Title: Impact of DDGS Particle Size on DM, Energy, Nitrogen, and Phosphorus Digestibility in Diets for Growing Pigs - **NPB#09-037**

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Industry Summary:

The objectives of this study were to determine DE and ME content, and evaluate the effect of different particle sizes of distillers dried grains with solubles (DDGS) at a 30% dietary inclusion rate in corn diets on DM, energy, nitrogen, and phosphorus digestibility and flowability in growing pigs. One source DDGS was processed through a hammer mill to achieve of mean particle sizes of 818, 595, and 308 µm, respectively. The control diet was based on corn (96.8%), with supplemental minerals and vitamins. Three additional diets were formulated by replacing 30% of corn from the control diet with DDGS of different particle sizes. Thirty six growing pigs (initial body weight of 40 ± 1.13 kg) were assigned to 1 of 4 treatments in a randomized complete block design according to their body weight and housed in individual metabolic crates for a 9 day adaptation period followed by a 4 day total collection of feces and urine. Pigs were provided free to access water and fed an amount of experimental diets equivalent to 3% BW. Samples were analyzed for dry matter, gross energy, nitrogen, and phosphorus, and diet apparent total tract digestibility, as well as DE and ME content of corn and DDGS particle sizes, were calculated. Diet drained and poured angles of repose were measured using a modified Hele-Shaw cell method to evaluate diet flowability.

Our results confirm that adding 30% DDGS to a corn based diet reduces flowability, and grinding DDGS to 308 µm further reduces flowability compared to 594 and 818 µm particle sizes. Adding 30% DDGS to a corn based diets decreases dry matter digestibility, which will result in an increase in fecal excretion and manure production. However, for each 25 micron decrease in DDGS particle size from 818 microns to 308 microns, the ME contribution of DDGS to the diet is increased by 13.7 kcal/kg DM. If it is economic and feasible to pellet DDGS diets, the concern about flowability is eliminated and the extra energy value from using finely ground DDGS can be realized. However, if pelleting is not a viable option, and diets must be manufactured and fed in meal form, flowability may be acceptable if the DDGS particle size is greater than 600 µm, and some of the improved ME value of DDGS from a reduced particle size can be obtained. Compared to the price (e.g. $330/ton) and energy value (e.g. 7,956 kcal/kg) of choice white grease as an energy source in

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grower-finisher swine diets, the difference in economic value of increased ME content for DDGS with particle size of 308 µm compared to 818 µm would be approximately $25.50 per ton of DDGS. Based on our results, DDGS particle size does not affect protein and phosphorus digestibility, so there is no additional economic or feeding value due to particle size on these economically important nutrients.

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Scientific Abstract:

Impact of DDGS particle size on nutrient digestibility, DE and ME content, and flowability in diets for growing pigs P. Liu, L.W.O. Souza, and G.C. Shurson, University of Minnesota, St. Paul.

A study was conducted to determine DE and ME content, and evaluate the effect of different particle sizes of distillers dried grains with solubles (DDGS) at a 30% dietary inclusion rate in corn diets on DM, energy, nitrogen, and phosphorus digestibility and flowability in growing pigs. One source DDGS was processed through a hammer mill to achieve of mean particle sizes of 818, 595, and 308 µm, respectively. The control diet was based on corn (96.8%), with supplemental minerals and vitamins. Three additional diets were formulated by replacing 30% of corn from the control diet with DDGS of different particle sizes. Thirty six growing pigs (initial BW of 40 ± 1.13 kg) were assigned to 1 of 4 treatments by RCB design according to their BW and housed in individual metabolic crates for a 9 d adaptation period followed by a 4 d total collection of feces and urine. Pigs were provided free access to water and fed an amount of experimental diets equivalent to 3% BW. Samples were analyzed for DM, GE, N, and P, and diet ATTD as well as DE and ME of corn and DDGS particle sizes were calculated. Diet drained and poured angles of repose were measured using a modified Hele-Shaw cell method to evaluate the diet flowability. Inclusion of 30% DDGS with 308 µm improved ($P < 0.05$) dietary ATTD of DM and GE, as well as DE (4006 vs. 3783, kcal/kg DM) and ME (3861 vs. 3583, kcal/kg DM) compared to 818 µm DDGS. No differences were found in N and P digestibility among 3 DDGS particle size diets. The DDGS particle size of 595 µm had higher ($P < 0.05$) DE, but not ME compared to 818 µm DDGS, and DE and ME were not different between 308 and 595µm. Compared with a 595 µm or 818 µm DDGS, grinding DDGS to 308 µm reduced diet flowability indicated by a higher ($P < 0.05$) drained angle of repose. These results suggested that for each 25 micron decreased in DDGS particle size from 818 microns to 308 microns, the ME contribution of DDGS to the diet is 13.6 kcal/kg DM, but diet flowability will be reduced.

Introduction:

It is well documented that particle size of complete feeds and feed ingredients affects nutrient digestibility. By reducing diet particle size, more surface area of the feed is exposed to digestive enzymes resulting in a subsequent improvement in nutrient digestibility and reduction in fecal excretion (manure production). Several researchers have consistently demonstrated improvements in growth rate and feed conversion when feeding diets of low average particle size compared to feeding more coarsely ground diets (Lawrence, 1983; Hedde et al., 1985; Goodband and Hines, 1988; Giesemann et al., 1990; Cabrera et al., 1994; and Healy et al., 1994). In general, for every 100 µm in particle size above 600 µm, feed:gain is increased by 1.3% (Wondra et al., 1995). Improved feed conversion corresponds to a reduction in fecal (manure) excretion.

Recently, Gaines and Kocher (2008) reported that the increased contribution of ME from corn in swine finishing diets based on each 25 micron increase in particle size from 450 microns to 850 microns was 3 kcal/lb. This relationship has not been determined for DDGS. Apparent total tract digestibility of energy in DDGS is lower than in corn because of the higher concentration of fiber. Corn DDGS fiber has low digestibility in the small intestine and the fermentation of this fiber in the large intestine to produce volatile fatty acids is less than 50% complete. As a result, DDGS has lower apparent total tract digestibility of energy (82.9%) compared with corn (90.4%; Pedersen et al., 2007). However, because of the higher oil concentration in corn DDGS than in corn, the concentration of gross energy (GE) is greater in DDGS than in corn (5,434 vs. 4,496 kcal GE/kg dry matter; DM; Pedersen et al., 2007). The net result is that the concentration of digestible energy (DE) in corn DDGS is similar to that found in corn (4,088 vs. 4,140 kcal DE/kg DM; Stein et al., 2005; Pedersen et al., 2007).

The effects of extrusion and dietary inclusion rate of DDGS on nitrogen retention of growing pigs has been determined by Dietz et al. (2008). As the level of DDGS increased in the diet, fecal N concentration increased but the concentration of N in the urine decreased. Extrusion and inclusion of DDGS in the diet reduced the amount of N digested per day, and the digestibility of N as a percentage of N intake decreased when DDGS was included in the diet but it was not affected by extrusion. Nitrogen retention also tended to be reduced by dietary inclusion of DDGS and was reduced by extrusion, resulting in a trend for reduced net protein utilization from extrusion. These results suggest that extrusion of diets containing DDGS may reduce N retention in growing pigs, but the effects of DDGS particle size on N digestibility and retention are unknown.

Fermentation results in the release of a portion of the phytate bound phosphorus in corn, which in turn results in a greater digestibility of P in fermented feed ingredients than in corn. Therefore, the apparent total tract digestibility of phosphorus is much greater in DDGS than in corn (Pedersen et al., 2007). However, there are no data on the effects of DDGS particle size on apparent total tract digestibility of phosphorus in growing pigs.

Two DDGS nutrient analysis and physical characteristics surveys were conducted by researchers at the University of Minnesota in 2004 (34 samples from ethanol plants in 11 different states) and 2005 (35 samples). Average particle size was between 665 to 737 µm, but the range in particle size was extremely large 73 to 1217 µm. Therefore, depending on the particle size of the source being used, energy and nutrient digestibility of DDGS could vary significantly (potentially 137 kcal difference between the low and high particle size in this range) based on particle size, if the same relationship reported by Gaines and Kocher (2008) for corn applies to DDGS. Based upon the current price ($330/ton) and ME value (3608 kcal/lb) of choice white grease (energy source), this potential difference in energy value of DDGS due to the range in particle size would be approximately $12.50 per ton of DDGS. If particle size similarly affects protein and phosphorus digestibility, this difference in value would be even greater.

Objectives:

The aim of this research study is to determine the effects of particle size (1200, 900, 600, and 300 μm) of distillers dried grains and solubles (DDGS) on dry matter, energy, nitrogen, and phosphorus digestibility in growing pigs.

Materials & Methods:

<u>Animals and housing</u>

Thirty six barrows weighing approximately 40 kg were housed individually in metabolism cages at the Southern Research and Outreach Center in Waseca, Minnesota, to facilitate separate total collection of feces and urine. Pigs were allowed a 9-d period to adapt to their assigned diets followed by a 4-d period in which all feces and urine from each pig were collected. Pigs were fed a daily amount of feed equivalent to 3 times maintenance energy requirements (about 3% of body weight) during the adaptation period and collection period. Feeders were located at the front of each metabolism cage and a nipple water was located at the side of the cage to provide pigs *ad libitum* access to water. The amount of feed provided to animals was recorded at each feeding time. Any feed remaining from the previous feeding period was removed, weighed, and subtracted from the amount added to determine average daily feed disappearance. Pig weights were determined on d 0.

<u>DDGS Sourcing and Particle Size Processing</u>

The original intent of this project was to work with a commercial ethanol plant to obtain DDGS samples with different levels of particle sizes by modifying the fineness of grind of the corn used to produce DDGS. By using this approach, we were hopeful that we could standardize nutrient composition and focus only particle size effects to avoid confounding the results using multiple DDGS sources of different particle sizes. After extensive discussion with a number of ethanol plants and DDGS marketers, we were unsuccessful in finding a participant willing to go through the extra work of changing the fineness of grind and alter ethanol yields and the fermentation process. We then obtained sample particle size, mycotoxin, and nutrient composition data from several ethanol plants and selected a source that had consistently low levels of mycotoxins and the highest average particle size. One ton of DDGS for the low mycotoxin, high particle size source was shipped to Agricultural Utilization Research Institute in Waseca, MN for actual particle size determination and particle size reduction. The actual DDGS particle size of the source used was 818 μm, which was less than desired to give 4 particle size treatments as originally proposed. Therefore, the original particle size of the delivered DDGS served as the highest particle size in the experiment. After several DDGS grinding tests using different equipment, we chose to use an Urshel Commitrol with a 0060 cutter head to produce a 594 μm medium particle size, and a hammermill with a 5/32 inch screen to produce a 308 μm fine particle size DDGS for the experimental diets.

In addition, a sample of the DDGS delivered was analyzed for mycotoxin concentrations. There were no detectable levels of aflatoxin or fumonisin, but low levels of deoxynivalenol (1 ppm) and zearalenone (200 ppb) were detected, but were considered to be low enough to have minimal impact on our results.

<u>Experimental design and diets</u>

Each barrow was assigned to one of 4 experimental diets (9 pigs per dietary treatment) according to a completely randomized design: a corn basal diet (particle size 878 μm) containing 0.15% synthetic lysine (CON); and three CON diets containing 30% DDGS with particle size 818 μm (coarse), 594 μm (medium), or 308 μm (fine). The basal diet was formulated on an available P basis and was designed to meet the pig's requirements for all minerals and vitamins (Table 1). Corn was replaced with 30% DDGS in each of the 3 particle size diets. Based on the NRC nutrient composition of corn and corn DDGS used for swine, nutrient composition of the basal and DDGS diets were calculated shown in Table 1. The experimental diets were manufactured at the University of Minnesota Southern Research and Outreach Center, Waseca, MN feed mill and delivered in labeled bags to the swine metabolism unit. A sample of each batch of experimental diet was collected and retained for subsequent nutrient analysis. Samples of the corn basal diet and the three 30% DDGS diets of different particle sizes were collected and analyzed for poured and drained angle of repose (McGlinchey, 2005) using a modified Hele-Shaw cell (Johnston et al., 2009).

Table 1. Ingredients of corn basal diet for finishing pigs (as-fed basis)

Ingredient	**Corn basal**	**DDGS**
Corn	96.8	66.8
DDGS	0.0	30.0
Dicalcium phosphate	1.2	1.2
Limestone	0.9	0.9
Sodium chloride	0.4	0.4
Vitamin-trace mineral premix[1]	0.5	0.5
Total	100.0	100.0
Calculated analysis		
ME, kcal/kg	3310	3131
Crude protein, %	8.03	15.00
Total P, %	0.49	0.62
Available P, %	0.26	0.40
Ca, %	0.62	0.67
Total Lys, %	0.25	0.36
SID Lys, %	0.33	0.45

[1]Provided the following per kilogram of diet: vitamin A, 7,716 IU; vitamin D_3, 1,929 IU; vitamin E, 39 IU; vitamin B_{12}, 0.04 mg; riboflavin, 12 mg; niacin, 58 mg; pantothenic acid, 31 mg, Cu (oxide), 35 mg; Fe (sulfate), 350 mg; I (CaI), 4 mg; Mn (oxide) 120 mg; Zn (oxide), 300 mg; Se (Na_2SeO_3), 0.3 mg.

Sample collection

Feed and ingredient samples were retained from each experimental diet and stored at -18˚C until subsequent analysis was performed. After the adaptation period, feces and urine from each pig will be collected for a period of 4 days. During collection period, fecal samples were collected at least 3 times per day, weighed, sealed in plastic bags, and stored in a freezer at -18˚C. For each pig, fecal samples were pooled, weighed, and dried in a forced-draft oven at 55-60˚C. After drying and grinding, subsamples from the whole sample were prepared for further chemical analysis. Total urine output was collected twice daily in a plastic container located under funnels of the metabolism cages. One hundred milliliters of 10% HCl was added to the urine collection containers during the 4 collection days to limit microbial growth and to reduce loss of ammonia. Urine volume was recorded twice daily and a subsample of about 10 to 30% of the urine excreted from each pig, was collected in labeled, capped, plastic containers, and stored in a freezer at approximately -18˚C until the end of the collection period. Urine samples were pooled for each pig and a subsample was used for further analysis. Urine samples were freeze-dried for energy determination.

Chemical analysis

Gross energy content of corn, DDGS, experimental diets, feces, and urine was determined by bomb calorimetry. Nitrogen content of feed, feces, and urine was determined by the LECO combustion method. From these data, we calculate DE, ME and nitrogen-corrected ME content of the diets and test ingredients using the difference approach outlined by Adeola (2001). Phosphorus concentration in feed, feces, and urine was determined using ICP procedures to determine P digestibility AOAC (1990).

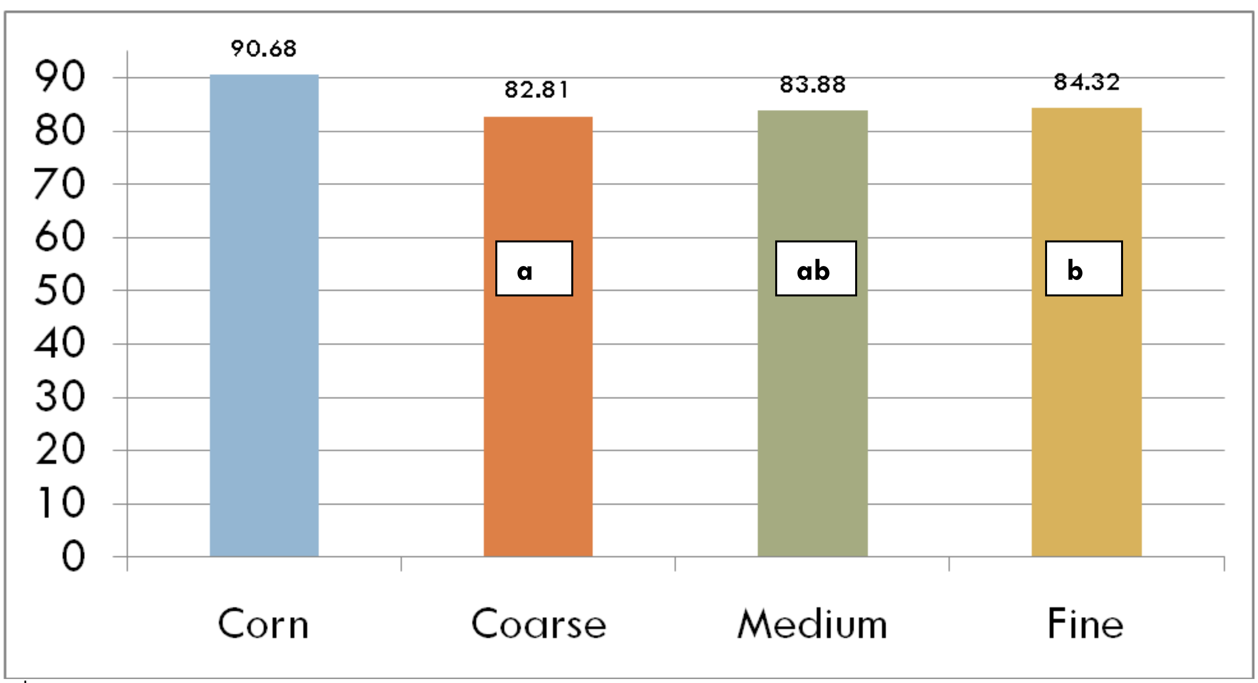
Statistical analysis

Data were analyzed using Proc Mixed Procedures of SAS (SAS Institute Inc., Cary, NC) using pig as the experimental unit. The UNIVARIATE procedure of SAS was used to test homogeneity of the data and the residual vs. the predicted plot procedure was used to check normality and outliers of the data set. All the data had a normal distribution, equal variance, and no outliers. Apparent total tract digestibility of DM, GE, N, and P, as well as DE and ME from three different particle sizes of DDGS and DDGS diets were compared by two-way ANOVA using particle size as a fixed effect and block as a random effect. Preplanned comparisons of the corn diet with 3 DDGS particle size diets were analyzed using one-way ANOVA. A similar approach was used to compare drained and poured angles of repose among the three DDGS diets and between the corn diet and all DDGS diets. The LSM procedure was used to estimate mean values and the Tukey test was used to separate means. Differences among treatments were considered significant when P value was less than 0.05, and trends were identified when P values were less than 0.10, but larger than 0.05.

Results:

Apparent total tract dry matter (DM) digestibility was higher ($P < 0.01$) in corn than in DDGS (Figure 1). Dry matter digestibility was improved by fine grinding DDGS compared to the coarse DDGS particle size ($P < 0.05$), but DM digestibility of medium particle size DDGS was not different compared with coarse and fine DDGS particle size.

Figure 1. Apparent total tract dry matter digestibility (%) of corn and DDGS diets.



[a, b] Means within DDGS containing diets with different superscripts are different ($P < 0.05$).

Gross energy (GE) intake, fecal, and urine excretion was higher (P < 0.05) for DDGS diets compared with the corn basal diet (Table 2). Gross energy intake and urine excretion was not different among DDGS particle size diets, but fecal GE excretion was higher (P < 0.05) in the coarse diet compared with the medium and fine diets, although fecal GE excretion was not different between the medium and fine DDGS diets (Table 2).

Nitrogen intake and fecal and urine excretion was higher (P < 0.0001) in DDGS diets compared with the corn diet (Table 2). As a result, more N was absorbed and retained (P < 0.0002) for pigs fed the DDGS diets compared to the corn diet (Table 2), but the percentage of N retained for the diet as well as corn and DDGS was not different. There were no differences among DDGS particle sizes or diets for N intake, fecal and urine excretion, absorption, or retention (Table 2).

Diets containing DDGS had similar DE and ME content compared with corn (Table 3), but DDGS had higher DE and ME on an as-fed basis (P < 0.0001) and DE on a DM basis (P < 0.02), and tended (P = 0.09) to have higher ME on a DM basis compared with corn. On an as-fed basis, the DE and ME content of the fine particle size DDGS (3,709 and 3,577 kcal/kg, respectively) was higher (P < 0.05) than the coarse particle size DDGS (3,487 and 3,345 kcal/kg, respectively), with the medium particle size DDGS being intermediate (3,681 and 3,507 kcal/kg, respectively; Table 3). Similar differences were observed among DDGS particle sizes when DE and ME were expressed on a DM basis.

Table 2. Daily energy and nitrogen balance of diets

		DDGS			DDGS Particle Size		Corn vs. DDGS	
Item	Corn	Coarse	Medium	Fine	SEM	P[1]	SEM	P[2]
GE intake, kcal	4320	4766	4747	4734	118.30	0.71	114.23	0.0001
GE in feces, kcal	485.7	912.6[a]	854.4[ab]	816.8[b]	18.74	0.005	19.04	0.0001
GE in Urine, kcal	109.5	126.0	135.9	122.1	9.15	0.37	7.85	0.03
N intake, g	90.9	146.6	146.3	145.7	3.64	0.76	3.23	0.0001
N in feces, g	16.1	28.1	28.0	27.0	0.59	0.25	0.59	0.0001
N in urine, g	51.7	84.6	83.7	84.2	2.72	0.89	2.95	0.0001
N absorbed, g	74.8	118.5	118.2	118.8	3.77	0.93	3.27	0.0001
N retained, g	23.1	33.9	34.5	34.5	1.54	0.92	1.83	0.0002
Diet N retention, %	25.8	23.1	23.5	23.8	0.68	0.80	1.87	0.39
Ingredient N retention, %	25.8	19.65	20.7	21.7	2.27	0.80	2.32	0.14

[a, b] Means within DDGS containing diets with different superscripts are different (P < 0.05).
[1] Comparison among three DDGS containing diets.
[2] Comparison between the corn diet and all DDGS containing diets.

Phosphorus intake, fecal excretion and retention were higher (P < 0.05) in DDGS diets compared with the corn diet (Table 4). Also, pigs fed the DDGS diets had a better P retention (P < 0.0002) compared to those fed the corn diet (Table 4). There were no differences among DDGS particle sizes or diets for P intake, fecal and urine excretion, or retention (Table 4).

Table 3. Digestible (DE) and metabolizable (ME) energy of diets and ingredients

		Corn-DDGS			DDGS		Corn VS. DDGS	
Item	Corn	Coarse	Medium	Fine	SEM	P[1]	SEM	P[2]
Diet DE, kcal/kg (as- fed)	3212	3192[a]	3250[b]	3258[b]	20.83	0.02	17.56	0.40
Ingredient DE, kcal/kg (as- fed)	3212	3487[a]	3681[ab]	3709[b]	69.45	0.02	54.30	0.0001
Ingredient DE, kcal/kg DM	3682	3738[a]	3835[b]	4006[b]	77.91	0.02	61.13	0.016
Diet ME, kcal/kg (as-fed)	3120	3088[a]	3136[ab]	3157[b]	21.84	0.05	17.32	0.78
Ingredient ME, kcal/kg (as-fed)	3120	3345[a]	3507[ab]	3577[b]	72.81	0.05	55.01	0.0001
Ingredient ME, kcal/kg DM	3577	3583[a]	3745[ab]	3862[b]	81.65	0.04	62.09	0.09

[a, b] Means within DDGS containing diets with different superscripts are different ($P < 0.05$).
[1] Comparison among three DDGS containing diets
[2] Comparison between the corn diet and all DDGS containing diets.

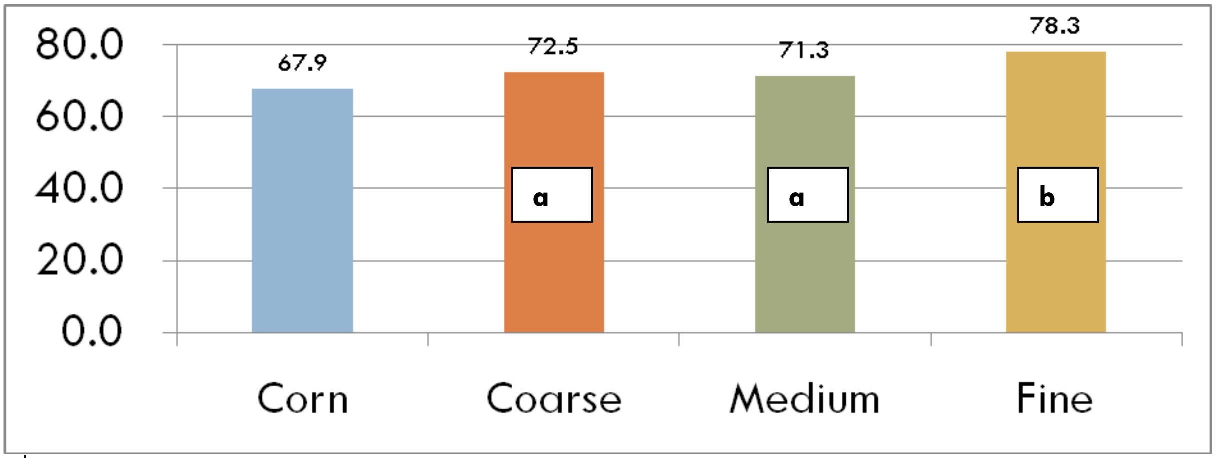
Table4. Daily phosphorus balance of diets

		Corn-DDGS			DDGS		Corn Vs DDGS	
Item	Corn	Coarse	Medium	Fine	SEM	P[1]	SEM	P[2]
P intake, g	5.1	6.5	6.4	6.4	0.16	0.1789	0.15	0.0001
P in feces, g	2.4	2.7	2.6	2.5	0.106	0.2064	0.09	0.0166
P in urine, g	1.1	1.2	1.4	1.3	0.114	0.518	0.09	0.065
P retained, g	1.7	2.6	2.4	2.6	0.109	0.3934	0.09	0.0001
P retention, %	32.7	39.9	37.5	40.5	1.715	0.4275	1.49	0.0001

[1] Comparison among three DDGS containing diets
[2] Comparison between corn diet with all DDGS containing diets.

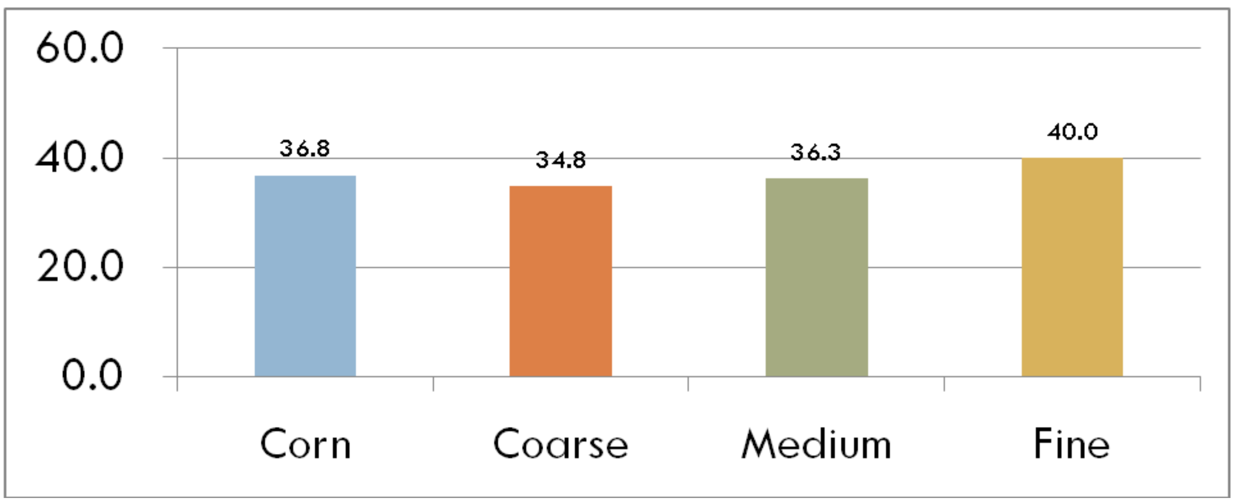
Diet flowability, as measured by the increased drained angle of repose (Figure 2) was reduced ($P = 0.03$) in the 30% DDGS diets compared with the corn diet, and flowability was the lowest ($P < 0.01$) for the fine particle size DDGS diet compared with the medium and coarse DDGS particle size diets. However, using poured angle of repose as a measure of flowability (Figure 3), there were no differences between the corn diet and the DDGS diets nor were there differences among DDGS particle size diets.

Figure 2. Drained angle of repose (°) of corn and DDGS particle size diets.



[a, b] Means within DDGS containing diets with different superscripts are different ($P < 0.05$).

Figure 3. Poured angle of repose (°) of corn and DDGS particle size diets.



Discussion:

The reduced DM digestibility in DDGS diets compared to corn was primarily a result of the higher fiber (NDF) content of DDGS (35.3%) compared to corn (9.6%), which results in an increased amount of feces excreted (Stein and Shurson, 2009; NRC, 1998). Pigs are able to utilize moderate, but not high level of fiber in the nursery (Whitney and Shurson, 2004; Weber et al., 2008) and finisher (Whitney et al., 2006) phases of growth. However, reducing diet particle size in DDGS improved DM digestibility. It is well documented that particle size of complete feeds and feed ingredients affect nutrient digestibility (Wondra et al., 1995). By reducing diet particle size, more surface area of feed is exposed to digestive enzymes resulting in a subsequent improvement in nutrient digestibility and reduction in fecal excretion (manure production). Several researchers have consistently demonstrated improvements in growth rate and feed conversion when feeding diets of low average particle size compared to feeding more coarsely ground diets (Lawrence, 1983; Hedde et al., 1985; Goodband and Hines, 1988; Giesemann et al., 1990; Cabrera et al., 1994; and Healy et al., 1994). These Improvements are a direct result of improved dry matter digestibility when particle size of diet is reduced.

Gross energy (GE) intake, along with fecal and urine GE excretion was higher for DDGS diets compared with the corn basal diet. These results are consistent with those reported by Stein and Shurson (2009) where the GE of corn was reported to be 4,496 kcal/kg DM compared to an average GE in DDGS of 5,434 kcal/kg DM, but apparent total tract digestibility of energy was higher in corn (90.4%) compared to DDGS (76.8%). Gross energy intake and urine excretion was not different among DDGS particle size diets, but fecal GE excretion was higher in the coarse diet compared with medium and fine diets. The increase in dietary DE and ME was expected because a reduction in particle size increases nutrient digestibility. These results agree with those reported by Mendoza et al. (2010) who showed that DE and ME content of DDGS can be improved by grinding to a lower particle size.

Nitrogen intake and fecal and urine excretion was higher in DDGS diets compared with the corn diet. Nitrogen intake for pigs consuming DDGS diets was higher because DDGS contains approximately 3 times more crude protein (N) than corn, diets were formulated without the use of supplemental protein sources (e.g. soybean meal and synthetic amino acids) and were not balanced for amino acids. Because the diets contained lysine and other amino acids below the pig's requirement, and the DDGS diets contained more digestible lysine than the corn diet, more N was absorbed and retained for pigs fed DDGS diets compared to the corn diet, but the percentage of N retained in the diet as well as corn and DDGS was not different. Corn and corn co-products (i.e. DDGS) have poor protein quality (low lysine:crude protein ratio) relative to pig's requirement. Therefore, excess nitrogen is excreted in feces and urine due to inadequate lysine in the diet (Noblet et al., 1987). There were no differences among DDGS particle sizes or diets for N intake, fecal and urine excretion, absorption, or retention.

Diets containing DDGS had similar DE and ME content compared with corn, but DDGS had higher DE and ME on an as-fed basis, and DE on a DM basis, and tended to have higher ME on a DM basis compared with corn. On an as-fed basis, the DE and ME content of the fine particle size DDGS (3,709 and 3,577 kcal/kg, respectively) was higher than the coarse particle size DDGS (3,487 and 3,345 kcal/kg, respectively), with the medium particle size DDGS being intermediate (3,681 and 3,507 kcal/kg, respectively). Similar differences were observed among DDGS particle sizes when DE and ME were expressed on a DM basis. Pedersen et al. (2007) reported that DDGS DE and ME values can vary significantly among different sources, and ranged from 3,947 to 4,593 kcal of DE/kg of DM, and 3,674 to 4,336 kcal of ME/kg of DM. The DE and ME values we obtained for DDGS were lower than those reported by Pedersen et al. (2007). Perhaps the nutrient composition and nutrient values of DDGS source used in our study was inferior to those used by Pedersen et al. (2007). Another possible explanation for these differences in DE and ME values may be due to the presence of low levels of mycotoxins (deoxynivalenol and zearalenone) in DDGS used in our study. However, the primary goal of this study was to estimate the relative changes in DE and ME due to particle size differences in DDGS. Our results suggest that for each 25 µm decrease in particle size from 818 to 308 µm, ME content of DDGS increased by 13.7 kcal/kg on a DM basis. This improvement in ME content is more than twice the improvement in ME content (6.6 kcal/kg) for each 25 µm reduction in corn particle size reported by Gaines and Kocher (2008) over a similar particle size range (450 µm to 850 µm). This finding is significant because this relationship can be used to account for some of the differences in ME content among DDGS when comparing economic value and energy contribution during diet formulation.

In our study, the corn basal diet was formulated on an available P basis to meet the requirement of a 40 kg growing pig. Because DDGS has a much higher amount of digestible P (65%) than corn (14%), adding 30% DDGS to the corn basal diet significantly increased total and available P content. Feeding diets containing DDGS resulted in an increase in P intake, fecal and urine excretion than pigs fed the corn diet, but the amount of daily P retained and % P retention were also increased. Even though the diets were formulated to contain levels of available P above the pig's requirement, the lower feed intake of pigs in this experiment may have resulted in a need to digest and absorb more P compared to the recommended concentration based on a higher level of expected feed intake reported in NRC (1988). These results confirm previous reports (Stein and Shurson, 2009) demonstrating that DDGS is an excellent source of available P for swine. No difference in P retention was observed among different DDGS particle sizes, suggesting that unlike for DE and ME, reducing DDGS particle size has no effect on P digestibility.

One of the negative characteristics of DDGS is that it can have poor flowability and cause bridging during transport and in bulk storage bins and feeders. This physical characteristic has limited the use of DDGS in swine diets in some situations. Diet flowability, as measured by the increased drained angle of repose, was reduced in the 30% DDGS diets compared with the corn diet, and flowability was the lowest for the fine particle size DDGS diet compared with the medium and coarse DDGS particle size diets. Results from studies by Ganesan et al. (2008a,b,c) indicated that reduced particle size, increased moisture, the amount of solubles added before drying, and many other factors contribute to reduced flowability of DDGS. Johnston et al. (2009) also evaluated several physical and chemical characteristics of DDGS and their relationship to flowability. Their results showed that moisture was the main factor affecting flowability and that particle size was not a significant factor. However, the range of DDGS particle size evaluated in this study was 584 to 668 µm, which was much less than the particle size range of DDGS (308 µm to 818 µm) evaluated in this study.

Our results confirm that adding 30% DDGS to a corn based diet reduces flowability, and grinding DDGS to 308 µm further reduces flowability compared to 594 and 818 µm particle sizes. However, for each 25 micron decrease in DDGS particle size from 818 microns to 308 microns, the ME contribution of DDGS to the diet is increased by 13.7 kcal/kg DM. If it is economic and feasible to pellet DDGS diets, the concern about flowability is eliminated and the extra energy value from using finely ground DDGS can be realized. However, if pelleting is not a viable option, and diets must be manufactured and fed in meal form, flowability may be acceptable if the DDGS particle size is greater than 600 µm, and some of the improved ME value of DDGS from a reduced particle size can be obtained. Compared to the price (e.g. $330/ton) and energy value (e.g. 7,956 kcal/kg) of choice white grease as an energy source in grower-finisher swine diets, the difference in economic value of increased ME content for DDGS with particle size of 308 µm compared to 818 µm particle size would be approximately $25.50 per ton of DDGS. Based on our results, DDGS particle size does not affect protein and phosphorus digestibility, so there is no additional economic or feeding value due to particle size on these economically important nutrients.

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