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Nutrient database for sorghum distillers dried grains with solubles from ethanol plants in the western plains region and their effects on nursery pig performance[1,2]

K. M. Sotak,* R. D. Goodband,*[3] M. D. Tokach, S. S. Dritz,† J. M. DeRouchey,* and J. L. Nelssen*

*Department of Animal Sciences and Industry, College of Agriculture; and †Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University, Manhattan 66506-0201

ABSTRACT: Samples of sorghum distillers dried 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 Kansas and Texas. Each sample (n = 21) was analyzed for AA, DM, CP, crude fiber, crude fat, ash, NDF, ADF, trace minerals, and starch. Mean values (DM basis) 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 those within plants for most nutrients. Results of these analyses were used to formulate diets for 2 nursery trials. The 2 experiments were conducted to determine the effects of adding sorghum DDGS (29.0% CP and 7.2% crude fat) 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 used in a 34-d study. Pigs were allotted to 1 of 8 dietary treatments with 5 pigs per pen and 9 pens per treatment. 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%). Diets were formulated to 1.30 and 1.25% standardized ileal digestible (SID) Lys in phases 1 and 2, respectively, but were not balanced for energy. Overall, 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, $P < 0.01$). There was a DDGS × grain source interaction (linear, $P < 0.04$) observed for G:F. In corn-based diets, pigs fed increasing sorghum DDGS had relatively similar G:F. However, in pigs fed sorghum-based diets, G:F was best for those fed 0% DDGS but was decreased in pigs fed 15, 30, or 45% sorghum 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 or sorghum DDGS). Diets were formulated to 1.27% SID Lys and were not balanced for energy. Overall, there were no differences in ADG among pigs fed sorghum- or corn-based diets as well as no differences among pigs fed sorghum or corn DDGS. Pigs fed diets with 30% DDGS gained less ($P < 0.03$) than pigs fed basal diets. These results indicate sorghum can be a suitable replacement for corn in nursery pig diets, but increasing sorghum DDGS decreased ADG.

Key words: corn, distillers dried grains with solubles, nursery pigs, nutrient analysis, sorghum

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INTRODUCTION

Distillers dried grains with solubles (**DDGS**) is a by-product of ethanol production that is commonly used in swine diets to lower feed costs, but concerns about consistency and quality variation among ethanol plants present challenges to swine nutritionists in formulating diets with DDGS. Distillers dried grains with solubles also tend to have low Lys and Trp concentrations, thus limiting their inclusion rate (Spiehs et al., 2002). Quality of DDGS depends on crop selection, fermentation,

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[3]Corresponding author: goodband@k-state.edu
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and drying temperature and duration (Spiehs et al., 2002). Although most of the information gathered to date has focused on corn DDGS, little information is available about 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 dry 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% of the value for 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. Therefore, the objectives of these studies were to determine the nutrient content of Great Plains sorghum DDGS and to compare corn- and 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 and TX = 1) in May and June 2010. Four of the plants contributed 4 individual samples, and 1 plant contributed 5 individual samples. Of the 5 ethanol plants, 3 produced pure sorghum DDGS whereas 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; method 975.44; AOAC Int., 2007), AA analysis (University of Missouri-Columbia, Columbia, MO; AOAC Int., 2007), 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 + ether extract + Ash + NDF)]} – (16 × ADF); Ewan (1989),

ME kcal/kg = (1 × DE) – (0.68 × CP); Noblet and Perez (1993), and

NE kcal/kg = (0.726 × ME) + (13.3 × ether extract) + (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. Descriptive statistics also were used to calculate the standard deviation from samples within each plant, within all samples of each DDGS type, and among plants within each DDGS type (Tables 1, 2, 3, and 4).

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 approximately 19 d of age at weaning and were fed a common pelleted starter diet for 7 d. At weaning, pigs were allotted to pens by initial BW. Pens of pigs were randomly allotted in a completely randomized design to 1 of 8 treatments on d 7 postweaning; therefore, d 7 postweaning is d 0 of the experiment. There were 5 pigs/pen and 9 pens/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). Standardized ileal digestibility (**SID**) values for the sorghum DDGS were derived from Urriola et al. (2009). The SID values for corn DDGS were derived from Stein (2007). Other nutrient values for sorghum DDGS were derived from previous analyses of sorghum DDGS samples collected from the ethanol plant where the sorghum DDGS used for this study originated (source 1; Table 5). The digestibility of P in sorghum DDGS was assumed to be equal to that of corn DDGS (77%). The sorghum

Table 1. Proximate analysis of sorghum distillers dried grains with solubles (DDGS) from ethanol plants located in the Western Plains region (DM basis)

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

[1]Values in parentheses represent the SD of the mean.

[2]Pure samples made from 100% sorghum DDGS.

[3]Sorghum–corn sample made from 60% sorghum and 40% corn.

[4]Sorghum–corn sample made from 70% sorghum and 30% corn.

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 6 and 7, respectively). All pigs and feeders were weighed on d 0, 14, and 34 to determine 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. Pigs were allotted to pens by initial BW to achieve the same average weight for all pens at weaning. Like Exp. 1, pens of pigs were randomly allotted to 1 of 6 dietary treatments on d 17 postweaning; therefore, d 17 postweaning is d 0 of the experiment. There were 6 pigs/pen and 5 pens/treatment. Each pen (1.2 × 1.5 m) had woven wire flooring, one 3-hole, dry self-feeder, and a 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 one used in Exp. 1. Dietary treatments were fed for 21 d (Table 8). Pigs and feeders were weighed on d 0, d 7, d 14, and d 21 to determine 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 Inst. 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.

Table 2. Essential AA concentrations for sorghum distillers dried grains with solubles (DDGS) from ethanol plants located in the Western Plains region (DM basis)

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

[1]Values in parenthesis represent the standard deviation of the mean.

[2]Pure samples made from 100% sorghum.

[3]Sorghum–corn sample made from 60% sorghum and 40% corn.

[4]Sorghum–corn sample made from 70% sorghum and 30% corn.

[5]Assumed DM of 89.0% for nutrient calculations.

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, 2, 3, and 4). Care must be exercised in that there are only 3 ethanol plants contributing samples of the pure sorghum DDGS and 2 plants for the sorghum–corn blend DDGS. Further samples were collected over a 2 mo period. For the pure sorghum samples, the average DM was 89.5% with a standard deviation of 0.96% (Table 1). The average CP was 34.2% with a standard deviation of 3.78%. The CP in DDGS from the two Kansas ethanol plants was consistently between 31 and 33%, with CP from the Texas plant considerably greater at 39.1%. It is possible that differences in initial CP content of the sorghum from each geographic location may have contributed to the differences in CP content to the individual 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. 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 greater than the CP of the grain from which it originated; therefore, 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 a 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%, less than the reported values in the present study.

For the pure sorghum DDGS samples, the average ADF was 26.43% with a standard deviation of 4.96%, and the average NDF was 35.07% with a standard deviation of 5.34%. 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 with the DDGS in the present study.

For AA, the average Lys content in the pure sorghum DDGS was 0.88% whereas the sorghum–corn DDGS samples had a value of 0.87% (Table 2). Feoli (2008) reported sorghum-based DDGS had 0.97% Lys, but Stein (2007) reported corn DDGS had 0.88% Lys. For sorghum grain, the NRC (1998) published a Lys

Table 3. Mineral composition of distillers dried grains with solubles (DDGS) from ethanol plants located in the Western Plains region (DM basis)

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

[1]Values in parentheses represent the standard deviation of the mean.
[2]Pure samples made from 100% sorghum.
[3]Sorghum–corn sample made from 60% sorghum and 40% corn.
[4]Sorghum–corn sample made from 70% sorghum and 30% corn.

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's (2008) value of 0.17% but similar to Stein's (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 less than Feoli's (2008) sorghum DDGS of 0.59% and Stein's (2007) corn DDGS value of 0.62%.

For pure sorghum DDGS, Arg (1.17%), His (0.67%), and Phe (1.48%) average values were less 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 based 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% whereas the content of the sorghum–corn DDGS samples was 0.74% (Table 3).

The average ash concentration in the pure sorghum DDGS samples was 4.42%, with the Kansas ethanol plants (5.02 and 4.93%) producing higher values 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 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 (DM basis) whereas the GE for sorghum–corn DDGS samples was 4,825 kcal/kg with a standard deviation of 62.1 (DM basis; Table 4). The GE values for the sorghum–corn DDGS samples were greater than those of the pure sorghum DDGS samples, which was expected because corn has a greater energy content than sorghum grain (NRC, 1998). In comparison, Feoli (2008) reported a DE value of 3,466 kcal/kg for sorghum DDGS whereas Stein (2007) reported 4,140 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 4). The difference

Table 4. Energy concentration and particle size of sorghum distillers dried grains with solubles (DDGS) from ethanol plants located in the Western Plains region (DM basis)

Sample origin	No. of samples	Energy, kcal/kg[1]				Particle size, µm	
		GE	DE[2]	ME[3]	NE[4]	Mean	SD
Pure samples[5]							
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[6]	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[7]	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	Sorghum DDGS	4,921	3,466	–	–	–	–
Stein, 2007	Corn DDGS	5,434	4,140	3,898	–	–	–
NRC, 1998	Sorghum grain	–	3,799	3,752	2,533	–	–

[1]Values in parentheses represent the standard deviation of the mean from all individual samples.

[2]DE = –174 + (0.848 × GE) + {2 × [100 – (CP + ether extract + Ash + NDF)]} – (16 × ADF).

[3]ME = (1 × DE) – (0.68 × CP).

[4]NE = (0.726 × ME) + (13.3 × ether extract) + (3.9 × starch) – (6.7 × CP) – (8.7 × ADF).

[5]Pure samples made from 100% sorghum.

[6]Sorghum–corn sample made from 60% sorghum and 40% corn.

[7]Sorghum–corn sample made from 70% sorghum and 30% corn.

in energy content between sorghum grain and sorghum DDGS is wider than we expected. Research has shown that corn and corn DDGS have similar energy values (Pedersen et al., 2007). Also, the energy value standard deviations of the pure sorghum DDGS were approximately double those of the sorghum–corn DDGS, meaning variation in energy content was larger within samples for the pure sorghum DDGS compared with the sorghum–corn DDGS samples.

Particle size of the pure sorghum DDGS samples varied from 447 to 843 µm, with an average of 670 µm. Range in average particle size between plants was considerable, which may have been influenced by the initial grind size of the sorghum before fermentation. The average of the sorghum–corn DDGS samples was 632 µm. Particle size, fat, and DM are generally considered the three biggest contributors to the flow ability of both corn and sorghum DDGS, with greater mois-

Table 5. Formulated and analyzed nutrient composition of ingredients (as-fed basis)

Item	Sorghum		Corn		Sorghum distillers dried grains with solubles (DDGS)		Corn DDGS	
	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).

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

	Corn				Sorghum			
	Sorghum distillers dried 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
TSAA: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,[4] %	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 kilogram 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 kilogram 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]Based on NRC (1998).

ture and fat content and smaller particle size negatively affecting flow ability.

Experiment 1

From d 0 to 14, a DDGS × grain source interaction (linear, $P < 0.04$) was observed for G:F. In corn-based diets, pigs fed increasing sorghum DDGS had relatively similar G:F. However, in pigs fed sorghum-based diets, G:F was best for those fed 0% DDGS but was decreased in pigs fed 15, 30, or 45% sorghum DDGS. Grain source did not influence ADG or ADFI; however, ADG decreased (linear, $P < 0.01$) as sorghum DDGS increased in the diet due to a tendency ($P < 0.07$) for decreased ADFI (Table 9).

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 decreased ($P < 0.01$) for pigs fed sorghum-based diets. Increasing sorghum DDGS in the corn- and sorghum-based diets decreased ADG (linear, $P < 0.01$), decreased 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

Table 7. Composition of diets, (d 14 to 34, Exp. 1, as-fed basis)[1]

	Corn				Sorghum			
	Sorghum distillers dried 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
TSAA: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, %[4]	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 kilogram 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 kilogram 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]Based on NRC (1998).

sorghum DDGS increased in corn-based diets, G:F was identical for pigs fed 0, 15, and 30% DDGS but decreased for those fed 45% DDGS. In sorghum-based diets, G:F was best for those fed 0% DDGS but was decreased 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 decreased ($P < 0.05$) 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), no grain source × DDGS interaction was observed for ADG, ADFI, and G:F (Table 10). There were no differences among pigs fed diets containing either corn or sorghum DDGS for growth performance and in final BW.

As observed in Exp. 1, ADG and ADFI were not different 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 10). Increasing DDGS from 0 to 30% reduced ($P < 0.03$) ADG but did not affect ADFI or G:F.

Grain sorghum has been shown to be a suitable replacement for corn in nursery pig diets. In both experi-

Table 8. Composition of diets, (d 0 to 21, Exp. 2, as-fed basis)[1]

	Grain source					
	Corn			Sorghum		
	Distillers dried grains with solubles (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
TSAA: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, %[5]	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 kilogram 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 kilogram 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 phytase units/kg, with release of 0.1% available P.

[5]Based on NRC (1998).

ments, 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 decreased 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 regarding a decrease in nursery pig growth per-

Table 9. Effects of sorghum distillers dried grains with solubles (DDGS) on nursery pig performance (Exp. 1)[1]

	Grain source									Probability, $P <$				
	Corn				Sorghum					DDGS × grain source		Corn vs.	DDGS	
	Sorghum DDGS, %													
Item	0	15	30	45	0	15	30	45	SED	Linear	Quadratic	sorghum[2]	Linear	Quadratic
Initial BW, kg	6.9	6.8	6.8	6.8	6.8	6.8	6.8	6.8	0.4	0.60	0.83	0.82	0.63	0.91
d 0 to 14														
ADG, g	313	302	294	282	336	308	286	288	21	0.49	0.46	0.53	0.01	0.49
ADFI, g	465	464	441	412	442	469	440	433	29	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	0.040	0.04	0.23	0.47	0.18	0.05
d 14 to 34														
ADG, g	610	602	586	534	600	585	603	563	24	0.16	0.70	0.70	0.01	0.15
ADFI, g	962	947	928	891	964	984	992	950	39	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	0.013	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	0.51	0.57	0.60	0.01	0.47
ADFI, g	757	748	728	694	749	772	765	736	32	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	0.013	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	1.8	0.39	0.51	0.53	0.01	0.61

[1]A total of 360 nursery barrows (Line 1050; PIC, Hendersonville, TN; 7 d postweaning) 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).

formance 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 structures for the experiments conducted by Senne et al. (1995, 1996) to make diets isocaloric, but these differences also could 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. Although DDGS have a greater concentration of GE than corn or sorghum grains, the digestibility of this energy is considerably less than (Pedersen et al., 2007). In a series of 11 experiments, Pedersen et al. (2007) determined the apparent total tract digestibility 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

Table 10. An evaluation of corn and sorghum distillers dried grains with solubles (DDGS) on nursery pig performance (Exp. 2)[1]

	Treatments										
	A	B	C	D	E	F					
	Grain source							Probability, $P <$			
	Corn			Sorghum							
	DDGS source and level, %										
	None	Sorghum	Corn	None	Sorghum	Corn		Grain source × DDGS interaction	Corn vs. sorghum[2]	DDGS source[3]	Control vs. DDGS[4]
Item	0	30	30	0	30	30	SED				
Initial BW, kg	10.7	10.7	10.7	10.7	10.7	10.7	0.8	1.00	0.93	0.94	0.96
ADG, g	529	496	513	540	521	499	20	0.38	0.56	0.86	0.03
ADFI, g	807	819	805	862	837	800	32	0.47	0.89	0.39	0.32
G:F	0.656	0.606	0.638	0.627	0.625	0.623	0.024	0.22	0.46	0.27	0.14
Final BW, kg	21.8	21.1	21.5	22.0	21.6	21.2	1.3	0.60	0.74	0.85	0.13

[1]A total of 180 nursery pigs (Line 327 × 1050; PIC, Hendersonville, TN; 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 (treatments A, B, and C vs. treatments D, E, and F).

[3]Corn DDGS vs. sorghum DDGS (treatments C and F vs. treatments B and E).

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

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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