	0.07	0.28
G:F	0.672	0.685	0.02	0.715	0.658	0.662	0.678	0.02	0.45	0.18	0.05
d 14 to 34											
ADG, g	583	588	11.85	605	594	595	548	16.76	0.70	0.01	0.15
ADFI, g	932	973	19.56	963	966	960	921	27.66	0.04	0.14	0.29
G:F	0.626	0.605	0.01	0.629	0.616	0.620	0.596	0.01	0.01	0.01	0.37
d 0 to 34											
ADG, g	466	471	10.19	490	475	469	440	14.42	0.60	0.01	0.47
ADFI, g	732	756	15.76	753	760	746	715	22.29	0.14	0.07	0.23
G:F	0.636	0.624	0.01	0.650	0.626	0.629	0.615	0.01	0.01	0.01	0.37
Final BW, kg	22.6	22.9	0.89	23.5	23.0	22.8	21.8	1.25	0.53	0.01	0.61

[1]A total of 360 nursery barrows (Line 1050, PIC, Hendersonville, TN; initially 6.8 kg and 7 d post-weaning) were used in a 34-d growth trial to evaluate the effects of growth performance of grain source and increasing sorghum DDGS on pig performance. There were 5 pigs per pen and 9 pens per treatment.

Table 2.11 An evaluation of corn and sorghum dried distiller's grains with solubles (DDGS) on nursery pig performance (Exp. 2)[1]

	Treatments							Probability, *P* <			
	A	B	C	D	E	F					
	Grain source										
	Corn			Sorghum							
	DDGS source and level, %										
	None	Sorghum	Corn	None	Sorghum	Corn		Grain source ×	Corn vs.	DDGS	Control vs.
Item	0	30	30	0	30	30	SED	DDGS interaction	Sorghum[2]	source[3]	DDGS[4]
Initial BW, kg	10.7	10.7	10.7	10.7	10.7	10.7	0.79	1.00	0.93	0.94	0.96
ADG, g	529	496	513	540	521	499	19.83	0.38	0.56	0.86	0.03
ADFI, g	807	819	805	862	837	800	31.84	0.47	0.89	0.39	0.32
G:F	0.656	0.606	0.638	0.627	0.625	0.623	0.02	0.22	0.46	0.27	0.14
Final BW, kg	21.8	21.1	21.5	22.0	21.6	21.2	1.28	0.60	0.74	0.85	0.13

[1]A total of 180 nursery pigs (Line 327 × 1050, PIC, Hendersonville, TN; initially 10.7 kg and 38 d of age) were used in a 21-d growth trial to determine the effects of corn vs. sorghum DDGS (0, 30%) on growth performance. There were 6 pigs per pen and 5 pens per treatment.

[2]Corn vs. sorghum (Trt A, B, & C vs. Trt D, E, & F).

[3]Corn DDGS vs. sorghum DDGS (Trt C & F vs. Trt B & E).

[4]Basal diets vs. diets with sorghum or corn DDGS (Trt A & D vs. Trt B, C, E, & F).

Table 2.12 Main effects of grain source and dried distiller's grains with solubles (DDGS) on nursery pig performance (Exp. 2)[1]

	Grain source			DDGS source			DDGS, %			Probability, *P* <		
Item	Corn	Sorghum	SED	Corn	Sorghum	SED	0	30	SED	Grain source	DDGS source	DDGS level[2]
Initial BW, kg	10.7	10.7	0.45	10.7	10.7	0.56	10.7	10.7	0.28	0.93	0.94	0.96
d 0 to 21												
ADG, g	513	520	11.45	506	508	14.02	535	507	7.01	0.56	0.86	0.03
ADFI, g	810	833	17.59	803	828	21.54	834	815	10.77	0.21	0.25	0.32
G:F	0.633	0.625	0.01	0.630	0.615	0.01	0.641	0.623	0.01	0.46	0.27	0.13
Final BW, kg	21.5	21.6	0.74	21.4	21.4	0.91	21.9	21.4	0.45	0.73	0.96	0.13

[1]A total of 180 nursery pigs (Line 327 × 1050, PIC, Hendersonville, TN; initially 10.7 kg and 38 d of age) were used in a 21-d growth trial to determine the effects of corn or sorghum DDGS (0, 30%) on growth performance. There were 6 pigs per pen and 5 pens per treatment.

[2]Values for 30% DDGS include corn and sorghum DDGS.

Chapter 3 - The Effects of Sorghum Dried Distiller's Grains with Solubles on Finishing Pig Growth Performance, Carcass Characteristics, and Fat Quality[1]

ABSTRACT

A total of 288 finishing pigs (BW 58.8 ± 4.43 kg; TR 4×1050, PIC) were used in a 73-d study to determine the effects of sorghum dried distiller's grains with solubles (DDGS) in sorghum- or corn-based diets on growth performance, carcass characteristics, and fat quality. Pigs were allotted to 1 of 6 dietary treatments with 8 pigs per pen and 6 pens per treatment. Treatments included sorghum-based diets with 0, 15, 30, or 45% sorghum DDGS (29.0% CP; 7.2% crude fat); a sorghum-based diet with 30% corn DDGS (25.7% CP; 8.7% crude fat), and a corn-based diet with 30% corn DDGS. The diets were formulated to 0.95%, 0.83%, and 0.71% standardized ileal digestibility Lys in phases 1, 2, and 3, respectively and were not balanced for energy. On d 73, a subsample of 72 pigs (1 barrow and 1 gilt/pen) was slaughtered at Kansas State University's Meats Laboratory (Manhattan, KS). Standard carcass characteristics were measured, as well as loin eye color, marbling and firmness, and fat color score. Fat samples from the 10th rib were taken and analyzed for fatty acid profile and IV. The remaining pigs were taken to a commercial packing plant (Triumph Foods, St. Joseph, MO) for carcass measurements and jowl IV. Overall, increasing sorghum DDGS reduced (linear, $P < 0.01$) ADG and increased (linear, $P < 0.01$) backfat iodine value (IV), while fat color became less red (a*; linear, $P < 0.01$) and tended to be less yellow (b*; linear, $P < 0.06$). No differences were observed in growth performance or backfat IV among pigs fed corn- or sorghum-based diets with 30% corn DDGS. No differences were observed in carcass yield among pigs fed the increasing sorghum DDGS. Pigs fed the sorghum-based diet with 30% corn DDGS had fat color that was more yellow (b*; $P < 0.03$) than pigs fed the sorghum-based diet with 30% sorghum DDGS. Pigs fed the sorghum-based diet with 30% sorghum DDGS also had decreased backfat IV ($P < 0.01$) and fat that was whiter (L*; $P < 0.02$) than those fed the sorghum-based diet with corn DDGS. Pigs fed sorghum with 30% sorghum DDGS had decreased ($P < 0.01$) backfat IV than pigs fed corn with 30% corn DDGS. Feeding a sorghum-based diet with 30% sorghum DDGS produces firmer pork fat than those fed a corn-based diet with 30% corn DDGS which may have an important role in pork export markets.

Keywords: corn, dried distiller's grains with solubles, finishing pigs, sorghum

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Introduction

In the Great Plains region of the United States, sorghum is grown due to its ability to survive in drought conditions. Due to the large production of sorghum in the area and its use in ethanol production, sorghum DDGS are more available to swine producers than corn DDGS.

Sorghum grain has a feeding value of 96 to 100% that of the value of corn, and produces similar pig growth performance when used to completely replace corn when formulated in swine diets (Shelton et al., 2004; Issa, 2009; Benz et al., 2011). Sotak et al. (2011) found sorghum to be a suitable replacement for corn in nursery pig diets. However, increasing sorghum DDGS from 0 to 45% in nursery pig diets linearly reduced growth performance. Feoli (2008) also observed a reduction in growth performance when 30% sorghum DDGS were included in nursery pig diets.

The decrease in growth performance observed by Sotak et al. (2011) and Feoli (2008) could be due to the reduction in diet digestibility. Pedersen et al. (2007) determined corn DDGS to have a greater concentration of GE than corn; however, the GE digestibility was lower for DDGS when compared to corn. Due to the decrease in digestibility, DDGS and corn have similar values for DE and ME. Dried distiller's grains with solubles contain approximately 35% insoluble and 6% soluble dietary fiber (University of Illinois, Urbana, IL, unpublished). This increase in insoluble dietary fiber content causes DDGS to have a reduction in digestibility, including GE.

In addition to reducing diet digestibility, including corn DDGS in swine diets creates carcass that has a higher concentration of unsaturated fatty acids and thus decreases pork fat firmness. However, sorghum contains a lower concentration of crude fat than corn; therefore, creating a lower fat DDGS product. Therefore, sorghum DDGS could have a less negative impact on finishing pig fat quality by decreasing the level of unsaturated fat the pig consumes. While a large database of information is available on the nutritional value of sorghum, little is known about sorghum DDGS. Therefore, the objective of this study was to determine the effects of increasing sorghum DDGS in corn- or sorghum-based diets on pig growth performance, carcass characteristics, and fat quality.

MATERIALS AND METHODS

The protocols for these studies were approved by the Kansas State University Institutional Animal Care and Use Committee. The studies were conducted at the Kansas State University Swine Teaching and Research Center, Manhattan.

The facility is an environmentally controlled barn with mechanical ventilation. The room (26.8 × 23.2 m) in which the pigs were housed has 36, 2.4 × 3.1 m pens. Each pen was equipped with slatted floors, 1, 5-hole self-feeder (Farmweld, Teutopolis, IL), and a cup waterer. Throughout the trial, the pigs had ad libitum access to feed and water. The facility uses a computer feeding system (FeedPro; Feedlogic Corp., Wilmar, MN) to distribute and weigh feed deliveries.

The sorghum grain used in this study was a red pericarp variety, and the corn grain used was #2 Yellow dent. The corn DDGS used were golden brown, and the sorghum DDGS were slightly darker than the corn DDGS in visual color. The sorghum, corn, sorghum DDGS, and corn DDGS were analyzed for their AA profile at the University of Missouri-Columbia (Columbia, MO; AOAC 975.44, 2006). Standard ileal digestibility values for the sorghum DDGS were derived from Urriola et al. (2009). These values were then used in diet formulation (Table 2.1). Fatty acid analyses were conducted on the corn, sorghum, corn DDGS, and sorghum DDGS utilized in the study at the Kansas State University Analytical Lab (Manhattan, KS; Table 2.2; Sukhija and Palmquist, 1988).

A total of 288 finishing pigs (BW 58.8 ± 4.43 kg; Line TR4 × 1050, PIC, Hendersonville, TN) were used in a 73-d study to determine the effects of increasing sorghum DDGS in sorghum-based diets on pig growth performance, carcass characteristics, and fat quality. Pigs were allotted to 1 of 6 dietary treatments with 8 pigs (4 barrows and 4 gilts) per pen and 6 pens per treatment. These dietary treatments were fed in 3 phases and included: sorghum-based diets with sorghum DDGS included at 0, 15, 30, or 45%, a sorghum-based diet with 30% corn DDGS, and a corn-based diet with 30% corn DDGS (Tables 2.3, 2.4, and 2.5). Pigs and feeders were weighed on d 0, 28, 56, and 75 to determine ADG, ADFI, and G:F. Bulk densities (g/L) were also measured for the treatment diets (Table 2.6).

At the end of the study (d 73), the heaviest barrow and gilt were selected from every pen, and taken to the Kansas State University's Meats Laboratory. Pigs were transported 10 minutes from the farm to the Meats Laboratory and withheld from feed for 12 h. Standard carcass characteristics were measured, as well as loin eye color, marbling and firmness, and fat color score (HunterLab Miniscan^{TM} XE Plus spectrophotometer; Model 45/0 LAV, 2.54-cm diameter aperture, 10° standard observer, Illuminant D65, Hunter Associates Laboratory, Inc., Reston, VA). Visual loin and fat color scores were also evaluated using the National Pork Producers Council's color and marbling standards (NPPC, 2000). Ultimate pH of the loin eye was analyzed and recorded (glass tip probe model FC 200; meter model HI 9025, Hanna Instruments, Woonsocket, RI). Purge loss was measured by weighing the whole packaged loin, blotting the loin dry after removing it from the package, and then reweighing the dried loin and package. Drip loss was calculated by weighing each loin, placing it in a plastic bag, and sealing it following fabrication. The loins were then stored for 24 h at 0° to 4°C. Following storage, the loins were removed from the bag, blotted dry, and reweighed to determine percentage drip loss. Fat samples from the 10th rib were taken and analyzed for fatty acid profile and IV was calculated using these values. The backfat IV was calculated using the equation IV= [C16:1]× 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723. The remaining pigs were transported 210 km to a commercial packing plant (Triumph Foods LLC, St. Joseph, MO) for standard carcass data collection and jowl fat IV. Jowl fat IV was calculated using Near Infrared Spectroscopy (NIR; Bruker MPA; Multi-Purpose Analyzer) using the equation of Cocciardi et al. (2009). These pigs, like the 72 pigs slaughtered at the Kansas State University's Meats Laboratory, were withheld from feed 12 h prior to harvest. Each carcass was evaluated for carcass yield, backfat depth, and loin depth with HCW measured immediately after evisceration. Carcass yield was calculated by dividing HCW by live weight obtained from the Kansas State University's farm prior to transport to Triumph Foods' packing plant. Fat depth and loin depth were measured with an optical probe inserted approximately 7.1 cm from the dorsal midline between the 3rd and 4th last rib (counting from the ham end of the carcass).

Fecal samples were collected on d 7 of Phase 3 (d 63 of the trial) via rectal massage from 4 pigs per pen. The phase 3 diets contained 0.5% chromic oxide as an inert digestibility marker. After collection, fecal samples were stored in a freezer (-20°C) until they were then thawed and combined within each pen. The samples were then dried in a 50°C forced air drying oven and then ground for bomb calorimetry and chromium concentration. The digestibility values were calculated using the indirect method (Adeola, 2001).

Data were analyzed in a completely randomized design with pen as the experimental unit. Analysis of variance was used with the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Single degrees of freedom contrasts were used to make comparisons between: 1) the sorghum- and corn-based diets with 30% corn DDGS, 2) the sorghum diet with 30% sorghum DDGS vs. the corn-based diet with 30% corn DDGS, and 3) linear and quadratic effects of increasing sorghum DDGS (0, 15, 30, and 45%). Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

RESULTS

Chemical Analysis

As expected, the corn and corn DDGS contained greater concentrations of linoleic acid (C18:2n-6) as well as lower MUFA and PUFA concentrations than sorghum and sorghum DDGS (Table 2.2). Sorghum and sorghum DDGS had greater concentrations of SFA and total *trans* fatty acids than the corn and corn DDGS. Therefore, this resulted in the corn and corn DDGS having greater IV than the sorghum and sorghum DDGS, respectively. As the amount of dietary DDGS increased, bulk density of the diet decreased.

Growth Performance

Overall (d 0 to 73), increasing DDGS (0, 15, 30, or 45%) decreased (linear, $P < 0.04$) ADG, ADFI, and final BW weight with no change in G:F (Table 2.7). Growth performance between pigs fed the corn- and sorghum-based diets with 30% corn DDGS was similar, as was the performance of pigs fed either the sorghum-based diets with either 30% sorghum or corn DDGS.

Carcass Characteristics

For carcass data of pigs taken to the commercial packing plant (Triumph Foods; St. Joseph, MO), jowl IV increased (linear, $P < 0.01$) with increasing sorghum DDGS (Table 2.7). Increasing sorghum DDGS decreased (linear, $P < 0.01$) backfat depth but had no effect on loin depth resulting in increased (linear, $P < 0.01$) fat free lean index (FFLI). Hot carcass weight decreased (linear, $P < 0.04$) with increasing sorghum DDGS, but carcass yield was similar among treatments. Jowl IV was greater ($P < 0.01$) in pigs fed the corn-based diet with 30% corn DDGS than those fed the sorghum-based diet with 30% corn DDGS. Pigs fed sorghum-based diets with 30% sorghum DDGS had decreased ($P < 0.04$) jowl fat IV than pigs fed the sorghum-based diets with 30% corn DDGS or pigs fed the corn-based diet with 30% corn DDGS.

For carcass data of pigs slaughtered at the Kansas State University's Meat Laboratory, increasing sorghum DDGS had no effect on HCW, carcass yield, purge loss, or drip loss; however, pH tended ($P < 0.06$) to increase with increasing DDGS (Table 2.8). Increasing sorghum DDGS had no effect on backfat thickness nor 10^{th} rib loin eye, color, firmness, and marbling. Increasing sorghum DDGS decreased 10^{th} loin redness (linear, $P < 0.03$; a*) and tended to decrease the degree of yellowness (linear, $P < 0.06$; b*). For backfat samples collected at the 10^{th} rib, the degree of redness (a*) decreased (linear, $P < 0.01$) and yellowness (b*) tended to increase (linear, $P < 0.06$) as sorghum DDGS increased. Surprisingly, pigs fed the corn-based diet with 30% corn DDGS had a decreased degree of yellowness (b*; $P < 0.03$) than pigs fed the sorghum-based diet with 30% sorghum DDGS.

Carcass characteristics were not different among pigs fed sorghum- or corn-based diets with 30% corn DDGS or for pigs fed sorghum-based diets with either corn or sorghum DDGS. Pigs fed the sorghum diet with 30% corn DDGS had 10^{th} rib loin eyes that tended ($P < 0.08$) to be firmer and have more marbling than those fed the corn diet with 30% corn DDGS.

Pigs fed sorghum with 30% sorghum DDGS had fat color that was more white (L*) and less yellow (b*) ($P < 0.03$) in color than pigs fed sorghum with 30% corn DDGS. Pigs fed the corn-based diet with 30% corn DDGS had fat color that was less yellow (b*; $P < 0.01$) and tended to be less red (a*, $P < 0.08$) than pigs fed the sorghum-based diet with 30% corn DDGS; however, no differences were observed for fat color among pigs fed the sorghum-based diet with 30% sorghum DDGS compared to those fed the corn-based diet with 30% corn DDGS.

Carcass Fatty Acid Composition

Increasing sorghum DDGS reduced (linear, $P < 0.01$) palmitic (C16:0), stearic (C18:0), and oleic (C18:1 *cis*-9) fatty acids in backfat (Table 2.9). On the other hand, linoleic (C18:2n-6) and linolenic (C18:3n-3) concentrations increased (linear, $P < 0.01$). As a result, SFA and MUFA decreased (linear, $P < 0.01$) and PUFA and backfat IV increased (linear, $P < 0.01$) with increasing sorghum DDGS.

Pigs fed the corn-based diet with 30% corn DDGS had greater ($P < 0.05$) concentrations of C18:1 *cis*-9 and MUFA than pigs fed the sorghum-based diet with 30% corn DDGS (Table 2.9). Pigs fed the corn-based diet with 30% corn DDGS had decreased ($P < 0.03$) concentrations of C14:0, C16:0, C18:3n-3, and total *trans* fatty acids than pigs fed the sorghum-based diet with 30% sorghum DDGS. Pigs fed the sorghum diet with corn DDGS had greater concentrations ($P < 0.01$) of C18:1 *cis*-9, C18:1n-7, and MUFA, while pigs fed diets with sorghum DDGS had greater concentrations ($P < 0.01$) of C18:2n-6, C20:2, and PUFA than pigs fed diets with corn DDGS.

Increasing sorghum DDGS increased (linear, $P < 0.01$) jowl IV. A tendency ($P < 0.10$) for higher jowl IV was observed in pigs fed the corn-based diet with 30% corn DDGS when compared to those fed the sorghum-based diet with 30% corn DDGS. Furthermore, pigs fed the sorghum-based diet with 30% sorghum DDGS had decreased ($P < 0.01$) jowl IV vs. pigs fed the sorghum- or corn-based diet with 30% corn DDGS.

Nutrient Digestibility

A trend for an increase (quadratic, $P < 0.08$) was observed for apparent digestibility of DM among the dietary treatment groups with DM digestibility increasing when pigs were fed sorghum-based diets with 15 or 45% sorghum DDGS (Table 2.10). The digestibility of N increased (linear, $P < 0.01$) as sorghum DDGS increased. Nitrogen digestibility was increased ($P < 0.01$) among pigs fed the sorghum-based diet with 30% corn DDGS or the corn-based diet with 30% corn DDGS vs. those fed the sorghum-based diet with 30% sorghum DDGS. The digestibility of GE increased when 15% sorghum DDGS were included in the diet, but decreased (quadratic, $P < 0.04$) with 30 or 45% DDGS to values similar to the sorghum-based basal diet. An increase in DE of the diet (quadratic, $P < 0.01$) was found as sorghum DDGS increased. Furthermore, DE of the corn-based diet was greater ($P < 0.01$) than the DE of the sorghum-based diet with either 30% sorghum or corn DDGS.

DISCUSSION

Grain sorghum has been shown to be a suitable replacement for corn in many experiments (Shelton et al., 2004; Issa, 2009; Benz et al., 2011). The results of this study agree with previous research as there were no differences among pigs fed a sorghum-based diet with 30% corn DDGS and a corn-based diet with 30% corn

DDGS. Stein and Shurson (2009) reviewed several studies evaluating increasing corn DDGS on pig performance and generally found no negative effects up to an inclusion of 30% DDGS in the diet. The linear reduction in ADG in the present study was expected. The diets were not balanced for energy; however, as sorghum DDGS increased, ME decreased as the sorghum DDGS had decreased ME than sorghum grain. Furthermore, the dietary ME decreased as sorghum DDGS were included; therefore, reducing ADG. The decrease in ADG for pigs fed sorghum-based diets with increasing sorghum DDGS could potentially be due to the decrease in bulk density limiting ADFI. In addition, a reduction in palatability when increased DDGS were included in the sorghum-based diets could have caused a reduction in ADFI. Because the sorghum DDGS used in Exp. 1 contained more dietary crude fiber than the corn DDGS, it is likely the sorghum DDGS contain a greater concentration of insoluble and soluble dietary fiber. Pedersen et al. (2007) determined corn DDGS contained approximately 35% insoluble fiber and 6% soluble dietary fiber. Therefore, the decrease in ADFI, and subsequently the reduction in ADG, could also be due to the linear increase in fiber, and subsequent reduction in dietary ME, present in the sorghum-based diets.

Senne et al. (1995, 1996) fed nursery and finishing pigs increasing corn or sorghum DDGS to determine the effects on growth performance. In these studies, fat was added to DDGS-based diets to equal the energy content of the control diet without DDGS. Senne et al. (1995, 1996) found nursery and finishing pigs could be fed up to 30% sorghum DDGS without adverse effects on growth performance when formulated in isocaloric diets. However, in a follow up study, when the diets were not balanced for energy, a reduction in growth performance was observed when 40% sorghum DDGS were fed (Senne et al., 1998). Feoli et al. (2008a), fed corn-based diets with 0 or 40% sorghum DDGS and observed reduced ADG and G:F when compared to those fed the basal corn diet. The reduction in ADG in our study agrees with the findings by Feoli et al. (2008a); however, we did not observe a worsening of G:F among pigs fed the sorghum-based basal diet or pigs fed the sorghum-based diet with either 30% corn or sorghum DDGS.   Linneen et al. (2008) conducted a study in a commercial research facility to determine the optimal level of corn DDGS on growing and finishing pig performance and carcass characteristics. In the first experiment, Linneen et al. (2008) fed corn-based diets with 0, 5, 10, or 20% DDGS with 6% added fat in all diets. A linear reduction in ADG and ADFI was observed in pigs fed diets containing DDGS; however, G:F tended to improve. Additionally, backfat and FFLI tended to decrease as DDGS increased. These growth performance and carcass characteristic results agree with the findings in Exp. 1 with the exception of the tendency for improved G:F may have been due to the differences in added fat levels between the experiments.

In a series of 11 experiments, Pedersen et al. (2007) determined the apparent total tract digestibility (ATTD) of GE to be 90.4% for corn and 76.8% for corn DDGS. The measured concentrations of DE and ME of corn DDGS were found to be similar to those concentrations found in corn. Feoli et al. (2007c) also observed sorghum or corn DDGS to have greater GE than corn, but again digestibility of GE was lower than corn. As stated previously, the reduction in feed intake was most likely due to a decrease in energy and an increase in insoluble dietary fiber which in turn resulted in gut fill before the energy requirement of the pig could be met.

Urriola et al. (2009) conducted an experiment to measure the apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of AA in sorghum DDGS and a blend of sorghum-corn DDGS to compare these values to the AID and SID of AA in corn DDGS. They reported apparent ileal digestibility (AID) of CP in sorghum DDGS was 64.5%, a sorghum-corn DDGS blend was 63.2%, and 8 samples of corn DDGS were between 57.6 and 70.9%. Furthermore, Urriola et al. (2009) found pigs fed increasing sorghum DDGS had linearly increased N digestibility, but pigs fed corn DDGS had greater N digestibility than those fed sorghum DDGS. These findings agree with the digestibility values in the present study where the pigs fed the sorghum-based diet with 30% corn DDGS had a greater digestibility of N than those fed the sorghum-based diet with 30% sorghum DDGS.

Along with a reduction in growth performance, increasing sorghum DDGS to finishing pig diets worsened fat quality as measured by IV. Because DDGS have a greater concentration of UFA, the fat IV linearly increases as DDGS increase. Due to the decrease in fat saturation associated with increasing DDGS, several commercial packing plants have placed limits on the maximum fat IV allowed; thereby limiting producers' use of DDGS in swine diets. Xu et al. (2010) conducted a study to evaluate the growth performance, carcass characteristics, and fat quality of grower-finisher pigs fed corn-based diets with increasing DDGS. Pigs were fed corn-based diets with 0, 10, 20, or 30% corn DDGS. Xu et al. (2010) found backfat and jowl IV linearly increased as corn DDGS increased in the corn-based diets which agrees with the linear increase in backfat and jowl IV found in the present study. Furthermore, in our study, a reduction in both jowl and backfat IV were observed in dietary treatments containing sorghum DDGS vs. those containing corn DDGS. The reduction in fat IV was expected because sorghum DDGS have a lower crude fat concentration than corn DDGS, and contain less UFA. The results found in this study agree with previous research conducted on the effect of DDGS on carcass fat composition (Benz et al., 2011a). Benz et al. (2011a) found higher concentrations of UFA in pigs fed diets containing DDGS causing them to have higher jowl and backfat IV. Furthermore, Benz et al. (2011b) found pigs fed corn-based diets had higher backfat IV than those fed sorghum-based diets.

Because a growing percentage of United States pork is exported to international markets, sorghum DDGS may have an important role in the future of swine diets due to its ability to produce pork fat that is lighter in color and is less yellow. Previous research conducted to determine the effects of diet composition on fat color found no differences when feeding barley, yellow, or white corn; however, the barley-based diet was found to produce harder fat compared to that of pigs fed the yellow and white corn-based diets (Fent et al., 2003, Lampe et al., 2003, 2006). Xu et al. (2010) observed no differences for fat a* for pigs fed increasing DDGS. However, pigs increasing DDGS had darker fat (L*) and increased yellowness (b*) compared to the pigs fed the corn-based basal diet. These results disagree with findings in Exp.1 where pigs fed increasing sorghum DDGS had backfat that was less red (a*) and yellow (b*); however, no differences were observed for fat paleness (L*). Furthermore, in Exp. 1, pigs fed diets containing sorghum DDGS had lighter fat (L*) with decreased yellowness (b*) than those fed corn DDGS. Positive ramifications of feeding sorghum DDGS could be found in packing plants due to the potential for higher fat quality due to the lower IV and lighter fat color.

In summary, the economic value of ADG and G:F must be evaluated when considering adding sorghum DDGS to nursery diets. The decrease in pig growth performance will need to be offset by a reduction in diet cost when using sorghum DDGS; therefore, its inclusion needs to be evaluated on an income over feed cost basis.

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FIGURES AND TABLES

Table 3.1 Analyzed nutrient composition of ingredients (As-fed basis)[1]

Item	Sorghum	Corn	Sorghum DDGS[2]	Corn DDGS
DM, %	86.12	86.22	89.64	89.00
CP, %	8.24	7.39	29.04	25.70
Crude fat, %	2.07	2.36	7.17	8.71
Crude fiber, %	1.74	1.72	5.28	5.62
Ash, %	1.29	1.31	4.24	4.23
Amino acids, %				
Cys	0.13	0.14	0.44	0.43
Ile	0.28	0.22	1.04	0.88
Leu	0.95	0.76	2.94	2.65
Lys	0.21	0.22	0.73	0.86
Met	0.12	0.13	0.39	0.47
Thre	0.24	0.22	0.85	0.87
Trp	0.06	0.05	0.15	0.18
Val	0.37	0.32	1.34	1.21

[1]Values represent the mean of 1 sample. Diets were prepared using the analyzed values.
[2]Dried distiller's grains with solubles.

Table 3.2 Fatty acid analysis of dietary ingredients

Item	Corn	Sorghum	Corn DDGS	Sorghum DDGS
Myristic acid (C14:0); %	0.11	0.07	0.08	0.09
Palmitic acid (C16:0), %	16.30	14.35	15.02	16.82
Palmitoleic acid (C16:1), %	0.63	0.01	0.34	0.57
Margaric acid (C17:0), %	0.16	0.16	0.13	0.13
Stearic acid (C18:0), %	1.71	2.25	2.13	1.84
Oleic acid (C18:1 *cis*-9), %	26.36	22.42	26.25	27.57
Vaccenic acid (C18:1n-7), %	2.10	1.06	1.44	1.99
Linoleic acid (C18:2n-6), %	55.77	47.33	50.86	46.70
α-Linolenic acid (C18:3n-3), %	2.55	1.52	1.91	2.41
Arachidic acid (C20:0), %	0.25	0.63	0.41	0.27
Gadoleic acid (C20:1), %	0.29	0.23	0.26	0.27
Eicosadienoic acid (C20:2), %	0.10	0.10	0.09	0.09
Arachidonic acid (C20:4n-6), %	0.12	0.06	0.06	0.08
Other fatty acids, %	1.98	1.36	1.03	1.17
Total SFA,[1] %	17.94	19.08	18.32	19.69
Total MUFA[2], %	23.81	29.48	28.34	30.48
Total PUFA[3], %	57.49	50.19	52.95	49.33
Total *trans* fatty acids,[4] %	1.52	2.55	1.98	2.53
UFA:SFA ratio[5]	4.85	4.18	4.44	4.05
PUFA:SFA ratio[6]	3.20	2.63	2.89	2.51
Iodine value,[7] g/100g	121	114	118	114

[1] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]), brackets indicate concentration.

[2] Total MUFA = ([C14:1] + [C16:1] + [C18:1 *cis*-9] + [C18:1n-7] + [C20:1] + [C24:1]), brackets indicate concentration.

[3] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]), brackets indicate concentration.

[4] Total *trans* fatty acids = ([C18:1 *trans*] + [C18:2 *trans*] + [C18:3 *trans*]), brackets indicate concentration.

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

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

[7] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723, brackets indicate concentration.

Table 3.3 Phase 1 diet composition (As-fed basis)[1]

	Grain source					
	Sorghum	Sorghum	Sorghum	Sorghum	Sorghum	Corn
	DDGS[2] source and level, %					
	None	Sorghum	Sorghum	Sorghum	Corn	Corn
Item	0	15	30	45	30	30
Ingredient, %						
Sorghum	76.20	63.10	50.20	36.90	51.05	---
Soybean meal (46.5% CP)	20.85	19.25	17.45	15.85	16.50	17.65
Corn	---	---	---	---	---	49.90
Sorghum DDGS	---	15.00	30.00	45.00	---	---
Corn DDGS	---	---	---	---	30.00	30.00
Monocalcium P (21% P)	0.90	0.55	0.20	---	0.25	0.30
Limestone	0.90	1.03	1.15	1.30	1.20	1.20
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix[4]	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.31	0.31	0.31	0.30	0.31	0.29
DL-methionine	0.12	0.08	0.04	---	0.01	---
L-threonine	0.08	0.04	0.01	---	0.02	0.02
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible amino acids, %						
Lysine	0.95	0.95	0.95	0.95	0.95	0.95
Isoleucine: lysine	62	68	73	79	68	67
Methionine: lysine	35	33	31	29	29	30
Met & Cys: lysine	58	58	58	58	58	59
Threonine: lysine	60	60	60	64	60	60
Tryptophan: lysine	17.1	17.1	17.0	17.0	17.0	17.0
Valine: lysine	70	78	86	93	81	80
Total lysine, %	1.04	1.07	1.10	1.13	1.12	1.12
CP, %	17.3	19.4	21.5	23.7	21.0	20.9
ME, kcal/kg	3,272	3,212	3,153	3,086	3,280	3,318
Ca, %	0.60	0.59	0.58	0.60	0.58	0.60
P, %	0.56	0.55	0.53	0.56	0.53	0.54
Available P, %	0.27	0.27	0.27	0.31	0.27	0.27

[1] Diets were fed in meal form from d 0 to 28 of the experiment.
[2]Dried distiller's grains with solubles
[3]Vitamin premix provided per kg of complete feed: 11,023 IU of vitamin A, 1,377 IU of vitamin D, 44.1 IU of vitamin E, 4.4 mg of vitamin K, 0.04 mg of vitamin B_{12}, 50.0 mg of niacin, 27.6 mg of pantothenic acid, and 8.3 mg of riboflavin.
[4]Trace mineral premix provided per kg of complete feed: 16.5 mg of Cu from $CuSO_4 \cdot 5H_2O$, 0.30 mg of I as $C_2H_2(NH_2)_2 \cdot 2HI$, 165 mg of Fe as $FeSO_4H_2O$, 39.7 mg of Mn as $MnSO_4 \cdot H_2O$, 0.30 mg of Se as Na_2SeO_3, and 165 mg of Zn as $ZnSO_4$.

Table 3.4 Phase 2 diet composition (As-fed basis)[1]

	Grain source					
	Sorghum	Sorghum	Sorghum	Sorghum	Sorghum	Corn
	DDGS[2] source and level, %					
	None	Sorghum	Sorghum	Sorghum	Corn	Corn
Item	0	15	30	45	30	30
Ingredient, %						
Sorghum	79.85	66.80	53.75	40.45	54.80	---
Soybean meal (46.5% CP)	17.30	15.70	14.05	12.30	12.95	13.85
Corn	---	---	---	---	---	53.90
Sorghum DDGS	---	15.00	30.00	45.00	---	---
Corn DDGS	---	---	---	---	30.00	30.00
Monocalcium P (21% P)	0.85	0.48	0.10	---	0.15	0.20
Limestone	0.90	1.03	1.15	1.30	1.18	1.15
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix[4]	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.29	0.28	0.28	0.28	0.28	0.26
DL-methionine	0.09	0.05	0.01	---	---	---
L-threonine	0.07	0.03	---	---	---	---
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible amino acids, %						
Lysine	0.83	0.83	0.83	0.83	0.83	0.83
Isoleucine: lysine	67	70	76	82	70	68
Methionine: lysine	34	31	29	30	30	32
Met & Cys: lysine	58	58	58	61	60	63
Threonine: lysine	60	60	62	66	61	61
Tryptophan: lysine	17.0	17.0	17.0	17.0	17.0	17.0
Valine: lysine	73	81	90	99	85	84
Total lysine, %	0.91	0.94	0.97	1.00	0.99	1.00
CP, %	15.8	17.9	20.1	22.2	19.5	19.4
ME, kcal/kg	3,272	3,212	3,153	3,084	3,283	3,325
Ca, %	0.58	0.56	0.55	0.59	0.54	0.55
P, %	0.53	0.51	0.50	0.54	0.49	0.50
Available P, %	0.25	0.25	0.25	0.30	0.25	0.25

[1] Diets were fed in meal form from d 28 to 56 of the experiment.
[2] Dried distillers grains with solubles.
[3] Vitamin premix provided per kg of complete feed: 11,023 IU of vitamin A, 1,377 IU of vitamin D, 44.1 IU of vitamin E, 4.4 mg of vitamin K, 0.04 mg of vitamin B_{12}, 50.0 mg of niacin, 27.6 mg of pantothenic acid, and 8.3 mg of riboflavin.
[4] Trace mineral premix provided per kg of complete feed: 16.5 mg of Cu from $CuSO_4 \cdot 5H_2O$, 0.30 mg of I as $C_2H_2(NH_2)_2 \cdot 2HI$, 165 mg of Fe as $FeSO_4H_2O$, 39.7 mg of Mn as $MnSO_4 \cdot H_2O$, 0.30 mg of Se as Na_2SeO_3, and 165 mg of Zn as $ZnSO_4$.

Table 3.5 Phase 3 diet composition (As-fed basis)[1]

	Grain source					
	Sorghum	Sorghum	Sorghum	Sorghum	Sorghum	Corn
	DDGS[2] source and level, %					
	None	Sorghum	Sorghum	Sorghum	Corn	Corn
Item	0	15	30	45	30	30
Ingredient, %						
Sorghum	83.35	70.30	57.25	43.80	58.20	---
Soybean meal (46.5% CP)	13.55	11.90	10.25	8..55	9.20	10.10
Corn	---	---	---	---	---	57.30
Sorghum DDGS	---	15.00	30.00	45.00	---	---
Corn DDGS	---	---	---	---	30.00	30.00
Monocalcium P (21% P)	0.75	0.40	0.05	---	0.10	0.15
Limestone	0.88	1.00	1.13	1.30	1.18	1.15
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.13	0.13	0.13	0.13	0.13	0.13
Trace mineral premix[4]	0.13	0.13	0.13	0.13	0.13	0.13
L-lysine HCl	0.26	0.25	0.25	0.25	0.26	0.23
DL-methionine	0.07	0.03	---	---	---	---
L-threonine	0.06	0.02	0.02	0.01	---	---
Chromic oxide	0.50	0.50	0.50	0.50	0.50	0.50
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible amino acids, %						
Lysine	0.71	0.71	0.71	0.71	0.71	0.71
Isoleucine: lysine	65	73	80	87	73	71
Methionine: lysine	33	31	30	33	33	34
Met & Cys: lysine	58	58	60	66	65	68
Threonine: lysine	62	62	67	70	63	63
Tryptophan:lysine	17.0	17.0	17.0	17.0	17.0	17.0
Valine: lysine	76	86	96	106	90	89
Total lysine, %	0.78	0.81	0.84	0.87	0.86	0.87
CP, %	14.3	16.4	18.6	20.7	18	17.9
ME, kcal/kg	3,258	3,199	3,139	3,069	3,267	3,311
Ca, %	0.54	0.53	0.52	0.58	0.52	0.53
P, %	0.49	0.48	0.47	0.52	0.47	0.47
Available P, %	0.23	0.23	0.23	0.30	0.23	0.23

[1]Diets were fed in meal form from d 56 to 73 of the experiment.
[2]Dried distiller's grains with solubles
[3]Vitamin premix provided per kg of complete feed: 11,023 IU of vitamin A, 1,377 IU of vitamin D, 44.1 IU of vitamin E, 4.4 mg of vitamin K, 0.04 mg of vitamin B_{12}, 50.0 mg of niacin, 27.6 mg of pantothenic acid, and 8.3 mg of riboflavin.
[4]Trace mineral premix provided per kg of complete feed: 16.5 mg of Cu from $CuSO_4 \cdot 5H_2O$, 0.30 mg of I as $C_2H_2(NH_2)_2 \cdot 2HI$, 165 mg of Fe as $FeSO_4H_2O$, 39.7 mg of Mn as $MnSO_4 \cdot H_2O$, 0.30 mg of Se as Na_2SeO_3, and 165 mg of Zn as $ZnSO_4$.

Table 3.6 Bulk densities of experimental diets (As-fed basis)[1]

	Grain source					
	Sorghum	Sorghum	Sorghum	Sorghum	Sorghum	Corn
	DDGS source and level, %					
	None	Sorghum	Sorghum	Sorghum	Corn	Corn
Item	0	15	30	45	30	30
Bulk density, g/L[2]						
Phase 1	658	596	585	555	595	577
Phase 2	654	631	619	586	606	599
Phase 3	669	637	622	593	608	596

[1]Bulk densities represent the mass per unit volume. Diet samples were taken from the tops of feeders during each phase.
[2]Phase 1 was d 0 to 28; Phase 2 was d 28 to 56; Phase 3 was d 56 to 73.

Table 3.7 Effects of sorghum dried distiller's grains with solubles (DDGS) on finishing pig growth performance and carcass characteristics[1,2]

	Treatments											
	A	B	C	D	E	F						
	Grain source											
	Sorghum	Sorghum	Sorghum	Sorghum	Sorghum	Corn		Probability, *P* <				
	DDGS source and level, %											
	None	Sorghum	Sorghum	Sorghum	Corn	Corn						
Item	0	15	30	45	30	30	SED	Linear DDGS[3]	Quad. DDGS[3]	Grain source[4]	DDGS source[5]	30% sorghum DDGS vs. 30% Corn DDGS[6]
Initial BW, kg	58.7	58.7	58.9	58.8	58.7	58.8	3.38	0.94	0.96	0.94	0.91	0.98
d 0 to 73												
ADG, kg	1.05	1.02	0.99	0.99	1.02	1.02	0.02	0.01	0.53	0.88	0.19	0.88
ADFI, kg	3.18	3.13	3.05	3.08	3.06	3.04	0.07	0.04	0.40	0.77	0.89	0.99
G:F	0.329	0.325	0.326	0.322	0.335	0.336	0.01	0.26	0.92	0.89	0.15	0.88
Final BW, kg	134.6	132.6	130.4	129.5	133.3	132.4	5.64	0.04	0.74	0.73	0.26	0.43
Carcass characteristics[2]												
Jowl IV value	69.6	71.2	72.1	74.5	73.8	75.2	0.93	0.01	0.40	0.10	0.04	0.01
Backfat, mm[7]	26.2	24.1	23.4	22.8	23.2	22.6	0.98	0.01	0.23	0.54	0.81	0.35
Loin depth, cm[7]	5.9	5.9	5.8	5.8	5.9	6.0	0.22	0.44	0.84	0.90	0.39	0.29
FFLI, %[7,8]	48.8	49.5	49.8	50.0	49.9	50.1	0.38	0.01	0.22	0.54	0.82	0.36
HCW, kg	96.9	94.4	93.5	91.5	94.3	94.4	2.63	0.04	0.86	0.99	0.70	0.67
Carcass yield, %[9]	71.8	71.4	71.6	71.3	71.4	71.4	0.68	0.55	0.88	0.97	0.81	0.77

[1] A total of 288 pigs (Line TR4 × 1050, PIC, Hendersonville, TN) were used in the 73-d trial with 36 pens and 6 replications per diet.
[2] Values are the means of 6 pigs per pen and 6 pens per treatment collected at the Triumph Foods LLC packing plant, St. Joseph, MO.
[3] Contrasts compare only sorghum-based diets.
[4] Sorghum with 30% corn DDGS vs. Corn with 30% corn DDGS (Trt E vs. Trt F).
[5] Sorghum with 30% Sorghum DDGS vs. Sorghum with 30% Corn DDGS (Trt C vs. Trt E).
[6] Sorghum with 30% Sorghum DDGS vs. Corn with 30% Corn DDGS (Trt C vs. Trt F).
[7] Carcass characteristics adjusted using HCW as a covariate.
[8] FFLI=50.767+ (0.035 × HCW, kg) - (8.979 × BF, mm).
[9] Yield percent was calculated by dividing HCW by live weight (before transport to the packing plant, Triumph Foods, LLC. St Joseph, MO).

Table 3.8 Effect of sorghum dried distiller's grains with solubles (DDGS) on finishing pig carcass measurements[1]

	Treatments							Probability, *P* <				
	A	B	C	D	E	F						
	Grain source											
	Sorghum	Sorghum	Sorghum	Sorghum	Sorghum	Corn						
	DDGS source and level, %											
	None	Sorghum	Sorghum	Sorghum	Corn	Corn						
Item	0	15	30	45	30	30	SED	Linear DDGS[4]	Quad. DDGS[4]	Grain source[5]	DDGS Source[6]	30% sorghum DDGS vs. 30% corn DDGS[7]
Carcass measurements[2]												
Live wt, kg	135.1	136.5	133.7	137.8	135.6	137.1	4.07	0.68	0.64	0.73	0.65	0.42
HCW, kg	101.8	102.2	99.9	101.7	101.0	100.2	2.46	0.74	0.68	0.74	0.65	0.91
Carcass yield, %	74.05	74.45	74.74	74.29	73.78	74.61	0.58	0.87	0.62	0.18	0.81	0.83
Purge loss, %	4.14	3.84	4.07	4.54	4.52	4.77	0.82	0.58	0.51	0.76	0.59	0.40
Drip loss, %	3.14	3.31	3.24	3.00	2.89	2.92	0.33	0.34	0.62	0.94	0.30	0.33
pH	5.61	5.63	5.65	5.65	5.65	5.65	0.02	0.06	0.39	0.83	0.77	0.94
Backfat												
1st Rib, mm[2]	43.7	42.2	42.6	40.6	40.6	42.8	1.87	0.14	0.84	0.23	0.28	0.90
10th Rib, mm[2]	24.6	27.3	25.8	23.2	25.0	24.0	2.44	0.47	0.14	0.68	0.76	0.47
Last Rib, mm[2]	27.7	26.3	25.0	26.9	26.8	25.5	2.30	0.64	0.31	0.57	0.43	0.82
Last Lumbar, mm[2]	19.5	21.6	21.0	19.6	20.5	21.4	1.28	0.96	0.06	0.45	0.66	0.15
10th rib loin characteristics												
Loin muscle area, mm[2]												
Color	2.38	2.08	2.21	2.21	2.04	2.17	0.24	0.62	0.39	0.60	0.49	0.86
Firmness	1.50	1.25	1.50	1.67	1.50	1.08	0.22	0.29	0.19	0.07	1.00	0.07
Marbling	1.25	1.17	1.25	1.21	1.33	1.08	0.14	0.92	0.83	0.08	0.55	0.23
Loin eye color[3]												
L*	59.88	59.91	60.25	59.44	60.18	58.41	1.01	0.76	0.56	0.09	0.94	0.08
a*	10.92	10.84	10.76	10.09	10.69	10.09	0.36	0.03	0.26	0.11	0.84	0.07
b*	16.69	16.52	16.68	15.88	16.45	15.83	0.37	0.06	0.23	0.10	0.53	0.03
Fat color[3]												
L*	84.79	85.40	85.66	85.42	83.93	84.90	0.70	0.34	0.40	0.18	0.02	0.29
a*	3.33	3.40	2.97	2.39	3.24	2.67	0.31	0.01	0.15	0.08	0.40	0.34
b*	11.14	11.05	10.90	10.60	11.55	10.63	0.29	0.06	0.61	0.01	0.03	0.36

[1]Values represent the mean of 6 observations (1 barrow and 1 gilt) per treatment slaughtered at Kanas State University's Meat Laboratory.

[2]Carcass characteristics adjusted using HCW as a covariate.
[3]CIE L* on a scale of 0-100 (0=black; 100=white); CIE a* is the degree of redness; CIE b* is the degree of yellowness.
[4]Contrasts compare only sorghum-based diets.
[5]Sorghum with 30% corn DDGS vs. Corn with 30% corn DDGS (Trt E vs. Trt F).
[6]Sorghum with 30% sorghum DDGS vs. Sorghum with 30% corn DDGS (Trt C vs. Trt E).
[7]Sorghum with 30% sorghum DDGS vs. Corn with 30% corn DDGS (Trt C vs. Trt F).

Table 3.9 Effect of sorghum dried distiller's grains with solubles (DDGS) on backfat fatty acid analysis[1]

	A	B	C	D	E	F		Probability, *P* <				
Grain source	Sorghum	Sorghum	Sorghum	Sorghum	Sorghum	Corn						
DDGS source and level, %	None	Sorghum	Sorghum	Sorghum	Corn	Corn						
Item	0	15	30	45	30	30	SED	Linear DDGS[2]	Quad. DDGS[2]	Grain source[3]	DDGS source[4]	30% sorghum DDGS vs. 30% corn DDGS[5]
Myristic acid (C14:0), %	1.45	1.41	1.37	1.31	1.34	1.28	0.04	0.01	0.81	0.12	0.45	0.03
Palmitic acid (C16:0), %	25.17	24.83	23.87	22.77	23.22	22.90	0.42	0.01	0.22	0.45	0.14	0.03
Palmitoleic acid (C16:1), %	2.33	2.26	1.96	1.93	1.87	1.84	0.11	0.01	0.83	0.76	0.43	0.27
Margaric acid (C17:0), %	0.50	0.48	0.56	0.54	0.58	0.49	0.04	0.14	0.99	0.04	0.61	0.12
Stearic acid (C18:0), %	13.51	13.11	12.68	11.67	12.21	12.08	0.50	0.01	0.40	0.80	0.35	0.24
Oleic acid (C18:1 *cis*-9), %	40.68	39.91	38.30	37.53	36.19	37.42	0.53	0.01	1.00	0.03	0.01	0.10
Vaccenic acid (C18:1n-7), %	3.37	3.23	3.00	3.00	2.73	2.76	0.09	0.01	0.28	0.67	0.01	0.01
Linoleic acid (C18:2n-6), %	9.39	10.99	14.24	17.04	17.76	17.20	0.57	0.01	0.24	0.45	0.01	0.01
α-Linolenic acid (C18:3n-3), %	0.56	0.60	0.74	0.84	0.71	0.64	0.73	0.01	0.21	0.10	0.53	0.03
Arachidic acid (C20:0), %	0.27	0.28	0.26	0.24	0.25	0.26	0.04	0.07	0.23	0.76	0.76	1.00
Gadoleic acid (C20:1), %	0.85	0.89	0.82	0.49	0.76	0.81	0.01	0.10	0.22	0.27	0.15	0.74
Eicosadienoic acid (C20:2), %	0.53	0.61	0.73	0.82	0.85	0.88	0.04	0.01	0.81	0.55	0.01	0.01
Arachidonic acid (C20:4n-6), %	0.10	0.11	0.12	0.13	0.11	0.10	0.01	0.01	0.50	0.34	0.46	0.09
Other fatty acids, %	1.29	1.29	1.35	1.69	1.42	1.34	0.06	0.05	0.89	0.23	0.49	0.60
Total SFA,[6] %	41.12	40.32	38.93	36.74	37.82	37.22	0.78	0.01	0.21	0.44	0.16	0.04
Total MUFA[7], %	47.31	46.39	44.17	43.34	41.63	42.91	0.63	0.01	0.92	0.05	0.01	0.05
Total PUFA[8], %	10.55	12.24	15.74	18.77	19.38	18.77	0.80	0.01	0.20	0.45	0.01	0.01
Total *trans* fatty acids[9], %	0.80	0.85	0.99	1.07	0.95	0.87	0.05	0.01	0.68	0.09	0.46	0.02
UFA:SFA ratio[10]	1.41	1.45	1.54	1.69	1.61	1.66	0.05	0.01	0.18	0.46	0.15	0.03
PUFA:SFA ratio[11]	0.26	0.30	0.40	0.51	0.51	0.50	0.03	0.01	0.16	0.73	0.01	0.01
Iodine value, [12] g/100g	58.66	60.72	64.78	69.23	68.66	68.61	1.23	0.01	0.12	0.93	0.01	0.01

[1] All values are on a DM basis.
[2] Contrasts compare only sorghum-based diets.
[3] Sorghum with 30% corn DDGS vs. Corn with 30% corn DDGS (Trt E vs. Trt F).

[4] Sorghum with 30% Sorghum DDGS vs. Sorghum with 30% Corn DDGS (Trt C vs. Trt E).
[5] Sorghum with 30% Sorghum DDGS vs. Corn with 30% Corn DDGS (Trt C vs. Trt F).
[6] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]), brackets indicate concentration.
[7] Total MUFA = ([C14:1] + [C16:1] + [C18:1 cis-9] + [C18:1n-7] + [C20:1] + [C24:1]), brackets indicate concentration.
[8] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]), brackets indicate concentration.
[9] Total trans fatty acids = ([C18:1 trans] + [C18:2 trans] + [C18:3 trans]), brackets indicate concentration.
[10] UFA: SFA = (total MUFA + total PUFA)/total SFA.
[11] PUFA: SFA = total PUFA/total SFA.
[12] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723, brackets indicate concentration.

Table 3.10 Effects of sorghum dried distiller's grains with solubles (DDGS) on finishing pig apparent total tract digestibility [1,2]

	Treatments							Probability, *P* <				
	A	B	C	D	E	F						
	Grain source											
	Sorghum	Sorghum	Sorghum	Sorghum	Sorghum	Corn						
	DDGS source and level, %											
	None	Sorghum	Sorghum	Sorghum	Corn	Corn						
Item	None	15	30	45	30	30	SED	Linear DDGS[3]	Quad. DDGS[3]	Corn vs. Sorghum[4]	Corn DDGS vs. Sorghum DDGS[5]	30% Sorghum DDGS vs. 30% Corn DDGS[6]
Digestibility, %												
DM	93.1	94.7	93.4	94.2	93.9	93.2	1.52	0.35	0.08	0.20	0.16	0.90
N	54.8	68.6	64.7	71.1	75.4	78.9	3.04	0.01	0.10	0.25	0.01	0.01
GE	75.4	81.6	77.7	78.9	80.1	79.6	1.69	0.23	0.04	0.79	0.17	0.26
DE (kcal/kg)[7]	2,916	3,347	3,292	3,313	3,301	3,521	68.9	0.01	0.01	0.01	0.90	0.01

[1]A total of 288 pigs were used in a 73-d trial with 36 pens and 6 replications per diet.
[2]Fecal samples were collected on d 7 of phase 3 (d 63 of trial) via rectal massage from at least 4 pigs/pen.
[3]Contrasts only compare sorghum-based diets.
[4]Sorghum with 30% sorghum DDGS vs. Corn with 30% corn DDGS (Trt E vs. Trt F).
[5]Sorghum with 30% sorghum DDGS vs. Sorghum with 30% corn DDGS (Trt C vs. Trt E).
[6]Sorghum with 30% sorghum DDGS vs. Corn with 30% corn DDGS (Trt C vs. Trt F).
[7]DE (kcal/kg) is on an as-fed basis.

Chapter 4 - The effects of corn- or sorghum-based diets with or without sorghum dried distiller's grains with solubles on lactating sow and litter performance

ABSTRACT

A total of 140 sows (PIC 1050) and their litters were used to determine the effects of corn- or sorghum-based diets with or without 20% sorghum dried distiller's grains with solubles (DDGS) on lactating sow and litter performance. Sows were allotted to 1 of 4 dietary treatments on d 110 of gestation in a RCBD. Weaning age was 21 d. Treatments were arranged in a 2 × 2 factorial with main effects of grain source (corn vs. sorghum) and sorghum DDGS (0 vs. 20%; 32.1% CP and 9.2% crude fat). All diets were formulated to 0.97% standardized ileal digestible Lys but were not balanced for energy. Litters were equalized to 13 pigs per treatment. There were 2 and 1 sows removed from the study for the sorghum and sorghum-DDGS treatments because of initial feed refusal. Overall (d 0 to 21), a tendency ($P < 0.08$) for a DDGS × grain source interaction was observed as ADFI increased in corn-based diets when DDGS were added, but decreased in sorghum-based diets. Sows fed the sorghum-based diets had decreased ($P < 0.04$) lactation BW loss compared with those fed corn-based diets. Litter weaning weights tended to be lower ($P < 0.06$) for sows fed the diets containing DDGS compared with those fed the diets without DDGS. With sows fed the sorghum-based diet with 20% sorghum DDGS had the lightest litter weaning weight at 70.2 kg, weaning weights averaged 73.0 to 73.6 kg for the other dietary treatments. Following this trend, litter weight gain tended ($P < 0.09$) to decrease when sorghum DDGS were added to corn- or sorghum-based diets. No differences were observed in piglet survivability among the dietary treatments. Overall, feeding sows corn- vs. sorghum-based diets (without DDGS) in lactation did not affect litter performance; however, the 4% decrease in litter weaning weight of sows fed sorghum with 20% sorghum DDGS needs to be taken into account when selecting ingredients for lactating sows.

Key Words: lactation, sorghum, sorghum dried distiller's grains with solubles, sow

INTRODUCTION

In the Great Plains region of the United States sorghum grain is grown due to its resilience in drought conditions. As a result, sorghum DDGS are often available to swine producers due to the larger acreage of sorghum in the area and its use in ethanol production.

Grain sorghum is a suitable replacement for corn in swine nursery and finishing diets and has been found to produce similar pig growth performance when formulated in diets (Shelton et al., 2004; Issa, 2009; Benz et al., 2011). Previous research has found gestating sow performance is not affected by corn DDGS inclusion rates from 40 to 80% (Thong et. al, 1978; Monegue and Cromwell, 1995), and lactating sow performance is not affected by corn DDGS at an inclusion rate of 30% (Song et al., 2007; Greiner et al., 2008). Louis et al. (1991) observed no differences for lactation weight loss among sows fed corn- or sorghum-based diets; however, a reduction in litter weaning weights was observed for sows fed the sorghum-based diets.

Similarly to sorghum replacing corn in swine diets, Sotak et al. (2011a,b) found sorghum DDGS to have similar effects on growth performance as corn DDGS when formulated in nursery and finishing pig diets. Growth performance linearly decreased as sorghum DDGS were included in the nursery and finishing pig diets; however, substituting sorghum DDGS for corn DDGS in finishing pig diets could have positive ramifications for improved carcass characteristics due to decreased carcass fat and IV, along with improved fat quality. These growth performance results agree with previous research conducted by Feoli (2008) where they reported a reduction in pig performance when fed corn-based diets with 20% corn or sorghum DDGS.

Pedersen et al. (2007) reported corn DDGS contain greater concentrations of GE than corn; however, due to increased insoluble dietary fiber, energy digestibility is reduced in DDGS. This reduction in energy caused DDGS and corn to have similar DE and ME values.

While research has been performed on lactating sows using corn DDGS, more research needs to be conducted to determine the feeding value of sorghum DDGS for lactating sows.

MATERIALS AND METHODS

All practices and procedures used in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. This study was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan. The facility is a totally enclosed, environmentally controlled, mechanically ventilated barn. The barn contains 29 farrowing crates (2.13 × 0.46 m for the sow and 2.13 × 0.48 m for the pigs) that are each equipped with a single feeder and nipple waterer.

The sorghum, corn, and sorghum DDGS were analyzed for DM (AOAC 930.15), CP (AOAC 990.03), crude fat (AOAC 920.39), crude fiber (Ankom Method, Ankom Technology, Macedon, NY) , and ash (AOAC 942.05) at the Kansas State University Analytical Laboratory (Manhattan, KS). Standard ileal digestibility values for the sorghum DDGS were derived from Urriola et al. (2009). These values were then used in diet formulation (Table 3.1). The sorghum grain used in this study was a red pericarp variety, and the corn grain used was #2 Yellow dent. The corn DDGS used were golden brown, and the sorghum DDGS were slightly darker than the corn DDGS in visual color. Bulk densities (g/L) were measured on the treatment diets (Table 3.2).

A total of 140 sows (PIC 1050) and their litters were used to determine the effects of corn- or sorghum-based diets with or without 20% sorghum DDGS on lactating sow and litter performance. Sows were randomly allotted to 1 of 4 experimental diets throughout 5 farrowing groups using farrowing group as the blocking criteria. There were 7 sows per treatment with 4 replications per farrowing group. During gestation, all sows were fed a corn-based diet with 20% corn DDGS. Feed amounts in gestation were assigned based on sow body condition (Young et al., 2004).

Treatments were arranged in a 2 × 2 factorial with main effects of grain source (corn vs. sorghum) and sorghum DDGS (0 vs. 20%; Table 3.3). Sows had ad libitum access to water throughout the study. Sows were switched to their experimental diets on d 110 of gestation, corresponding to their move to the farrowing house. Sows had restricted access to feed from d 110 until farrowing (2 kg). Sows were fed 2.7, 3.6, and 5.4 kg on d 0 of farrowing and subsequent 2 d, respectively. Sows had ad libitum access to feed for the remainder of the lactation period.

Average daily feed intake was determined by measuring total feed disappearance to d 0, 7, 14, 21, and wean. Sow weights were measured as the sows were placed into the farrowing house on d 110 of gestation, within 24 h post-farrowing, and at weaning.

After birth, pigs were weighed and processed. Mummified and stillborn pigs were also recorded to calculate total born and live born piglets. Pigs were cross-fostered within 24 h post-farrowing to standardize litter size within dietary treatments. Pigs were weighed after fostering to measure fostered litter weight. Litters were weighed at weaning to determine litter weight gain and survivability.

Data were analyzed as a randomized complete block design with sow as the experimental unit and farrowing group as the blocking criteria. The study was analyzed using the MIXED procedure in SAS (SAS Institute, Inc., Cary, NC). Contrasts were used to make comparisons between the 1) interaction of DDGS × grain source, 2) corn- and sorghum-based diets, and 3) effects of 20% sorghum DDGS. Differences among treatments were considered significant with P-values ≤ 0.05 and trends if P-values > 0.05 and ≤ 0.10.

RESULTS

There was a tendency for a DDGS × grain source interaction for ADFI from d 0 to 7 (P = 0.06) and overall (P = 0.08; Table 3.4). Sows fed the basal corn diet consumed less feed than those fed the corn diet with 20% sorghum DDGS, but sows fed the basal sorghum diet consumed more feed than those fed the sorghum diet with 20% sorghum DDGS (Table 3.5). No differences were observed in sow ADFI from d 7 to 14 or d 14 to weaning. For overall (d 0 to 21) ADFI, a tendency (P < 0.08) was observed for a DDGS × grain source interaction with consumption mirroring the trend on d 7. There were 2 sows removed from the study for the sorghum-based diet and 1 sow from the sorghum-based diet with 20% sorghum-DDGS treatments because of feed refusals. There were an additional 1 and 2 sows removed from the study for the sorghum and sorghum-DDGS treatments because of illness, respectively. When 20% sorghum DDGS were included in the corn- or sorghum-based diets, bulk density of the dietary treatment decreased.

No differences were observed among the sows fed the corn- or sorghum-based diets with no DDGS compared with those fed the corn- or sorghum-based diets with 20% sorghum DDGS for BF at entry to the farrowing house, post-farrowing weight, sow weaning weight, lactation weight change, or lactation BF change. A decrease (P < 0.04) in lactation weight change was found for sows fed diets containing 20% sorghum DDGS when compared to those fed the corn- or sorghum-based basal diets. Sows fed sorghum-based diets had a numerical increase (P = 0.15) in lactation BF loss compared with those fed corn-based diets.

No differences in fostered litter size or weaned litter size were found, as well as for pig survivability among the dietary treatment groups. Additionally, no differences were observed for litter weaning weight; however, a numerical decrease was observed for sows fed 20% sorghum DDGS. A tendency ($P < 0.06$) for a 0.3 kg decrease in individual pig weaning weights was observed for sows fed the diets containing 20% sorghum DDGS. Furthermore, a tendency ($P < 0.09$) for decreased litter weaning weight gain was observed for sows fed diets with 20% sorghum DDGS. The litter weaning weight gain reduction was numerically greater for sows fed the sorghum-based diet with 20% sorghum DDGS compared to those fed the corn-based diet with 20% sorghum DDGS.

DISCUSSION

Louis et al. (1991) conducted 2 experiments to 1) compare the reproductive performance of sows fed corn- or sorghum-based diets and 2) measure energy and N digestibility of sows fed corn- or sorghum-based diets. They reported no differences were observed for sow lactation weight loss; however, sows fed the sorghum-based diet had decreased feed intake compared to those fed the corn-based diet. Furthermore, sows fed the corn-based diet weaned heavier litters than those fed the sorghum-based diet. The decrease in litter weaning weight observed by Louis et al. (1991) agrees with the results of this study where, although not significant, there was a 6% decrease in litter weaning weight gain from sows fed sorghum-based diets vs. those fed corn-based diets. In addition, there were trends ($P < 0.10$) for reduced pig weaning weight and litter weaning weight gain when sows were fed diets with 20% sorghum DDGS compared to diets without DDGS. In the 2nd experiment, Louis et al. (1991) observed a numerical increase in GE intake, DM digestibility, DE, and ME among pigs fed the corn-based diet vs. those fed the sorghum-based diet; however, like findings reported by Cousins et al. (1981) and Diggs, et al. (1965), these differences were not significant. Because of previous research (Cousins et al., 1981; Diggs et al., 1965), we expected sows fed the basal corn- and sorghum-based diets to perform similarly; however, a decrease in lactation weight loss was observed among sows fed corn-based diets vs. sows fed sorghum-based diets. As 20% DDGS were included; and therefore decreasing diet digestibility a tendency for decreased individual pig weight was observed.

Earlier research determined lactating sows could consume diets containing 30% corn DDGS without negatively affecting their performance or litter performance (Song et al., 2007;

Greiner et al., 2008). This study determined 20% sorghum DDGS does not negatively affect sow performance; however, when the diet is sorghum-based, a numerical increase in BF loss was measured. This increase in BF loss could be due to an increase in dietary crude fiber and a subsequent decrease in energy. The crude fiber in the sorghum DDGS was almost double of the corn DDGS source. Because the sorghum DDGS contained more dietary crude fiber than the corn DDGS, it is likely the sorghum DDGS contain a greater concentration of insoluble and soluble dietary fiber. Pedersen et al. (2007) determined corn DDGS contained approximately 35% insoluble fiber and 6% soluble dietary fiber. Therefore, the decrease in ADFI could be due to the increased fiber present in the sorghum-based diets or from a reduction in palatability as sorghum DDGS increased.

The decrease in feed consumption the first 7 d of the study observed for sows fed the sorghum-based diet with 20% sorghum DDGS could also be due to the transition from the corn-based diet with 20% corn DDGS lactation diet. This result is similar to Wilson et al. (2003) report of a decrease in feed intake during the first 7 d when DDGS were not fed during gestation.

In a series of 11 experiments, Pedersen et al. (2007) determined the apparent total tract digestibility (ATTD) of GE to be 90.4% for corn and 76.8% for corn DDGS. The measured concentrations of DE and ME were found to be similar to those concentrations found in corn. Sotak (unpublished) found the GE digestibilities of corn and sorghum DDGS (Prairie Horizon, Phillipsburg, KS) were 83.4% and 68.2%, respectively. Sows fed the sorghum-based diets had increased lactation BF loss compared to those fed the corn-based diets due to a reduction in dietary energy when 20% sorghum DDGS were included. These diets contained lower amounts of crude fat than the corn-based diets, and therefore, had less energy available to the sow. Overall, feeding sows corn- vs. sorghum-based diets (without DDGS) in lactation did not statistically affect litter performance; however, there was a 6% reduction in litter weight gain in sows fed sorghum-based diets. Furthermore there was a 4% decrease in litter weaning weight of sows fed sorghum with 20% sorghum DDGS. These factors need to be taken into account when selecting ingredients for lactating sows.

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FIGURES AND TABLES

Table 4.1 Dietary ingredient composition (as-fed basis)

Item, %	Corn	Sorghum	Sorghum DDGS[1]
DM	88.47	88.05	92.53
CP	8.10	8.61	32.05
Crude fat	2.96	2.72	9.23
Crude fiber	1.36	1.31	7.03
Ash	1.40	1.42	4.19

[1]Sorghum DDGS originate from Prairie Horizon ethanol plant (Phillipsburg, KS).

Table 4.2 Bulk densities of experimental diets by farrowing group (as-fed basis)[1]

	Grain source			
	Corn	Corn	Sorghum	Sorghum
	DDGS source and level, %			
	None	Sorghum	None	Sorghum
Item	0%	20%	0%	20%
Bulk density, g/L				
Group 1	741	666	781	678
Group 2	688	662	735	669
Group 3	672	620	752	649
Groups 4 & 5	759	666	801	688

[1]Bulk densities represent the mass per unit volume.

Table 4.3 Lactation diet composition (as-fed basis)[1]

	Grain source			
Item	Corn		Sorghum	
Ingredient, %	None	DDGS	None	DDGS
Corn	66.20	51.85	---	---
Sorghum	---	---	67.05	52.80
Soybean meal (46.5% CP)	30.00	24.50	29.10	23.45
Sorghum DDGS	---	20.00	---	20.00
Monocalcium P (21% P)	1.10	0.60	1.05	0.60
Limestone	1.40	1.66	1.44	1.68
Salt	0.50	0.50	0.50	0.50
Vitamin premix[2]	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15
Sow add pack[4]	0.25	0.25	0.25	0.25
Lysine HCl	0.03	0.13	0.08	0.18
Phytase[5]	0.14	0.14	0.14	0.14
Total	100	100	100	100
Calculated analysis				
Standardized ileal digestible amino acids, %				
Lysine	0.97	0.97	0.97	0.97
Isoleucine:lysine	76	79	80	81
Methionine:lysine	29	30	29	30
Met & Cys:lysine	60	61	58	59
Threonine:lysine	66	66	66	66
Tryptophan:lysine	22	21	23	22
Valine:lysine	85	90	88	91
Total lysine, %	1.10	1.13	1.08	1.12
CP, %	19.6	21.5	19.8	21.5
ME, kcal/kg	3,278	3,186	3,225	3,144
Ca, %	0.86	0.86	0.86	0.86
P, %	0.62	0.59	0.62	0.59
Available P, %[6]	0.43	0.43	0.43	0.43

[1]Diets were fed in meal form beginning on d 3 before farrowing.

[2]Vitamin premix provided per kg of complete feed: 11,023 IU of vitamin A, 1,377 IU of vitamin D, 44.1 IU of vitamin E, 4.4 mg of vitamin K, 0.04 mg of vitamin B_{12}, 50.0 mg of niacin, 27.6 mg of pantothenic acid, and 8.3 mg of riboflavin.

[3]Trace mineral premix provided per kg of complete feed: 16.5 mg of Cu from $CuSO_4 \cdot 5H_2O$, 0.30 mg of I as $C_2H_2(NH_2)_2 \cdot 2HI$, 165 mg of Fe as $FeSO_4H_2O$, 39.7 mg of Mn as $MnSO_4 \cdot H_2O$, 0.30 mg of Se as Na_2SeO_3, and 165 mg of Zn as $ZnSO_4$.

[4]Sow add pack provided the following nutrients per kg of complete diet: 22 IU of vitamin E; 0.22 mg of biotin; 1.65 mg of folic acid; 5 mg of pyridoxine (as pyridoxine HCl); 551 mg of choline (as choline Cl); 50 mg of L-carnitine; 0.20 mg of chromium (as chromium picolinate).

[5]Natuphos classic (BASF Corp.) provided (per kg of complete diet): 300 FTU of phytase.

[6]Phytase provided 0.08% available P to the diet.

Table 4.4 The effects of sorghum DDGS on lactating sow and litter performance[1,2]

	Grain Source					Probability, *P* <		
	Corn		Sorghum					
	DDGS source and level, %							
Item	None 0	Sorghum 20	None 0	Sorghum 20	SED	DDGS × Grain source	Control vs. DDGS[3]	Corn vs. Sorghum
Sows, n	35	35	32	32				
ADFI, kg								
d 0 to 7	5.19	5.43	5.88	5.31	0.31	0.06	0.44	0.18
d 7 to 14	6.04	6.13	6.44	6.02	0.26	0.17	0.37	0.43
d 14 to wean	6.11	6.27	6.61	6.36	0.28	0.30	0.81	0.13
d 0 to wean	5.76	5.93	6.30	5.88	0.24	0.08	0.46	0.15
Sow backfat, mm								
Entry	14.2	14.3	13.9	13.7	0.87	0.80	0.72	0.49
Weaning								
Change	-1.4	-1.3	-1.7	-2.2	0.62	0.39	0.65	0.15
Sow BW, kg								
Post-farrow	248.1	243.8	240.8	244.2	6.59	0.40	0.93	0.46
Weaning	233.8	229.9	229.9	234.5	6.45	0.35	0.93	0.93
Change	-14.3	-13.9	-11.0	-9.7	2.65	0.86	0.65	0.04
Piglets								
Litter size, n								
Fostered	12.6	13.0	12.6	12.7	0.24	0.69	0.28	0.75
Weaned	11.8	12.1	11.8	11.8	0.29	0.38	0.48	0.58
Piglet BW, kg								
Fostered litter	19.2	20.6	21.4	19.3	1.22	0.23	0.68	0.62
Litter weaning	73.6	73.0	73.4	70.2	2.90	0.53	0.34	0.46
Pig weaning	6.3	6.0	6.3	6.0	0.43	0.74	0.06	0.72
Litter weaning gain	55.4	53.0	54.0	48.1	3.54	0.47	0.09	0.20
Survivability, %[4]	93.7	93.1	93.7	92.8	1.84	0.11	1.00	0.70

[1]A total of 140 sows (PIC 1050) and their litters were used to determine the effects of sorghum DDGS on lactating sow and litter performance. There were 2 and 1 sows removed from the sorghum-based basal diet because of feed refusal and illness, respectively. There were 1 and 2 sows removed from the sorghum-based diet with 20% sorghum DDGS due to feed refusal and illness, respectively.

[2]Farrowing group was used as the blocking factor.

[3]Basal diets vs. diets with 20% sorghum DDGS.

[4]Survivability was calculated by dividing the weaned litter size by the fostered litter size.

Table 4.5 Main effects of grain source and DDGS on lactating sow and litter performance [1,2]

	Grain source			DDGS, %			Probability, $P <$	
Item	Corn	Sorghum	SED	0	20	SED	Grain source	0 vs. 20% DDGS
Sows								
ADFI, kg								
d 0 to 7	5.31	5.60	0.21	5.53	5.37	0.21	0.18	0.44
d 7 to 14	6.09	6.23	0.18	6.24	6.08	0.18	0.43	0.37
d 14 to wean	6.19	6.49	0.20	6.36	6.32	0.20	0.13	0.81
d 0 to wean	5.85	6.09	0.17	6.03	5.91	0.17	0.15	0.46
Sow backfat, mm								
Entry	14.3	13.8	0.60	14.1	14.0	0.60	0.49	0.72
Weaning								
Change	-1.3	-2.0	0.43	-1.6	-1.8	0.43	0.15	0.65
Sow BW, kg								
Post-farrow	245.9	242.5	4.56	231.8	232.2	4.46	0.46	0.93
Weaning	231.8	232.2	4.46	231.8	232.2	4.46	0.93	0.93
Change	-14.1	-10.4	1.83	-12.6	-11.8	1.83	0.04	0.65
Piglets								
Litter size, n								
Fostered	12.7	12.6	0.17	12.6	12.8	0.17	0.75	0.28
Weaned	11.9	11.8	0.20	11.8	11.9	0.20	0.58	0.48
Piglet BW, kg								
Foster	19.9	20.3	0.84	20.3	20.0	0.84	0.62	0.68
Litter weaning	73.3	71.8	2.01	73.5	71.6	2.01	0.46	0.34
Pig weaning	6.2	6.1	0.14	6.3	6.0	0.14	0.72	0.06
Litter weaning gain	54.2	51.1	2.40	54.7	50.5	2.43	0.20	0.09
Survivability, % [3]	94.3	93.8	1.27	94.1	94.1	1.27	0.70	1.00

[1] A total of 140 sows (PIC 1050) and their litters were used to determine the effects of sorghum DDGS on lactating sow and litter performance. There were 2 and 1 sows removed from the sorghum-based basal diet because of feed refusal and illness, respectively. There were 1 and 2 sows removed from the sorghum-based diet with 20% sorghum DDGS due to feed refusal and illness, respectively.

[2] Farrowing group was used as the blocking factor.

[3]Survivability was calculated by subtracting the weaned litter size from the fostered litter size.