EFFECTS OF CORN OR SORGHUM DISTILLERS DRIED GRAINS WITH SOLUBLES ON APPARENT NUTRIENT DIGESTIBILITY OF GROWING PIGS.

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CHAPTER I

INTRODUCTION

Oil is a precious commodity in today's commercial industry; it is the driving force for the economy. However, demand for oil and fuel production has increased substantially over the past two decades and has resulted in pressuring fuel companies to meet the demand (Rausch and Belyea, 2005). To ease pressures of producing oil, a natural resource, ethanol companies have been supplying ethanol as a fuel additive to help meet the supply and demand for fuel. The explosive growth and demand for ethanol as a fuel additive has resulted in an increase in available by-products of the ethanol process (RFA, 2005; Robinson, 2005). The ethanol industry uses grains for the production of ethanol for beverages and fuels (Gibsion, 2005). Along with this growth in ethanol production is a consistent growth in production of distillers dried grains with solubles (DDGS) (Rausch and Belyea, 2006). Distillers dried grains with solubles is desirable to animal nutritionists due to the high protein content; however, it also has high fiber content, which limits its use in nonruminant diets (Gibson, 2005; Rausch and Belyea, 2005; Robinson, 2005). Furthermore, new technologies are constantly being implemented by the ethanol industry to not only provide ethanol for the fuel industry, but to also provide a consistent reliable source of distillers grains for the livestock feed industry.

Cereal grains are the most commonly used grains for ethanol production (Dale, 1991). Depending on the geographical location of production plants, certain types of cereal grains are limited for use. Grains such as wheat are limited for use because of its value as a food commodity for humans consumption. Oats and barley produce lower yields of ethanol as compared to corn (Morris, 1983; Dale, 1991). In the mid west, corn is the most commonly used livestock feed and its DDGS value is comparable to that of sorghum (Senne et al., 1996) As ethanol production increases, the animal feed industry has provided an outlet for ethanol byproducts (Shurson and Spiehs, 2002). The most commonly used byproducts are corn and sorghum DDGS.

CHAPTER II

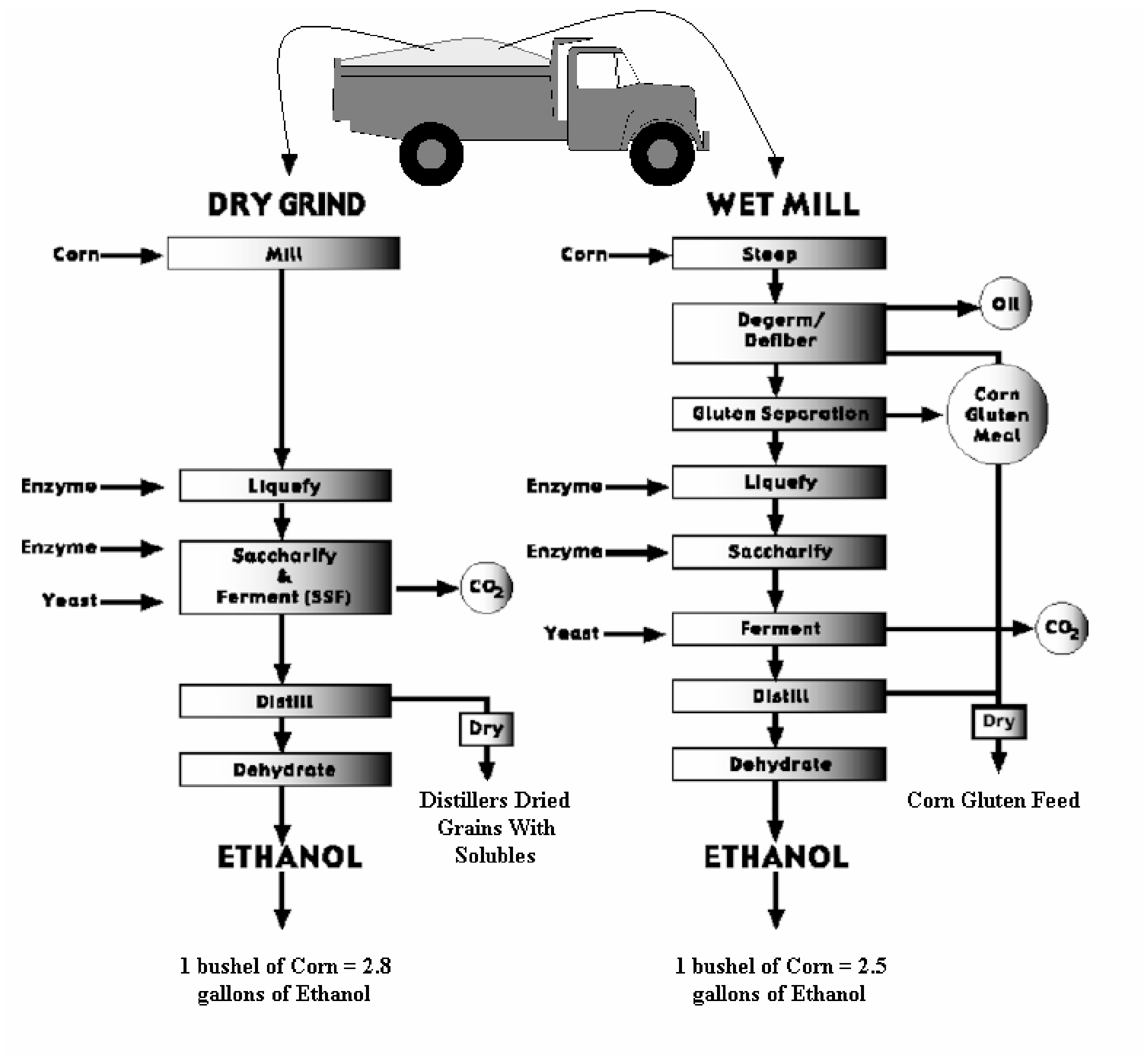
LITERATURE REVIEW

General Review on Ethanol Production

The production of ethanol can be performed by either one of two processes: wet milling or dry grinding. Both processes produce ethanol, but are different in several ways. The main difference between wet mill and dry grind facilities is the focus of resourcing (Bothast and Schlicher, 2005). The main focus for the dry grind plant is to maximize the capital return per gallon of ethanol. However, a wet mill plant's focus is on capital investments allowing for the separation of other valuable components in the grain before fermentation to ethanol (Rausch and Belyea, 2005).

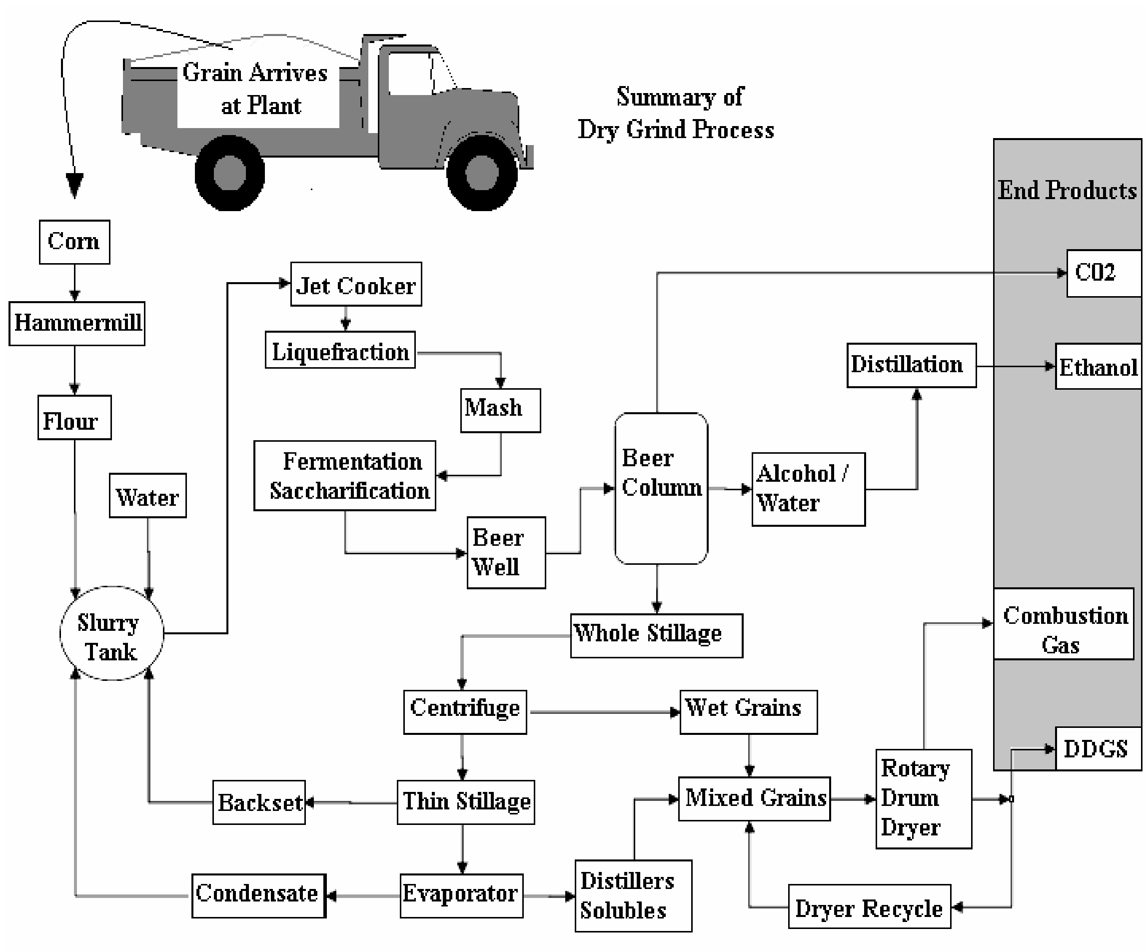
Wet milling involves breaking the corn kernel to isolate and recover the starch in a highly purified stream. Then the starch is used to produce the following products; glucose, high fructose corn syrup, ethanol, and other chemicals (Rausch and Belyea, 2005). The wet milling includes a process called steeping as the first step. This aids in separating the germ and fiber fractions, the germ fraction has lower density as compared to the rest of the kernel (Johnson and May, 2003; Rausch and Belyea, 2005). The fiber component is then separated and removed by screens and dried to corn gluten feed. Then the starch is recovered using the hydrocyclone system, cooked, liquefied, saccharified, and fermented into beer to yield ethanol (Rausch and Belyea, 2005;). Wet milling is described in Figure 1. The nutrients that are found in each of the by-products is found in Table 1.

Figure 1. Comparison of dry grind and wet mill ethanol production processes



(Adapted from Bothast and Schlicher, 2005)

Figure 2. Summary of the dry grind process



(Adapted from Rausch and Belyea, 2005)

The dry-grind process (Figure 2) is designed to subject the whole grain to fermentation and the residual components are separated at the end of the process (Bothast and Schlicher, 2005; Gibson, 2005; Rausch and Belyea, 2006). The five major steps in the dry grind process are milling, liquefaction, saccharification, fermentation, and distillation and recovery (Rausch and Belyea, 2006). The milling process begins by grinding the whole grain into coarse flour in a hammermill, then the flour is slurried with water, and a heat-stable enzyme (a-amylase) is added (Chi et al., 1995; Rausch and

Belyea, 2006). After the slurry has been liquefied, it is cooked using jet cookers, additional a-amylase is added to the mash and allowed to ferment (Bothast and Schlicher, 2005; Gibson, 2005). Saccharification occurs after the liquefication with a cooled mash and glucoamylase is added to complete the breakdown of starch into simple sugars. After cooling, yeast is mixed with the mash to ferment the sugars into ethanol and carbon dioxide, yielding ethanol and distillers grains. The fermented mash is then sent to distillation to extract the ethanol (Taylor et al., 2000). In distillation, the mash is considered stillage and is centrifuged, where the solids and liquid are separated (Rausch Belyea, 2006).

At the end of the dry grind process, the liquid that is separated either goes back into the cooking system, a rotary drum dryer, to yield DDGS to be sold as a livestock feed supplement (Rausch and Belyea, 2005; Taylor 2000), or is partially dehydrated into syrup called condensed distillers solubles (CDS). The end products of the dry grind process are ethanol, carbon dioxide, distillers dried grains with solubles or condensed distillers solubles (Table 1).

Table 1. Summary of ethanol processes, primary products and coproducts

Process	Brief Description	Primary product(s)	Coproducts
Wet Milling	Corn is steeped, lightly ground, germ removed, finely ground, fiber removed, protein separated from starch, starch further processed, Results in 99.5% pure starch product	ethanol, starch, high fructose corn syrup	Crude corn oil, corn gluten feed, corn gluten meal, and CO_2
Dry Grind	Corn is ground, cooked, liquefied, saccharified; fermented and distilled for manufacture of ethanol	ethanol	DDGS (primary livestock DDGS), and CO_2
Modified Dry Grind	Corn is soaked, lightly ground, germ and fiber removed, finely ground, cooked, liquefied, saccharified; fermented and distilled for manufacture of ethanol	ethanol	DDGS, germ (corn oil), fiber (nutraceuticals), and CO_2
Dry Milling	Small amount of water added to corn, kernel is abraded to separate components of pericarp, germ and endosperm. Remaining process is primarily physical size separation.	flaking grits	brewers grits, small grits, corn meal, and cones, and corn flour

(Adapted from Rausch and Belyea, 2005)

There are variations in the concentration of nutrients found in DDGS that have been produced over the past three decades. Shurson et al. (2004) states that DDGS for pigs has improved from the traditional sources produced by old ethanol plants (older than 1990). The modern ethanol plants produce DDGS that is higher in digestible and metabolizable energy, amino acids, and available phosphorus than values published in the NRC (1998). Spiehs et al. (2002) collected 118 samples from 10 modern ethanol plants in Minnesota and South Dakota between 1998 and 1999 to determine nutrient variability among plants. These values were compared to the NRC (1998), the values published were compared to the modern ethanol plants and to the old ethanol plants as described in Table 2 (Shurson et al., 2004). The major difference from the "old generation" ethanol plants and "new generation" is the change in the processes in producing ethanol: cooking time, amount of ethanol produced per bushel of corn, and enzymes used (Whitney et al., 2006; Shurson et al., 2004, Spiehs et al., 2002). Another contributing factor is that the dry grind process is becoming increasingly popular. Selling the DDGS as a livestock feed supplement allows for production cost to almost be completely covered (Bothast and Schlicher, 2005; Taylor et al., 2000).

Table 2. Comparing nutrient composition of "new Generation" DDGS to "old generation" DDGS

	New Generation DDGS (modern)	Old generation DDGS	NRC
Dry Matter %	89.1	89.5	93.0
Crude Protein %	30.50	29.00	29.80
Crude Fat %	10.70	9.70	9.00
Crude Fiber %	8.90	7.40	---
Ash %	5.80	8.00	---
Calculated DE, kcal/kg [a]	3,990	3,879	3,449
Calculated ME, kcal/kg [a]	3,749	3,661	3,038
Arg %	1.20	0.92	1.22
His %	0.76	0.61	0.74
Ile %	1.12	1.00	1.11
Leu %	3.55	2.97	2.76
Lys %	0.85	0.53	0.67
Met %	0.55	0.50	0.54
Phe %	1.47	1.27	1.44
Thr %	1.13	0.98	1.01
Try %	0.25	0.19	0.27
Val %	1.50	1.39	1.40
Ca %	0.06	0.44	0.22
P %	0.89	0.90	0.77
Available P %	0.80	No data	0.77

[a] Values calculated using crude protein and crude fat
(Adapted from Shurson et al., 2004)

Effects of inclusion rates of distillers grains with solubles

Research studies performed by the investigators of the University of Minnesota have concluded that the maximum percentage of DDGS inclusion in swine diets ranges from 25% in nursery pigs to 50% for gestating sows and boars (Shurson and Spiehs, 2002). However, Stein (2007) recommended that no DDGS be included in diets for early nursery pigs and that 40% is the maximum inclusion of DDGS in diets for gestating sows. The inclusion rates (Table 3) are based upon the knowledge that the DDGS sources are high in quality and free of mycotoxins.

Table 3. Inclusion rates of distillers dried grains with solubles in diets fed to swine

Category	Recommended [a]	Maximum [a]	Maximum [b]
Nursery, week 0-2	0	20	---
Nursery, after week 2	20	30	25
Grower	20	35	20
Early finisher	20	35	---
Late Finisher	20	20	---
Gestation and Boars	40	50	50
Lactation	20	---	20

[a] Adapted from Stein (2007)
[b] Adapted from Shurson and Spiehs (2002)

Current studies have shown that energy, amino acid digestibility, and phosphorus availability of DDGS produced from modern ethanol plants is higher than nearly all of the values reported in the NRC (1998) (Spiehs et al., 2002; Whitney et al., 2000; Whitney et al., 2006; Xu et al., 2006). Apparent digestible amino acids and available phosphorus nutrient values should be used for formulating practical diets for all phases of production to ensure that the maximum nutritional value of DDGS is obtained, and that optimal performance is achieved, particularly when adding more than 10% DDGS to any swine diet (Shurson and Spiehs, 2002; Stein, 2007).

The main concerns regarding feeding DDGS to swine are due to the nutrient variability in the distillers grains produced. However, like all co-products, there are large variations in the quality of DDGS available for livestock feeds (Shurson and Spiehs, 2002). Cromwell et al. (1993) completed a study to compare physical, chemical, and nutritional characteristics of nine different sources of DDGS for chicks and pigs. There were variations of color between sources ranging from very light to very dark, and odor ranged from a sweet smell to a smoky or burnt smell. There is also a wide range in nutrient concentrations among DDGS sources (Shurson and Spiehs, 2002; Stein, 2007), that include dry matter, crude protein, crude fat, phosphorus, ash, and lysine.

In order to effectively select distillers sources that are suitable for diet formulation for swine and poultry diets, Shurson and Spiehs (2002) reported data to establish nutrient specifications and recommended physical characteristics when selecting distillers sources from Minnesota and South Dakota ethanol plants. A summary of the Minnesota-South Dakota Nutrient Specifications and Physical Characteristics for distillers grains in swine and poultry diets are as follows in Table 4.

Table 4. Nutrient specifications and recommended characteristics for DDGS

Nutrient specifications:
Dry matter – minimum of 88%
Crude protein – minimum of 26.5%
Crude fat – minimum of 10%
Crude fiber – maximum of 7.5%
Physical characteristics:
Bulk density - 34 to 37 lb/cubic foot
Particle size:
Maximum coarse particles – 10% on 2000 screen
Maximum fine particles – 15% on 600 screen & in pan
Smell - fresh, fermented
Color - goldenrod

(Adapted from Shurson and Spiehs, 2002)

Weigel et al. (1997) recommended that an inclusion rate of no more than 7.5% of DDGS should be used in diets formulated for growing pigs and 10% DDGS be used in diets for finisher pigs. Stein (2007) suggested that 10% DDGS can replace approximately 4.25% soybean meal and 5.70% corn, but only if 0.10% crystalline lysine is included in the diet. Suggestions from other authors include that DDGS can serve as a satisfactory energy and protein source for grower-finisher diets at a concentration of 10% (Wahlstrom and German, 1968; Cromwell et al., 1984, Harper and Forsyth, 1998). Cromwell et al. (1984) and Harmon (1975) reported that diets containing 20% DDGS showed similar effects of body weight gain and feed efficiency when compared to pigs consuming corn-soybean meal diets. However, Wahlstrom and Libal (1969) observed a reduction in performance of pigs that consumed diets containing 20% DDGS. With a large variation in recommendations for feeding DDGS, it created an opportunity for more research studies to be conducted on DDGS from modern ethanol plants.

Resent studies have compared DDGS sources from modern ethanol plants to DDGS sources from old ethanol plants. The reason being is that modern ethanol plants have changed the way that ethanol is produced and the nutrient availability in the DDGS source. Spiehs et al. (2002) reported that modern ethanol plants that produce DDGS had greater concentrations of crude fat, lysine, and ME with improvements in phosphorus digestibility (Whitney and Shurson, 2001) when compared to values that are presented in the NRC (1998). This is based on DDGS sources that were produced from plants that were built before 1990. Furthermore, Whitney et al. (2000) showed that amino acid digestibility in high quality corn DDGS produced from modern ethanol plants are higher than values reported in the NRC (1998). With the information provided, the increased amino acid digestibility shows that greater inclusion rates of high quality DDGS can be used before requiring the addition of crystalline AA to maintain proper AA balance.

Increasing the amount of DDGS in the diet can result in excellent pig performance; however, there is a risk of reducing feed intake that results in a reduction in performance (Cook et al., 2005; DeDecker et al., 2005; Fu et al., 2004; Linneen et al., 2006; Whitney et al., 2004). Whitney et al. (2006) conducted a growth performance study to determine if adding increasing amounts of high-quality corn DDGS (0, 10, 20, 30%) to grower-finisher diets in a phase feeding program will support growth performance and carcass quality similar to that obtained with corn-soybean meal diets. When including 20 and 30% of DDGS in the diet, the Whitney et al. (2006) reported similar feed intakes as compared with the 0 and 10% dietary concentration; however, lower growth rates were reported for first feeding period. This resulted in poorer G:F ratios for pigs fed 30% DDGS diets when compared with the 0 and 10% DDGS diets.

The study concluded that high-quality corn DDGS was an acceptable source to substitute for corn and soybean meal in a diet without decreasing voluntary intake. However, when the diets were formulated on total amino acid basis the diets that contained more than 20% DDGS reported a reduction in growth rate and feed efficiency.

Whitney and Shurson (2004) reported that including DDGS in nursery diets can decrease growth performance. DDGS was included at 0, 5, 10, 15, 20, or 25% during Phases 2 and 3 of a three-phase nursery feeding program. Overall growth rate and body weight, and feed conversion were similar among pigs regardless of the DDGS, as shown in Table 5. In the first experiment with heavier pigs going into the nursery, feed intake was not affected by dietary treatment. However in a second experiment, using lighter pigs, there was a decrease in feed intake during Phase 2 and a tendency for decreased overall voluntary feed intake. Part of the reason that voluntary intake decreased is due to the increase in fiber of the DDGS source (Shurson and Spiehs, 2002; Xu et al., 2006). These results suggest that the corn distiller's dried grains with solubles used in this study can be included in Phase 3 diets for nursery pigs at dietary levels of up to 25% without negatively affecting growth performance after a 2-wk acclimation period (Whitney and Shurson, 2004).

As it was previously discussed, that fermentation (to ethanol) greatly concentrates the nonstarch components of the grain (e.g., protein, fat, fiber, ash, and amino acids) (Senne et al., 1996). DDGS can be added to nursery diets at a maximum inclusion rate with out detrimental effects on growth performance (Table 6). When including DDGS in swine diets, it is recommended to allow for a 5 – 7 day adjustment period to allow the animal to adjust to the diet. With the higher concentration of fiber in DDGS, it creates a problem for the animal to utilize nutrients available; especially in younger animals.

Table 5. Effects of increasing DDGS in nursery diets during a 35 day period

	DDGS Inclusion rate, %					
Item	0	5	10	15	20	25
Phases 2 and 3 (d 0–35)						
Start wt, kg	5.79	5.55	5.67	5.54	5.89	5.60
End wt, kg	20.78	20.84	20.64	19.69	20.55	19.63
ADG, g/d [c]	431.0	433.0	427.0	400.0	425.0	398.0
ADFI, g/d [b]	637.0	652.0	659.0	579.0	644.0	591.0
G/F [c]	0.70	0.67	0.68	0.71	0.66	0.66

[a]Each value represents a mean of four pens with four pigs each treatment. (with the average of two treatments)
[b] ADFI tended to linearly depress with increasing DDGS ($P < 0.10$)
[c] No linear or quadratic trends for ADG or G/F with increasing DDGS level ($P > 0.10$)
(adapted from Whitney and Shurson, 2004)

Table 6. Effects of sorghum-based DDGS on nursery performance

	% DDGS				
Variable	0	15	30	45	60
ADG, lb	1.07	1.1	1.02	0.88	0.71
ADFI, lb	1.72	1.62	1.43	1.42	1.28
G:F	0.62	0.68	0.71	0.62	0.55

The ADG was not affected ($P > 0.10$), but G:F improved with DDGS inclusion up to 30% ($P < 0.05$). The inclusion of 45 – 60% DDGS decreased ADG. The ADFI decreased with DDGS inclusion (linear, $P < 0.05$). The experimental diets were fed from day 7-28 of the nursery phase. (Adapted from Senne et al., 1996)

Senne et al. (1996) reported that in nursery diets with increasing amounts of sorghum DDGS, average daily gain (ADG) was not affected and gain/feed (G:F) was actually improved with as much as 30% DDGS included. However, when the amount increased to 45 and 60% DDGS, growth rate and efficiency of gain were decreased. This was probably due to the amount of fat in the diet. DeDecker et al. (2005) reported that adding 3% fat to a DDGS diet decreased ADFI. Also, increasing DDGS in chick diets in the starter phase resulted in a depression in body weight gain and feed conversion (Lumpkins et al., 2004). In a finishing experiment performed by Senne et al. (1996), ADG increased slightly; however, ADFI decreased and G:F was improved as the concentration of DDGS was increased. Carcass characteristics, hot carcass weight and backfat thickness increased as percentage DDGS increased (Table 7).

Other studies have reported that pigs fed increasing levels of DDGS at or above 20 or 30% had reduced ADG as compared to 0 or 10% DDGS, but ADFI was unaffected (Whitney et al., 2001). Feed:gain increased when pigs were fed 30% DDGS as compared to 0, 10, and 20% DDGS inclusion levels. When diets are formulated on a digestible amino acid basis, growth performance and carcass composition may not be hindered with dietary inclusion of DDGS of 20%. However, due to variations in DDGS nutrients, Whitney et al. (2006) indicated that ADG and G:F tends to decrease with increasing amounts of DDGS above 20% in the diet.

Carcass characteristics have also been studied to determine the effect of DDGS on quality, dressing percentage, and backfat (BF). Dressing percentage has been found to not be effected with increasing dietary DDGS level (Table 7), but hot carcass weight increased for pigs fed 20 or 30% DDGS (Whitney et al., 2006). Adding DDGS has shown to have no negative effects on pork quality except increasing the amount of unsaturated fat and reduced fat firmness with increasing dietary inclusion rates.

Table 7. Effects of sorghum-based DDGS on growth performance and carcass characteristics of finishing pigs

	% DDGS			
Variable	0	20	40	60
ADG, lb	2.09	2.22	2.22	2.19
ADFI, lb	6.97	6.75	6.66	6.38
G:F	0.30	0.33	0.33	0.34
HCW, lb.	169.0	174.0	175.0	175.0
Last Rib BF, in	0.85	0.98	0.90	0.98
Dressing %	71.10	70.80	71.40	71.90
Fat-free Lean %	0.30	0.33	0.33	0.34

The experimental diets were fed for 56 days (Adapted from Senne et al., 1996).

Determination of nitrogen digestibility in DDGS

Nitrogen (N) digestibility is measured by feeding pigs over a period of time and collecting feces from the animal (Adeola, 2001). It is important to mention that the apparent digestibility of N does not differentiate between endogenous N and undigested and unabsorbed N. This is affected by several factors including protein turnover in the body and protein levels in the feed. When an animal consumes excess amino acids above the requirement for maintenance and protein synthesis, they must be deaminated (Whitney and Shurson, 2004). Therefore, any diet that contains improperly balanced amino acids is less efficiently utilized by the animal. Additionally, increasing the level of fiber in the diet has been shown to reduce nutrient digestibility (Ewan, 2001).

During the drying of DDGS from the ethanol production process, heat damaged protein may occur and reduce the efficiency of protein utilization by animals (Cromwell et al., 1993). Cromwell found that apparent N digestibility can be decreased by elevating drying temperatures. Feeding DDGS has shown to increase N excretion and result in increased ammonia emissions from the slurry (Xu et al., 2006). The excess N resulting from the addition of DDGS to swine diets can be minimized by reducing dietary crude protein levels and supplementing with synthetic amino acids. (Spiehs et al., 2002)

Spiehs et al. (1999) found that increasing DDGS levels in the diet has tended to increase N intake. However, N retention, based on percentage, did not differ between treatments. Spiehs et al. (1999) suggested that feeding 10 to 20 % DDGS should maintain N retention while tending to increase N excretion when fed to grow-finishing pigs. Furthermore, the retention of N from DDGS sources has been reported by Pedersen et al. (2007) to be greater than corn, but only when calculated on a percentage basis. To accurately determine N digestibility, more studies are needed to determine digestibility of N in swine diets containing DDGS.

Determination of phosphorus digestibility in DDGS

Highly digestible phosphorus (P) in feed ingredients can reduce P excretion in swine manure (Xu et al., 2006). The indigestible form of P found in feed ingredients is phytic acid, which results in low levels of available phosphorus to be utilized by the animal. As mentioned previously, digestibility of phosphorus (P) can be decreased by the source, fermentation, processing or drying procedures from the dry grind method (Cromwell et al., 1993; Whitney and Shurson, 2004). Phosphorus digestibility can also be influenced by the Ca:P ratio. The higher the concentration of Ca as compared to P improves the digestibility of P (Xu et al., 2006). The amount of DDGS in the diet can also affect the digestibility of P.

Xu et al. (2005) observed improvements in bioavailability of P in pigs fed DDGS. This improvement also reflected an improvement in digestibility of P. Stein (2005) estimated the P digestibility to be 35% to 50% in corn DDGS. Table 8 shows a summary of calculated digestibility of P.

It has been recommended that feeding DDGS in swine diets increases percent P retention (Xu et al., 2006). The end result would be a decrease in P excretion. Spiehs et al. (1999) reported that feeding 10 - 20 % DDGS improved P retention and reduced P excretion. The relatively high digestibility of phosphorus in DDGS results in less inorganic phosphorus that is needed in diets containing DDGS (Stein, 2006). To accurately report P digestibility, more studies are needed focusing on digestibility in DDGS sources.

Table 8. Phosphorus digestibility comparisons of DDGS in diets for pigs

Source	Digestibility %
Stein, 2005	35-50
Pedersen et al., 2007	59.1

DDGS effects on phosphorus bioavailability

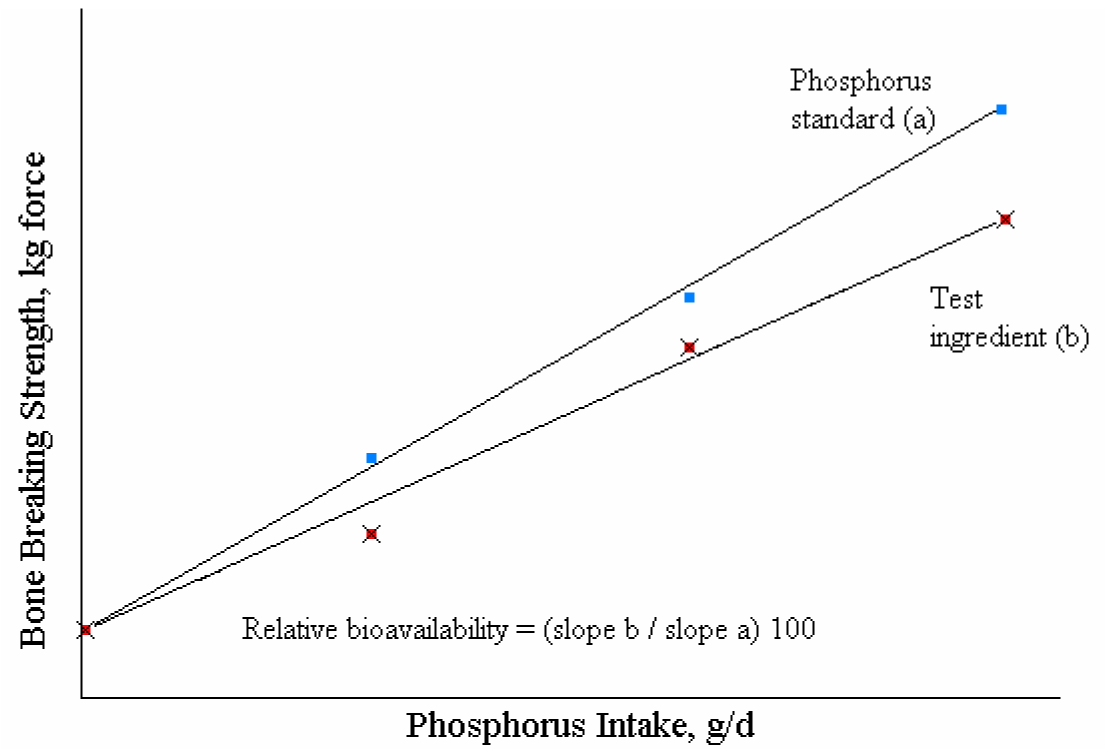
Phosphorus bioavailabilities for swine and poultry rations containing various inorganic and organic feed ingredients were summarized by Miller (1980), Soares (1995), and Cromwell (1992). Nursery diets formulated on available phosphorus including

DDGS have shown to have no effect on digestibility, retention, or excretion of P when compared to a corn-soybean diet (Xu et al., 2006).

There are variations in the biological availability of phosphorus in different feedstuffs. Digestibility studies and slope-ratio assays are two methods to evaluate the bioavailability of phosphorus in feed sources for pigs (Cromwell, 1980 and 1992; Fan et al., 2001; Jongbloed et al., 1991; Shen et al., 2002; Weremko et al., 1997). The slope-ratio assay provides an estimation of combining the digestive and post absorptive utilization of P at the tissue level; for example, bone strength (Jongbloed et al., 1991; Shen et al., 2002; and Weremko et al., 1997). The slope ratio assay results are variable and are affected by the criteria selected. An example of a slope ratio assay is found in Figure 3.

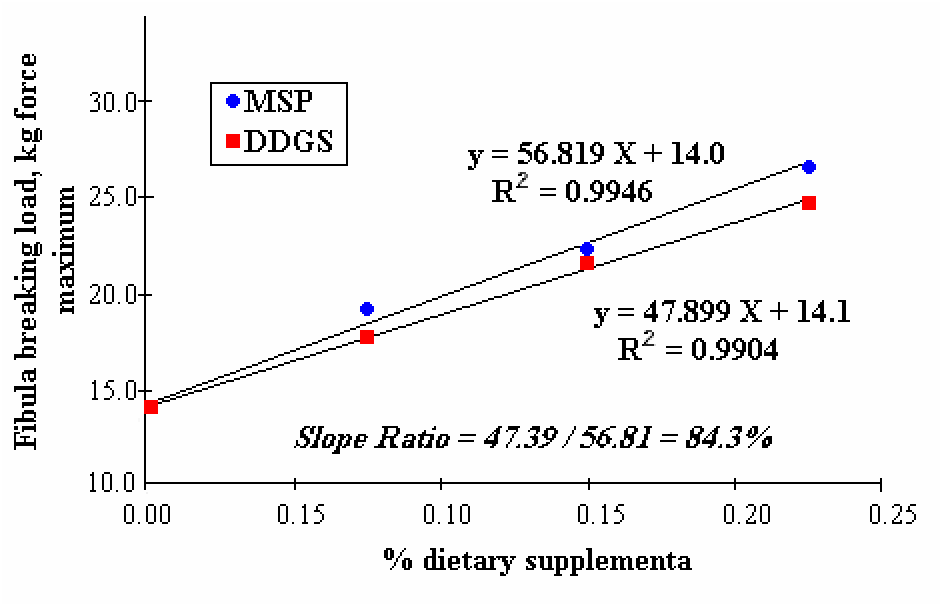
Fent et al. (2004) conducted a study to determine the bioavailability of phosphorus in DDGS as compared to monosodium phosphate (MSP) as the phosphorus reference. The MSP was believed to be based on 100% availability. The slope ratio assay was used to estimate the bioavailability of phosphorus in the DDGS with the response criteria being fibula breaking load versus percent dietary supplement. The experimental treatments were designed as a slope ratio assay including a basal diet (0.25 percent P, 1.25 percent TID Lys, 0.60 percent Ca) and with increasing amounts of 0.075, 0.150, and 0.225 percent additional P from either monosodium phosphate (MSP) or DDGS. Fent et al. (2004) reported that phosphorus bioavailability estimates for DDGS were approximately 85 percent (Figure 4).

Figure 3. Slope ratio assay for determination of P bioavailability



The slope ratio assay is used to determine the bioavailability of phosphorus in a specific feed source relative to a standard phosphorus source that is believed to be 100% available. The bone breaking strength for the standard and specific feed source is regressed on increasing levels of phosphorus intake. The difference between the two slopes provides an estimate of the availability of phosphorus in the specific feed sources.

Figure 4. Slope ratio of MSP and DDGS on fibula breaking strength



(Adapted from Fent et al., 2004)

Several other investigators have been successful in estimating phosphorus bioavailability by the use of the slope ratio method. One of the major differences between studies is the response criteria that were used. Whitney and Shurson (2001) used a slope-ratio assay to determine the availability of phosphorus in DDGS. The phosphorus retention was calculated as the difference between phosphorus intake and excretion. The control diet provided 2.33 g/d of phosphorus intake and the treatments provided 3.91 g/d (DDGS diet with 0.44% total P). Based on the slope ratios of the regression lines from each phosphorus source, the availability of phosphorus was approximant 87.5 % and 92.2 %, based on P excretion and P retention, respectively. This shows that the bioavailability of phosphorus in DDGS sources is higher than that listed in the NRC (1998).

In another study, cecetomized roosters were used by Lumpkins and Batal (2005) to conduct an experiment determining Lys and P bioavailabilities in DDGS, which was derived from corn fermentation in a modern non-beverage ethanol plant. In two different experiments, the relative bioavailability of phosphorus was assessed using slope-ratio chick growth experiments. In the experiments, a phosphorus deficient basal diet containing 0.12% non-phytate P was formulated. A linear growth and tibia bone ash (%) response were observed from the addition of 0.05 and 0.10% P from K_2HPO_4 and 2 levels of DDGS (5, 10, and 14%). Tibia bone ash (%) was regressed on P intake from K_2HPO_4 and DDGS, and the ratio of slopes indicated the relative bioavailability of P in DDGS. The values as a percentage of total P (0.74%) in DDGS yielded availability estimates of 68% and 54%.

DDGS effects on energy digestibilities

It is important when a nutritionist is formulating a diet for any phase of animal production that a consistent nutritional profile of all ingredients is available to determine its acceptance for routine use in commercial feed formulation (Xu et al., 2006). Pigs have requirements for digestible contents of nutrients such as energy that is needed for maintaining basic body functions (Stein, 2006). The concentration of nutrients such as energy and digestible nutrients determine the value of the ingredient in swine diets (Hastad et al., 2004). Corn DDGS produced by modern ethanol plants have been reported to contain significantly higher levels of digestible and metabolizable energy than found in DDGS produced by older, more traditional ethanol plants (Shurson, 2002). Over the past few years, several experiments have been conducted to measure the concentrations of energy and nutrients in DDGS fed to swine.

In one of these experiments, Spiehs et al. (1999) observed increasing amounts of DDGS in the diet increased gross energy (GE) intake. Pedersen et al. (2007) reported that the GE values for the DDGS samples were on average 5,434 kcal/kg dry matter (DM). Moreover, Stein (2007) states that the concentration of GE in DDGS is greater than in corn, and due to a lower digestibility of energy in DDGS than in corn, there is no difference in the concentration of digestible and metabolizable energy between DDGS and corn. The energy digestibility has been found to not differ among corn DDGS sources and ranged from 66.7 to 69.2% (Fastinger and Mahan, 2006).

In an experiment done by Spiehs et al. (1999) dietary digestible energy (DE) and metabolizable energy (ME) tended to be lower when comparing increasing amounts of DDGS. In 10 DDGS samples measured by Pedersen et al. (2007), the DE was 4,140 ± 205 kcal/kg DM. The DE values for the DDGS samples are comparable with average values of approximately 4,220 kcal DE and 4,040 kcal ME /kg DM that were measured in two sources of DDGS (Hastad et al., 2004).

Stein et al. (2006) reported that in ten samples, DE ranged from 3,382 to 3,811 kcal/kg of dry matter. The DE average of the DDGS sources was approximately 3,556 kcal/kg of DM this is higher than the NRC (1998) value. Spiehs et al. (2002) also calculated values for DE and ME in DDGS to be approximately 3,990 and 3,750 kcal/kg DM. However, the NRC (1998) DE and ME values for DDGS are 3,449 and 3,038 kcal/kg DM (Table 9). The variation of energy values leads to concerns to properly formulating a diet for pigs in commercial conditions.

Table 9. Comparison of energy values (dry matter basis) on corn DDGS soruces

	Modern DDGS calculated	Modern DDGS Trial Avg.	Old DDGS calculated	DDGS NRC (1998)	Corn NRC (1998)
DE, kcal/kg	3,965	4,011	3,874	3,449	3,961
ME, kcal/kg	3,592	3,827	3,521	3,038	3,843

Calculated values were determined from the crude protein and crude fat in the experimental diet. (Adapted from Shurson, 2002; Pederson, 2007)

Conclusion

There is very little data reporting digestibility values of N and P in DDGS sources on nursery and grow/finishing diets for pigs, as well as there is little data on sorghum DDGS sources. With this knowledge, we completed two experiments measuring growth performance, digestibility of N and P, and bioavailability of P in corn and sorghum DDGS sources on growing pigs.

CHAPTER III

DETERMINATION OF P BIOAVAILABILITY IN CORN AND SORGHUM DISTILLERS DRIED GRAINS WITH SOLUBLES IN GROWING PIGS.

Abstract

A total of 35 barrows (29.6 kg BW) were used in a 34-d study to determine the effects of corn or sorghum distillers dried grains with solubles (DDGS) on growth performance, bone traits, and P bioavailability. One corn and three sorghum DDGS were each collected from a different production plant. Pigs were blocked by weight and ancestry, and randomly allotted to one of seven dietary treatments with five pigs/treatment. The basal diet was a fortified corn starch-dextrose-soybean meal diet which was adequate in all nutrients except P. This diet contained 0.3% total P, which was provided by soybean meal and monosodium phosphate (MSP). Treatments were the basal, the basal plus MSP to provide 0.075 and 0.15% added P, and the basal plus corn DDGS or the three sorghum DDGS to provide 0.15% P. The corn DDGS contained 0.79% P and the three sorghum DDGS contained 0.80, 0.66, 0.69% P, respectively. All diets were formulated to 1.05% lysine and 0.70% Ca. Pigs were housed individually in stalls with ad libitum access to water and fed at 3.25 times maintenance daily. At the end of the 34-d study, all pigs were killed, the femurs excised, and the feet removed to collect the 3rd and 4th metacarpals and metatarsals. Bone breaking strength was determined and the metacarpals were dried and ashed. Increasing levels of MSP increased (linear, $P < 0.04$) ADG, ADFI, G:F, P intake, and increased (linear, $P < 0.01$) bone strength and ash. DDGS had no effect ($P > 0.10$) on performance or bone traits as compared to the high MSP diet. Also, there were few differences ($P > 0.10$) between corn and sorghum DDGS. Bone traits of pigs fed DDGS were compared to the standard curve for pigs fed increasing MSP. Bone traits were plotted against P intake and bioavailability was determined based on slope ratio. Bioavailability of P was approximately 80% in corn DDGS and one sorghum DDGS and 60% in the other two sorghum DDGS. These results suggest that the bioavailability of P in DDGS is relatively high; however, the bioavailability of P varied between DDGS sources.

Introduction

Distillers dried grains with solubles is a byproduct of the fermentation of cereal grains used in the production of alcohol for beverages or ethanol (Cromwell et al., 1993). The increased production of ethanol has increased the availability of DDGS for use in livestock feeds. However, increased environmental concerns related to excess P excretion have become a major issue for the swine industry. The bioavailability of P in corn is estimated to be approximately 15% (NRC, 1998). Corn DDGS has been shown to have high bioavailability of P being approximately 90%, which is greater than corn (Shurson et al., 2004). Fent et al. (2005) determined that P availability was approximately 85% using a slope ratio bioavailability assay using monosodium phosphate (MSP) as the control.

The most common DDGS source is from corn and there are several reports of the effects of corn DDGS on performance and P retention. The increased production of

DDGS has led to the use of a wide range of cereal grains, including sorghum. There is little data supporting the effects of sorghum DDGS on performance and bone strength of growing pigs. Therefore, the purpose of this study was to determine the effects of corn and sorghum DDGS on growth performance and bone strength.

Materials and Methods

Animals, Diets, and Treatments. A total of 35 Yorkshire barrows with an average body weight (BW) of 29.6 kg were used in a 34-day study to investigate the effects of corn DDGS and sorghum DDGS addition on growth performance and bone strength of pigs fed corn starch-dextrose-soybean meal-based diets. The dietary treatments included the basal, basal plus monosodium phosphate (MSP), and corn-based distillers dried grains with solubles (CDDGS), and three sorghum-based distillers dried grains with solubles (SDDGS). One corn and three sorghum DDGS were each collected from one of four different production plants in KS and NE, which was supplied by Kansas State University. Pigs were blocked by BW and ancestry, and allotted randomly to one of seven dietary treatments with five pigs per treatment in a randomized complete block design.

Concentration of P in DDGS sources was determined before mixing the experimental diets. All diets were corn starch-dextrose-soybean meal based (Table 10). Diet 1 served as the basal diet and was composed of corn starch, dextrose, and soybean meal. The basal diet contained 0.30% total P, which was provided by soybean meal and monosodium phosphate. Monosodium phosphate (MSP) was added to the basal diet in increasing amounts to provide 0.075 and 0.15% total P (Diets 2 and 3). Diets 4 to 7 were as Diet 1 with additions of DDGS to provide 0.15% total P. The corn DDGS contained 25.6% CP and 0.79% P and the three sorghum DDGS contained 29.3, 25.6, and 30% CP and 0.80, 0.66, and 0.69% P, respectively. All nutrients met or exceeded NRC (1998) standards except P and were formulated to contain 1.05% lysine and 0.70% Ca. All diets were fed in meal form.

Pigs were housed individually in 0.61 m x 1.52 m stalls in an environmentally-controlled room. Each stall was equipped with one nipple waterer and a stainless steel self-feeder. The flooring was composed of plastic slats. All pigs were allowed ad libitum access to water and fed twice daily. Feeding amounts were determined by feeding 3.25 times the pig's maintenance need based on expected energy values of the diet and weight of the animal.

Maintenance (NRC, 1998) was calculated as:

$$ME_{m,}\ \text{kcal/d} = 106 * \text{kg of BW}^{0.75}$$

Collection and Analyses. Random samples were taken to determine dry matter, ash, P and N of each DDGS source and experimental diets. Each sample was placed in a plastic bag and stored in a refrigerator. Grab samples of feces were collected at the end of the experiment and stored in plastic containers at -20 ^{o}C.

Initially, frozen fecal samples were freeze dried for 21- d before grinding. Dried feces and diets were ground through a 1 mm screen using a Wiley Mill (Standard Model No. 3; Arthur H. Thomas Co., Philadelphia, PA). Dry matter concentration of diets and feces was determined by drying at 100 ^{o}C overnight. Ash determination was performed by placing diet and fecal samples in a muffle furnace (Sybron, Dubuque, IA) at 550 ^{o}C overnight. Nitrogen concentration was determined by the Kjeldahl procedure (AOAC, 1998) using an automated analyzer (FOSS Tecator, 2020 Digestor, 2400 Kjeltec Analyzer; Hoganas, Sweden). Total phosphorus content in diets and feces was determined by a gravimetric quinolinium molybdophosphate method (AOAC, 1998). Also, DDGS samples were sent to the University of Missouri for determination of amino acid, mineral, and fiber concentrations.

Pigs were weighed at initiation and weekly during the experiment to allow calculation of ADG, ADFI, and G:F. At the end of the experiment, all pigs were slaughtered at the Oklahoma State University meat lab. Following scalding, scraping, and evisceration, front and rear feet were removed and the femurs were excised, and placed in a plastic bag and frozen (-20 ^{o}C). To collect the 3rd and 4th metacarpals (MC) and metatarsals (MT), the feet were allowed to thaw and autoclaved at 120 ^{o}C and 15 psi for approximately 6 minutes. After autoclaving, MC and MT were extracted and cleaned of extraneous tissue and frozen. All femurs, metacarpals, and metatarsals were allowed to thaw for 18 h before breaking strength analyses.

Bone breaking strength was determined using an Instron Universal Testing Machine (Model 4502, Instron, Canton, MA) by procedures of Cromwell et al. (1972). Bones were placed in a horizontal position on supports and breaking strength was defined as the amount of force (kg) required to break the bone. Breaking strength of the MC, MT, and femurs were recorded. Then, one MC from the right foot was dried for 6 h and soaked in petroleum ether for 24 h to remove fat. After fat extraction, the MC was dried for 6 h and ashed for 48 h at 550 ^{o}C. Percentage of ash in the MC was expressed on a dried, fat-free basis.

A slope ratio assay was conducted comparing bone strength and metacarpal ash to phosphorus intake to estimate the bioavailability of P in DDGS sources. The slope ratio assay is used to determine the bioavailability of phosphorus in DDGS sources relative to a standard phosphorus source, MSP, which is believed to be 100% available. The bone breaking strength for the standard and specific feed source is regressed on increasing levels of phosphorus intake. The ratio between the two slopes provides an estimate of the availability of phosphorus in the specific feed source (Figure 5).

Statistical Analysis. Data was analyzed as a randomized complete block design with initial weight as the blocking criterion. The model included the effects of block, treatment and block by treatment (error). In all cases, pig served as experimental unit. Treatment comparisons were: MSP linear, MSP Quadratic, DDGS vs. MSP, CDDGS vs. MSP, SDDGS vs. MSP, and CDDGS vs. SDDGS.

Results

The chemical analysis of DDGS sources (Table 11) indicated that the composition of CDDGS (25.95% CP and 0.79% P) and SDDGS (25.35, 30.19, 30.24% CP and 0.81, 0.66, 0.69% P) were similar to CDDGS values published for swine by the NRC (1998). Corn DDGS and Sorghum DDGS1 had similar values for CP and P. For Sorghum DDGS2 and 3, CP was higher and P values were lower as compared to Corn DDGS and Sorghum DDGS1. Lys, Met, Trp, and Thr values (0.94, 0.89, 0.89, 0.84%; 0.55, 0.49, 0.56, 0.49%; 0.21, 0.24, 0.21, 0.22%; 1.02, 0.93, 1.08, 1.03%) were similar between

DDGS sources. Reported Corn DDGS and Sorghum DDGS Lys values are higher than Corn DDGS values in NRC (1998). However, fermentation (to ethanol) greatly concentrates the nonstarch components of the seed (e.g., protein, fat, fiber, ash, and amino acids).

Increasing levels of MSP increased (linear, $P < 0.05$) ADG, ADFI, P intake, and increased (linear, $P < 0.01$) bone strength and ash (Table12). Also, increasing levels of MSP tended to increase ($P < 0.10$) G:F. There were no differences among DDGS sources ($P > 0.10$) for ADG, ADFI, and P intake. Sources of DDGS had no effect ($P > 0.10$) on performance or bone traits as compared to the high MSP diet (Table 12).

Increasing levels of MSP increased ($P < 0.01$) MC/MT and femur bone strength and MC ash weight. Source of DDGS had no effect ($P > 0.10$) on MC/MT and femur bone strength and MC ash weight. There were no differences ($P > 0.10$) in bone traits for pigs fed the high MSP diets vs. pigs fed DDGS diets.

Bone traits of pigs fed DDGS were compared to the standard curve for pigs fed increasing MSP (Figure 5). Bone traits were plotted against P intake and bioavailability was determined based on slope ratio. Bioavailability of P was approximately 80% in corn DDGS and one sorghum DDGS and 60% in the other two sorghum DDGS. These results suggest that the bioavailability of P in DDGS is relatively high; however, the bioavailability of P varied between DDGS sources.

Increasing levels of MSP increased ($P < 0.05$) fecal concentrations of P and ash, but did not effect ($P > 0.10$) fecal DM and N concentrations. Fecal P and ash concentration from pigs fed the DDGS diets did not differ ($P > 0.10$) from MSP diets. However, fecal DM concentration decreased and N concentration increased for pigs fed

DDGS diets (P < 0.05) compared with those fed the high MSP diets. Fecal DM, N, P and ash concentrations did not differ among DDGS sources (P > 0.10). Fecal concentrations are summarized in Table 13.

Discussion

Shurson et al. (2003) reported that DDGS produced in modern ethanol plants is higher in digestible energy, amino acids, and higher in available phosphorus than DDGS produced in older ethanol plants. The available P and lysine values in modern DDGS sources have been compared to NRC (1998), lysine values varied the most from 0.67 to 0.85% for modern DDGS sources and P values varied little from 0.83 to 0.89%. In our experiment, DDGS lysine values were higher than NRC (1998) and ranged from 0.84 to 0.94%. Corn DDGS P was reported at 0.79% (Table 11) and was slightly higher than corn DDGS values in NRC (1998).

The distillers dried grains with solubles used in this experiment is an excellent source of phosphorus. Distillers dried grains with solubles did not negatively effect ADG, ADFI, femur bone breaking strength, and metacarpal ash weight. Senne et al. (1996) reported that in nursery diets with increasing amounts of sorghum DDGS, ADG was not affected and G:F was actually improved with as much as 30% DDGS included. Overall growth rate, body weight, and feed conversion during the nursery phase were similar among pigs regardless of the DDGS as observed by Whitney and Shurson (2004). Lumpkins and Batal (2005) observed, in cectomized roosters, a linear growth and tibia bone ash (%) response with the addition of 0.05 and 0.10% P from K_2HPO_4 and 2 levels of DDGS (5 and 10%). In a finishing experiment performed by Senne et al. (1996), ADG increased slightly. However, ADFI decreased and F:G improved as the concentration of DDGS was increased. Due to variations in DDGS nutrients, Whitney et al. (2006) indicated that ADG and G:F tends to decrease with increasing amounts of DDGS above 20% in the diet. In this experiment comparing MSP to DDGS sources for available P, DDGS levels in this experiment were approximately 20% and had no effect on ADG or G:F.

Based on the slope ratios of the regression lines from each phosphorus source, Whitney and Shurson (2001) reported that the availability of phosphorus in corn DDGS was approximately 87.5 % and 92.2 %, based on P excretion and retention, respectively. Fent et al. (2004) reported that phosphorus bioavailability estimates for DDGS were approximately 85 percent, also in corn DDGS. In cectomized roosters, Lumpkins and Batal (2005) reported the values as a percentage of total P (0.74%) and DDGS yielded availability estimates of 68% and 54%. Phosphorus bioavailability values from a slope ratio assay for our experiment were 77% for the corn DDGS and 70, 69, and 64% for sorghum DDGS. This is a good indicator that DDGS is a good source of available P.

Spiehs et al. (1999) suggested that feeding 10 to 20% DDGS should maintain N retention and improve P excretion while tending to increase N when fed to grow-finishing pigs. In our experiment for growing pigs, fecal N concentration increased in pigs fed DDGS vs. the high MSP diet. Xu et al. (2005) reported that feeding DDGS in swine diets increases percent P retention, and leads to a decrease in P excretion. Fecal P concentrations, in our experiment, for pigs fed DDGS vs. the high MSP diet varied little. Furthermore, in our experiment, fecal ash concentration also decreased in pigs fed DDGS vs. the high MSP diet. Distillers dried grains with solubles fed at 20% in our experimental diet increased fecal N concentrations, had no effect on fecal P concentrations, and reduced fecal ash concentrations. These results suggest a possible increase in N excretion and reduction in P and ash excretion.

Implications

Distillers dried grains with solubles is an excellent source of P. There are variations among sources that must be considered when formulating diets for growing pigs. Phosphorus bioavailability is expected to be approximately 0.77% in corn and 0.64 to 0.70% in sorghum DDGS In conclusion, DDGS can be used in greater concentrations than previously suggested for pigs, if P bioavailability of diets is considered. Nutritionists should let ingredient prices and availability determine use of DDGS in diets for growing pigs. Diets should not exceed 20% DDGS due to possible reductions in overall performance.

Table 10. Composition of experimental diets, as-fed basis (Exp. 1)

	Diet						
	1	2	3	4	5	6	7
				DDGS[a]			
		MSP[a]		C	S 1	S 2	S 3
				Added P, %			
Ingredients	0	0.075	0.15	0.15	0.15	0.15	0.15
Corn Starch	48.05	47.79	47.52	33.44	34.50	34.50	34.50
Dextrose	16.02	15.93	15.84	11.15	11.50	11.50	11.50
SBM, dehulled	31.46	31.46	31.46	31.46	31.46	31.46	31.46
Corn DDGS	0.00	0.00	0.00	19.48	0.00	0.00	0.00
Sorghum DDGS	0.00	0.00	0.00	0.00	18.07	18.07	18.07
Monosodium P	0.39	0.74	1.10	0.39	0.39	0.39	0.39
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	1.00
DL-methionine	0.10	0.10	0.10	0.10	0.10	0.10	0.10
L-threonine	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Limestone	1.65	1.65	1.65	1.65	1.65	1.65	1.65
Sodium chloride	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin mix	0.15	0.15	0.15	0.15	0.15	0.15	0.15
TM mix	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Ethoxyquin	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Lincomix-20	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Calculated analysis							
CP, %	15.10	15.10	15.10	15.10	15.10	15.10	15.10
Lys, %	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Ca, %	0.70	0.70	0.70	0.70	0.70	0.70	0.70
P, %	0.30	0.38	0.45	0.45	0.45	0.45	0.45
Analyzed P, %	0.30	0.37	0.45	0.46	0.47	0.46	0.42

[a] MSP = Monosodium phosphate; C = corn distillers dried grains with solubles; S 1 = sorghum distillers dried grains with solubles sample 1; S 2 = sorghum distillers dried grains with solubles sample 2; S 3 = sorghum distillers dried grains with solubles sample 3.

Table 11. Chemical analysis of DDGS sources

	DDGS [a]				DDGS NRC (1998)	Corn NRC (1998)
	C	S 1	S 2	S 3		
DM, %	90.40	89.30	89.80	88.10	93.00	89.00
CP, %	25.95	25.35	30.19	30.24	27.70	8.30
Crude Fat, %	9.22	9.65	8.91	8.45	8.40	3.90
Crude Fiber, %	6.47	6.37	6.89	6.52	----	----
Ash %	4.76	4.39	3.54	3.76	----	----
Phosphorus, %	0.79	0.81	0.66	0.69	0.77	0.43
Calcium, %	0.10	0.10	0.04	0.07	0.20	0.05
Magnesium, %	0.33	0.31	0.27	0.28	0.19	0.12
Copper, ppm	25	40	36	33	57	3
Iron, ppm	127	411	118	174	57	29
Manganese, ppm	21	38	26	40	24	7
Zinc, ppm	92	54.	36	38	80	18
Lysine, %	0.94	0.89	0.89	0.84	0.62	0.26
Threonine, %	1.02	0.93	1.08	1.03	0.94	0.29
Methionine, %	0.55	0.49	0.56	0.49	0.50	0.17
M+C, %	1.18	1.03	1.18	1.07	1.02	0.36
Tryptophan, %	0.21	0.24	0.21	0.22	0.25	0.06
Valine, %	1.34	1.30	1.60	1.58	1.30	0.39
Isoleucine, %	1.00	0.96	1.25	1.25	1.03	0.28
Leucine, %	3.05	2.79	4.03	3.86	2.57	0.99
Histidine, %	0.77	0.72	0.79	0.72	0.69	0.23
Tyrosine, %	1.04	0.94	1.22	1.18	0.83	0.25
Phenylalanine, %	1.31	1.27	1.64	1.60	1.34	0.39
Arginine, %	1.22	1.22	1.23	1.17	1.13	0.37

(Analysis performed at University of Missouri Experiment Station Chemical Laboratory)
[a] C = corn distillers dried grains with solubles; S 1 = sorghum distillers dried grains with solubles sample 1; S 2 = sorghum distillers dried grains with solubles sample 2; S 3 = sorghum distillers dried grains with solubles sample 3.

Table 12. Effects of monosodium P and DDGS on performance and bone characteristics of growing pigs[aef].

	Diet							
	1	2	3	4	5	6	7	
				DDGS [b]				
		MSP [b]		C	S 1	S 2	S 3	
	Added P, %							
	0	0.075	0.15	0.15	0.15	0.15	0.15	SE
Performance								
ADG, g/d [d]	489.2	544.5	573.8	578.3	586.2	617.5	570.3	27.8
ADFI, kg/d [d]	1.26	1.27	1.32	1.30	1.29	1.30	1.27	0.02
G:F [e]	0.39	0.42	0.46	0.45	0.46	0.47	0.45	0.75
P intake, g/d [c]	3.75	4.79	5.93	6.01	6.10	5.98	5.73	0.09
Bone Traits								
MC/MT, kg [cf]	68.29	83.33	90.58	92.07	89.80	79.80	78.68	3.68
Femur, kg [c]	190.1	208.2	255.5	238.1	234.1	245.3	240.9	8.87
MC ash, % [c]	51.59	52.17	54.08	52.91	53.46	53.10	52.38	0.39

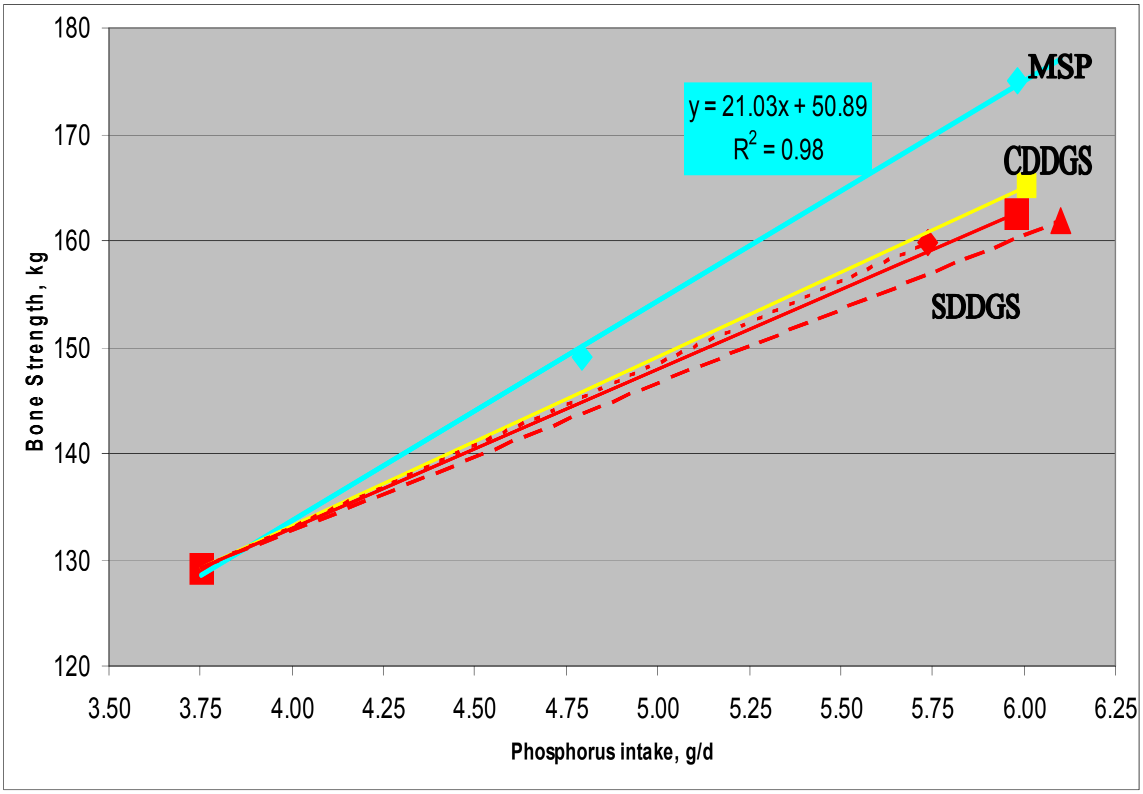
[a] Least squares means for 5 pigs/trt
[b] MSP = Monosodium phosphate; C = corn distillers dried grains with solubles; S 1 = sorghum distillers dried grains with solubles sample 1; S 2 = sorghum distillers dried grains with solubles sample 2; S 3 = sorghum distillers dried grains with solubles sample 3.
[c] Linear effect of monosodium P ($P < 0.01$)
[d] Linear effect of monosodium P ($P < 0.05$)
[e] Linear effect of monosodium P ($P < 0.10$)
[f] Average of metacarpal/metatarsal bone strength

Table 13. Fecal nutrient concentration for growing pigs fed MSP and DDGS diets (Exp. 1)[a]

	Diet							
	1	2	3	4	5	6	7	
				DDGS [b]				
		MSP [b]		C	S 1	S 2	S 3	
	Added P, %							
	0	0.075	0.15	0.15	0.15	0.15	0.15	SE
DM, % [d]	89.68	90.00	89.92	89.34	89.20	88.98	89.04	0.27
N, % [d]	2.28	2.48	2.63	3.14	2.94	3.44	3.91	0.15
P, % [c]	0.81	0.98	1.33	1.39	1.38	1.28	1.38	0.12
Ash, % [c]	9.46	10.06	12.28	11.87	11.12	10.75	11.14	0.69

[a] Least squares means for 5 pigs/trt
[b] MSP = Monosodium phosphate; C = corn distillers dried grains with solubles; S 1 = sorghum distillers dried grains with solubles sample 1; S 2 = sorghum distillers dried grains with solubles sample 2; S 3 = sorghum distillers dried grains with solubles sample 3.
[c] Linear effect of monosodium P ($P < 0.05$)
[d] High MSP vs. DDGS ($P < 0.05$)

Figure 5. P bioavailability based on average bone breaking strength for growing pigs fed MSP and DDGS Diets.



Slope Ratio values; MSP: 21.03, Corn DDGS: 16.19, Sorghum DDGS1: 14.49, Sorghum DDGS2: 14.79, Sorghum DDGS3: 13.55. Bioavailability, %; Corn DDGS: 77, Sorghum DDGS1: 69, Sorghum DDGS2: 70, Sorghum DDGS3: 64.

CHAPTER IV

DETERMINATION OF THE APPARENT DIGESTIBILITY OF N, P AND GE IN CORN AND SORGHUM DISTILLERS DRIED GRAINS WITH SOLUBLES IN GROWING PIGS.

Abstract

A total of 25 pigs (27.5 kg BW) were used in a 16-d study to determine the effects of corn or sorghum distillers dried grains with solubles (DDGS) on dry matter (DM), N, P, and gross energy (GE) digestibility. One corn and three sorghum DDGS were each collected from a different production plan. Pigs were blocked by weight and randomly allotted to one of five dietary treatments with 5 pigs/treatment. The control diet was a fortified corn-soybean meal diet which was adequate in all nutrients. The control diet contained 18.7% CP and 0.50% P. Treatments were the control, control plus corn DDGS diets, or one of three sorghum DDGS. Each DDGS diet consisted of 80% control and 20% DDGS. The corn DDGS contained 25.95 % CP and 0.79% P and the three sorghum DDGS contained 25.35, 30.19, and 30.24% CP and 0.80, 0.66, 0.69% P, respectively. Pigs were housed individually in metabolism chambers with ad libitum access to water and fed at 3.0 times maintenance daily. On d 11 and ending on d 16, daily fecal collections were taken for a 5 day fecal output total. Total fecal output, N, P, and GE digestibility were determined. There was no difference ($P > 0.10$) in DM intake. Intake of N, P, and GE increased ($P < 0.05$) in pigs fed DDGS diets vs. pigs fed the control diet. Total fecal DM, N, and GE excretion increased for pigs fed DDGS diets vs. pigs fed the

control diet ($P < 0.05$). However, P excretion did not differ ($P > 0.10$) on a g/d basis. Digestibility of DM, N and GE decreased ($P < 0.05$) for pigs fed DDGS diets vs. pigs fed the control diet. Digestibility of P did not differ ($P > 0.10$) among DDGS sources or from the control. With the results stated, diets containing 20% of corn or sorghum DDGS decreased N and GE digestibility, but did not affect P digestibility.

Introduction

In our first experiment, DDGS was included in the experimental diets at 20%. Bioavailability of P in corn and sorghum DDGS sources ranged from 64 to 77% and suggesting that DDGS is a good source of available P. Fecal nutrient concentrations increased for N, varied little for P, and were reduced for ash in pigs fed DDGS experimental diets. Digestibility is reduced for N and GE in DDGS sources, but P is similar among DDGS sources.

Source of DDGS from modern ethanol plants generally are improved in concentrations of nutrients and in nutrient digestibility (Spiehs et al., 2002; Whitney and Shurson, 2004; Whitney et al., 2006). Recent experiments concluded that the inclusion of 10% to 20% DDGS does not significantly impact growth performance or feed efficiency of growing pigs. The increased production of ethanol has increased the availability of DDGS for use in livestock feeds. With increased production of DDGS sources, there is variability among DDGS sources and this causes concern for formulating a complete diet for the growing pig. There is little data on nutrient digestibility of N, P, and GE in corn and sorghum DDGS sources. Therefore, the purpose of this study was to determine the effects of the corn and sorghum DDGS on digestibility of DM, N, P, and GE.

Materials and Methods

Animals, Diets, and Treatments. A total of 25 crossbred pigs with an average BW of 27.5 kg were used in a 16-d study to investigate the effects of corn DDGS and sorghum DDGS addition on growth performance and digestibility of DM, N, P, and GE of pigs fed corn-soybean meal-based diets. The five dietary treatments included a control diet, one corn-based distillers dried grains with solubles (CDDGS), and three sorghum-based distillers dried grains with solubles (SDDGS1, SDDGS2, SDDGS3). One corn and three sorghum DDGS were each collected from one of four different production plants in KS and NE, which was supplied by Kansas State University. Pigs were blocked by BW and ancestry and assigned randomly to one of five dietary treatments with five pigs per treatment in a randomized complete block design.

All diets were corn-soybean meal based (Table 14). Diet 1 served as the control diet and was composed of corn and soybean meal, which contained 18.70% CP and 0.50% P. Diets 2 – 5 consisted of 80% control and 20% DDGS: diet 2 - CDDGS, diet 3 – 5 one of three SDDGS. All nutrients met or exceeded NRC (1998) standard. All experimental diets were fed in meal form.

Pigs were housed individually in metabolism chambers in an environmentally-controlled room. The chambers were designed for the separate collection of feces, urine and feed waste. Each chamber was equipped with a galvanized steel mesh floor, stainless self feeder, and one nipple waterer. Underneath the flooring was a five-quart plastic container to collect urine and excess water. All pigs were allowed ad libitum access to water and fed twice daily. Feeding amounts were determined by feeding 3.0 times maintenance based on expected energy values of the diet and weight of the animal. Maintenance (NRC, 1998) was calculated as:

$$ME_m = 106 * \text{kg of BW}^{0.75}$$

Collection and Analyses. There was a 5-d collection period starting on 11 and ending on 16. Feces were collected twice daily during the collection period from the 1-mm screen that was placed under the flooring in the chamber. The feces were collected and placed into a plastic bag and frozen at -20 ^{o}C until samples were analyzed. At each collection, feed refusal was collected and weighed and urine containers were dumped. Feed samples were also collected and placed into a plastic bag and stored in a refrigerator.

Frozen fecal samples were dried in a forced-air oven for 5-days at 55 ^{o}C before grinding. Feed and fecal samples were ground through a 1 mm screen using a Wiley Mill (Standard Model No. 3; Arthur H. Thomas Co., Philadelphia, PA). Ground samples were placed in the oven to determine DM at 100 ^{o}C for 5 h. Ash determination was performed by placing diet and fecal samples in a muffle furnace (Sybron, Dubuque, IA) at 550 ^{o}C overnight. Nitrogen content was determined by the Kjeldahl procedure (AOAC, 1998) using an automated analyzer (FOSS Tecator, 2020 Digestor, 2400 Kjeltec Analyzer; Hoganas, Sweden). Total phophorus content in feces and diets was determined by a gravimetric quinolium molybdophosphate method (AOAC, 1998). Gross energy (GE) of each feed and fecal sample was determined by bomb calorimetry (Parr 1261, Isoperibol Calorimeter; Molin, IL).

Total DM, N, P, and GE intake was measured using the total feed consumed divided by the number of collection days (5-days). Feces were collected and analyzed and excretion was determined by multiplying fecal excretion (g/d) by nutrient concentration percent a shown in the formula below:

Fecal nutrient excretion, g/d = Fecal Output, g/d * Fecal Nutrient, %

Apparent nutrient digestibility was calculated using the following formula:

Apparent digestibility, g/d = ((Nutrient Intake, g/d – Fecal Output, g/d) / Nutrient Intake, g/d)*100.

After determining nutrient digestibly, we were interested in predicting digestibility of each, individual DDGS samples. Predicted digestibility was determined assuming that there were no positive or negative associative effects on digestibility of adding 20% DDGS to the control diet. Predicted digestibility of DDGS samples (Table 16) was calculated using the following formula:

Predicted digestibility = (nutrient digestibility of dietary treatment – (% digestibility of control diet * 0.80)) / 0.20.

This formula explains that the experimental diets contained 80% control diet and 20% DDGS.

Statistical Analyses. Data was analyzed as a randomized complete block design with initial BW as the blocking criterion. The model included the effects of block (rep), treatment, and block x treatment (error). In all cases, the pig served as the experimental unit. Treatment comparisons were: control vs. DDGS, control vs. CDDGS, control vs. average of SDDGS, and CDDGS vs. average of SDDGS.

Results

Dry matter intake was similar ($P > 0.10$) for all dietary treatments due to feed intake equalized among treatments. However, because the addition of 20% DDGS to the control diet increased the concentrations of N, P, and GE, intake of the nutrients increased ($P < 0.05$) for pigs fed DDGS vs. the control diet. Pigs fed SDDGS had greater intake of N vs. those fed CDDGS; however, there were no differences in ($P > 0.10$) P and GE intake among pigs fed the DDGS sources.

Fecal DM and GE concentrations did not differ ($P > 0.10$) for pigs fed control vs. DDGS and within the DDGS diets. Fecal N concentrations increased ($P < 0.10$) for pigs fed DDGS compared with pigs fed the control diet. Fecal P concentrations decreased ($P < 0.05$) for pigs fed DDGS compared to pigs fed the control diet. However, fecal N and P concentrations did not differ ($P > 0.10$) for pigs fed CDDGS vs. SDDGS.

Total fecal DM, N, and GE excretion increased ($P < 0.05$) for pigs fed DDGS compared with pigs fed the control diet. No differences ($P > 0.10$) were found among

DDGS sources for fecal DM, N, P, and GE excretion. Total fecal P excretion was similar for all dietary treatments.

The apparent digestibility of DM and GE decreased ($P < 0.05$) for pigs fed DDGS compared with pigs fed the control diet; also, apparent N digestibility decreased ($P < 0.10$) for pigs fed DDGS compared with pigs fed the control diet. Dry matter and GE digestibility also decreased ($P < 0.05$) for pigs fed the SDDGS compared with pigs fed the control diet as did N digestibility ($P < 0.10$). Apparent P digestibility was similar ($P > 0.10$) for pigs fed the control or DDGS diets. Furthermore, there was no difference found for DM, N, P, and GE digestibility among DDGS diets. Apparent digestibility values are summarized in Table 15.

Predicted digestibility of DDGS sources were calculated and are reported in Table 16. There was little difference observed in DM digestibility among DDGS sources. However, N, P and GE digestibility in corn DDGS was greater than that calculated for sorghum DDGS sources.

Discussion

Shurson et al. (2003) reported that DDGS produced in modern ethanol plants is higher in digestible energy, amino acids, and higher in available phosphorus than DDGS produced in older ethanol plants. The available P and lysine values in modern DDGS sources have been compared to NRC (1998). Lysine values varied the most from 0.67 to 0.85% for modern DDGS sources and P bioavailability ranged from 0.83 to 0.89%. In the first experiment, P bioavailability was found to be 0.77% for corn DDGS and lysine ranged from 0.84 to 0.94% in DDGS sources.

It has been recommended that feeding DDGS in swine diets increases P retention (Xu et al., 2006). The end result would be a decrease in P excretion. Spiehs et al. (1999) reported that feeding 10 to 20% DDGS improved P retention and reduced P excretion. The relatively high digestibility of phosphorus in DDGS results in less inorganic phosphorus that is needed in diets containing DDGS (Stein, 2006). Stein (2005) reported that digestibility of P in corn DDGS ranged from 35 to 50%; also, Pedersen et al. (2007) reported a value of 59.1%. Predicted digestibility of P in DDGS sources, in our experiment, ranged from 61.64 to 66.99%, and sorghum DDGS P digestibility is lower than corn DDGS P digestibility. Phosphorus digestibility for the experimental DDGS diets ranged from 57.04 to 58.11%.

When an animal consumes excess amino acids above the requirement for maintenance and protein synthesis, they must be deaminated (Whitney and Shurson, 2004). Therefore, any diet that contains improperly balanced amino acids is less efficiently utilized by the animal. Spiehs et al. (1999) found that increasing DDGS levels in the diet tended to increase N intake. However, N retention, based on percentage, did not differ among treatments. Spiehs et al. (1999) suggested that feeding 10 to 20% DDGS should maintain N retention while tending to increase N excretion when fed to grow-finishing pigs. In our experiment, we reported N digestibility to range from 86.7 to 87.4% in the DDGS experimental diets and predicted digestibility of the DDGS sources ranged from 77.1% to 80.3%. Since there is little data on N digestibility, we compared our results to that obtained for amino acid digestibility. Stein et al. (2006) reported in 10 corn DDGS samples the average standardized amino acid digestibility ranged from 67.3 to 77.6%. Also, Fastinger and Mahan (2006) observed in five corn DDGS sources that the average standardized amino acid digestibility ranged from 67.0 to 76.8% in essential amino acids and 64.1 to 76.1% in non essential amino acids. Predicted N digestibility for corn or sorghum DDGS, in our experiment, ranged from 77.1 to 80.4%, which is similar to the upper values reported by Stein (2005) and Fastinger and Mahan (2006). Nitrogen digestibility decreased as compared to the control due to the increase in N excretion in pigs fed DDGS. Distillers dried grains have increased fiber concentrations and fiber negatively influences digestibility of amino acids (Stein et al., 2006).

Corn DDGS produced by modern ethanol plants has been reported to contain significantly higher levels of digestible and metabolizable energy than found in DDGS produced by older, more traditional ethanol plants (Shurson, 2002). Spiehs et al. (1999) observed that increasing amounts of DDGS in the diet increased gross energy (GE) intake. In this experiment, GE intake increased for pigs fed DDGS compared with pigs fed the control diet; GE intake ranged from 4,925.8 to 5,038.4 kcal/d. Moreover, Stein (2007) states that the concentration of GE in DDGS is greater than in corn, and due to a lower digestibility of energy in DDGS than in corn, there is no difference in the concentration of digestible and metabolizable energy between DDGS and corn. Fastinger and Mahan (2006) reported, in 5 corn DDGS sources, that GE concentration ranged from 4,848 to 4,969 kcal/kg and GE digestibility ranged from 66.7 to 69.2%. Stein et al. (2006) reported, in 10 corn DDGS sources, GE concentration ranged from 4,705 to 4,984 kcal/kg, and apparent total tract digestibility for GE in the diet ranged from 72.5 to 77.6%. Calculated GE digestibility of DDGS ranged from 62.7 to 70.5%. Pedersen et al. (2007) also reported GE digestibility to range from 81.3 to 84.6% in corn DDGS sources. Predicted GE digestibility in our experiment ranged from 76.65 – 82.95%. Predicted GE digestibilities reported in our experiment are similar to the upper values reported by Fastinger and Mahan (2006), Pedersen et al. (2007), and Stein et al. (2006). Gross energy digestibility in sorghum DDGS sources is lower than corn DDGS sources. The decrease in GE digestibility is expected to be caused from the increased fiber concentration in DDGS sources.

Implications

Distillers dried grains with solubles is an excellent source of nutrients including N and P. Digestibility of nutrients in DDGS source can be expected to range from 77.1 to 80.3% for N, 61.6 to 66.9% for P, and 76.65 to 82.9% for GE. Fecal N increased with inclusion of DDGS in both experiments and decreased digestibility. However, the high fiber content in DDGS sources can limit nutrient digestibility. There are variations among DDGS sources that must be considered when formulating diets for growing pigs. Nutrient digestibility is important to consider, because what is not utilized by the animal will be excreted.

Table 14. Composition of experimental diets, as-fed basis (Exp. 2)

	Diet				
	1	2	3	4	5
		DDGS[b]			
Ingredients	Control	C	S 1	S 2	S 3
Corn	70.17	56.14	56.14	56.14	56.14
Soybean meal, dehulled	27.07	21.66	21.66	21.66	21.66
Corn DDGS	0.00	20.00	0.00	0.00	0.00
Sorghum DDGS	0.00	0.00	20.00	20.00	20.00
Dicalcium phosphate	0.60	0.48	0.48	0.48	0.48
Limestone	1.40	1.12	1.12	1.12	1.12
Sodium chloride	0.50	0.40	0.40	0.40	0.40
Trace mineral mix	0.10	0.08	0.08	0.08	0.08
Vitamin mix	0.15	0.12	0.12	0.12	0.12
Calculated Analysis					
CP, %	18.70	20.15	20.03	21.00	21.01
Lys, %	1.00	0.99	0.98	0.98	0.97
ad Lys, %	0.82	0.75	0.75	0.75	0.74
td Lys, %	0.88	0.82	0.81	0.81	0.80
Thr, %	0.70	0.76	0.75	0.78	0.77
Met, %	0.30	0.35	0.34	0.35	0.34
M+C, %	0.64	0.75	0.72	0.75	0.73
Trp, %	0.22	0.22	0.22	0.22	0.22
Ca, %	0.75	0.62	0.62	0.61	0.61
Phos, %	0.50	0.56	0.56	0.53	0.54
Av. Phos, %	0.18	0.29	0.29	0.29	0.29
ME, kcal/kg[a]	3329.2	2663.4	2663.4	2663.4	2663.4

[a] ME values for DDGS are reported low due to no knowledge of expected ME values.
[b] C = corn distillers dried grains with solubles; S 1 = sorghum distillers dried grains with solubles sample 1; S 2 = sorghum distillers dried grains with solubles sample 2; S 3 = sorghum distillers dried grains with solubles sample 3.

Table 15. Digestibility of DDGS sources fed to growing pigs[a]

	Diet					
	1	2	3	4	5	
		DDGS[b]				
	Control	C	S 1	S 2	S 3	SE
DM Intake, g/d	1078.7	1082.1	1079.5	1076.5	1098.0	14.7
Fecal DM output, g/d[deg]	112.95	135.55	142.06	142.72	134.44	6.50
Fecal DM, %	44.75	39.66	43.46	37.21	41.14	4.20
Fecal GE, kcal/kg	4429.7	4369.6	4379.1	4557.6	4754.5	99.2
Fecal N, % [df]	3.25	3.36	3.36	3.45	3.88	0.13
Fecal P, % [dg]	2.42	2.08	2.06	1.95	2.19	0.11
DM digestibility, % [deg]	89.53	87.42	86.81	86.79	87.8	0.60
GE intake, kcal/d [deg]	4760.0	5019.7	4925.8	4956.8	5038.4	66.3
Fecal GE, kcal/d [deg]	501.9	591.7	620.8	650.2	639.5	25.4
GE digestibility, % [dg]	89.49	88.18	87.37	86.92	87.37	0.51
N intake, g/d [degh]	34.05	36.24	37.13	38.54	39.67	0.50
Fecal N, g/d [dg]	3.70	4.54	4.77	4.99	5.29	0.37
N digestibility, % [cf]	89.18	87.42	87.16	87.17	86.77	0.92
P intake, g/d [deg]	6.12	6.78	6.81	6.51	6.78	0.09
Fecal P, g/d	2.70	2.83	2.92	2.75	2.89	0.08
P digestibility, %	55.89	58.11	57.04	57.72	57.26	1.15

[a] Least square means for 5 pigs/trt
[b] C = corn distillers dried grains with solubles; S 1 = sorghum distillers dried grains with solubles sample 1; S 2 = sorghum distillers dried grains with solubles sample 2; S 3 = sorghum distillers dried grains with solubles sample 3.
[c] Control vs. DDGS ($P < 0.10$)
[d] Control vs. DDGS ($P < 0.05$)
[e] Control vs. CDDGS ($P < 0.05$)
[f] Control vs. SDDGS ($P < 0.10$)
g Control vs. SDDGS ($P < 0.05$)
h CDDGS vs. SDDGS ($P < 0.05$)

Table 16. Predicted digestibility of DDGS sources fed to growing pigs[a]

	DDGS[b]			
	C	S 1	S 2	S 3
DM, %	C	S 1	S 2	S 3
GE, %	82.95	78.91	76.65	78.88
N, %	80.38	79.06	79.13	77.14
P, %	66.99	61.65	65.03	62.73

[a] Calculated by Predicted digestibility = (nutrient digestibility of dietary treatment – (% digestibility of control diet * 0.80)) / 0.20

[b] C = corn distillers dried grains with solubles; S 1 = sorghum distillers dried grains with solubles sample 1; S 2 = sorghum distillers dried grains with solubles sample 2; S 3 = sorghum distillers dried grains with solubles sample 3.

CHAPTER V

SUMMARY AND CONCLUSION

Distillers dried grains with solubles is desirable to animal nutritionists due to the high protein content; however, it also has a high fiber content, which limits its use in non-ruminant diets (Gibson, 2005; Rausch and Belyea, 2005; Robinson, 2005). Shurson et al. (2004) states that DDGS for pigs has improved from the traditional sources produced by old ethanol plants (older than 1990). Recent studies have shown that energy, amino acid digestibility, and phosphorus availability of DDGS produced from modern ethanol plants is higher than nearly all of the values reported in the NRC (1998) (Spiehs et al., 2002; Whitney et al., 2000; Whitney et al., 2006; Xu et al., 2006).

The chemical analysis of DDGS sources (Table 10) indicated that the composition of CDDGS (25.95% CP and 0.79% P) and SDDGS (25.35, 30.19, 30.24% CP and 0.81, 0.66, 0.69% P) were similar to CDDGS values published for swine by the NRC (1998). Lys, Met, Trp, and Thr values (0.94, 0.89, 0.89, 0.84%; 0.55, 0.49, 0.56, 0.49%; 0.21, 0.24, 0.21, 0.22%; 1.02, 0.93, 1.08, 1.03%) were similar among the DDGS sources used in our experiments. These values are similar to Spiehs et al. (2002) and summarized in Table 10.

Experimental diets contained approximately 20% DDGS without negatively effecting ADG, ADFI, G:F, femur bone breaking strength, and metacarpal ash weight. In previous studies, nursery diets that contained increasing amounts of sorghum DDGS, ADG was not affected and G:F was actually improved with as much as 30% DDGS included (Senne et al.,1996). Overall growth rate, body weight, and feed conversion during the nursery phase were similar among pigs regardless of the DDGS as observed by Whitney and Shurson (2004). In a finishing experiment performed by Senne et al. (1996), ADG increased slightly; however, ADFI decreased and F:G was improved as the concentration of DDGS was increased. Due to variations in DDGS nutrients, Whitney et al. (2006) indicated that ADG and G:F tends to decrease with increasing amounts of DDGS above 20% in the diet.

In the first experiment, we formulated diets based on available P and compared the results to the control MSP diets. Phosphorus bioavailability values from a slope ratio assay were 77% for the Corn DDGS and 70, 69, and 64% for Sorghum DDGS. The bioavailability of P was similar to the NRC (1998) and was 77% in corn DDGS. Whitney and Shurson (2001) reported available P values at 87.5 % and 92.2 %, based on P excretion and retention, respectively. Fent et al. (2004), also reported that phosphorus bioavailability estimates for DDGS were approximately 85% in corn DDGS. In cectomized roosters, Lumpkins and Batal (2005) reported the values as a percentage of total P (0.74%) in DDGS yielded availability estimates of 68% and 54%. Even though there are variations among reported available P values, DDGS is a good source of available P.

In the second experiment, nutrient digestibility of DM, N, P, and GE was determined. Inclusion of DDGS in the diet decreased digestibility for DM, N, and GE for pigs compared to pigs fed the control diet. The decrease in digestibility is expected to be caused by the increased fiber concentration in DDGS sources. Nitrogen digestibility was decreased due to the increased in N excreted in feces for pigs fed DDGS diets. In the experimental diet, N digestibility for corn DDGS was 87.4% and sorghum DDGS was 87.1, 87.1, and 86.7%, respectively. Stein et al. (2006) reported in 10 corn DDGS samples the average standardized amino acid digestibility ranged from 67.3 to 77.6%. Also, Fastinger and Mahan (2006) observed in five corn DDGS sources that the average standardized amino acid digestibility ranged from 67.0 to 76.8% in essential amino acids and 64.1 to 76.1% in non essential amino acids. Predicted N digestibility for corn or sorghum DDGS, in our experiment, ranged from 77.1 to 80.4%, this is similar to the supper values reported by Stein (2005) and Fastinger and Mahan (2006). Nitrogen digestibility in our second experiment decreased as compared to the control due to the increase of N excretion in pigs fed DDGS. Nitrogen excretion (g/d) increased with the inclusion of DDGS in the experimental diets. The increased fecal N concentration in our first experiment could be used to explain why N digestibility decreased in the second experiment. Distillers dried grains have increased fiber concentrations and fiber negatively influences digestibility of amino acids (Stein et al., 2006).

Predicted P digestibility in our second experiment for corn DDGS was 66.9 % and sorghum DDGS was 61.6, 65.0, and 62. 7%. In comparing P digestibility to fecal P concentration from both experiments, we see a similar trend with CDDGS to be higher than SDDGS. Phosphorus digestibility values were similar to reported values from Pedersen et al. (2007) of 59.1%. It has been recommended that feeding DDGS in swine diets increases percent P retention (Xu et al., 2006). The end result would be a decrease in P excretion. Spiehs et al. (1999) reported that feeding 10 - 20 % DDGS improved P retention and reduced P excretion. The relatively high digestibility of phosphorus in

DDGS results in less inorganic phosphorus that is needed in diets containing DDGS (Stein, 2006).

Predicted GE digestibility for corn DDGS was 82.9% and sorghum DDGS was 78.9, 76.6, and 78.8%. Fastinger and Mahan (2006) reported GE digestibility for corn DDGS ranged from 66.7 to 69.2%. Stein et al. (2006) reported, in 10 corn DDGS sources, apparent total tract digestibility for GE in the diet ranged from 72.5 to 77.6%. Calculated GE digestibility of DDGS ranged from 62.7 to 70.5%. Pedersen et al. (2007) also reported GE digestibility to range from 81.3 to 84.6% in corn DDGS sources. Predicted GE digestibilities reported in our experiment are similar to the upper values reported by Fastinger and Mahan (2006), Pedersen et al. (2007), and Stein et al. (2006).

In conclusion, distillers dried grains with solubles is an excellent source of available P. We see a trend with higher N, P, and GE digestibility in corn DDGS than sorghum DDGS. Corn DDGS and Sorghum DDGS 2 phosphorus bioavailability also shows the same trend with P digestibility being higher than Sorghum DDGS 1 and 3. However, DM, N, and GE digestibility was decreased. There are variations among sources that must be considered when formulating diets for growing pigs. Nutritionists should let ingredient prices and availability determine use of DDGS in diets for growing pigs. Diets can contain up to 20% DDGS without negatively effecting performance and digestibility of nutrients in the pig.

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APPENDIX

Pigs Means and Analysis of Variance Tables

Appendix Table 1

Pigs means for average daily gain, average daily feed intake, gain:feed, and phosphorus intake (Experiment 1).

Pen	Trt	Rep	Initial Wt	Final Wt	ADG, g	ADFI, kg	G:F	P intake, g
1	6	1	71.40	123.50	696.38	1.41	0.47	6.46
2	5	1	72.10	114.00	560.05	1.45	0.39	6.83
3	3	1	73.70	114.00	538.66	1.43	0.38	6.38
4	1	1	76.60	112.50	479.85	1.34	0.36	3.98
5	2	1	76.40	118.50	562.72	1.37	0.41	5.15
6	7	1	66.90	121.50	729.80	1.40	0.52	6.30
7	4	1	73.10	120.50	633.56	1.45	0.44	6.69
19	7	2	66.30	108.50	564.06	1.33	0.42	6.02
20	5	2	65.00	116.50	688.36	1.34	0.52	6.31
21	6	2	65.10	112.50	633.56	1.41	0.45	6.46
22	2	2	64.30	109.50	604.16	1.34	0.45	5.04
23	3	2	63.90	104.50	542.67	1.37	0.40	6.10
24	1	2	63.00	95.50	434.41	1.34	0.33	3.98
25	4	2	63.20	103.50	538.66	1.37	0.39	6.34
8	3	3	58.30	94.00	600.00	1.28	0.47	5.73
9	4	3	59.40	101.50	562.72	1.31	0.43	6.04
10	2	3	57.80	99.50	557.37	1.27	0.44	4.77
11	7	3	62.60	106.00	580.10	1.28	0.45	5.76
12	6	3	59.90	102.50	569.40	1.31	0.44	6.00
13	1	3	57.70	97.00	525.30	1.30	0.41	3.85
14	5	3	59.80	104.00	590.79	1.35	0.44	6.35
26	4	4	55.90	98.50	571.51	1.40	0.41	6.46
27	1	4	53.80	93.50	502.65	1.39	0.36	4.13
28	7	4	54.30	93.00	484.75	1.39	0.35	6.24
29	6	4	56.90	104.00	670.66	1.36	0.49	6.27
30	2	4	53.90	93.00	494.39	1.37	0.36	5.15
31	5	4	52.80	94.50	466.85	1.31	0.36	6.16
32	3	4	54.40	98.50	588.04	1.37	0.58	6.12

Appendix Table 1 (continued)

Pen	Trt	Rep	Initial Wt	Final Wt	ADG, g	ADFI, kg	G:F	P intake, g
15	6	5	50.80	92.50	517.80	1.03	0.50	4.72
16	5	5	48.80	94.00	625.22	1.03	0.61	4.87
17	1	5	40.60	78.00	504.03	0.95	0.53	2.83
18	7	5	53.10	93.50	493.01	0.97	0.51	4.35
33	3	5	50.30	85.50	600.00	1.20	0.50	5.36
34	4	5	50.20	91.00	585.28	0.98	0.60	4.52
35	2	5	42.00	76.50	504.03	1.03	0.49	3.86

Trt 1: Corn starch-dextrose-soybean meal diets + 0% monosodium phosphate

Trt 2: Corn starch-dextrose-soybean meal diets + 0.075% monosodium phosphate

Trt 3: Corn starch-dextrose-soybean meal diets + 0.15% monosodium phosphate

Trt 4: Corn starch-dextrose-soybean meal diets + 19.48% Corn DDGS

Trt 5: Corn starch-dextrose-soybean meal diets + 18.07% Sorghum DDGS 1

Trt 6: Corn starch-dextrose-soybean meal diets + 18.07% Sorghum DDGS 2

Trt 7: Corn starch-dextrose-soybean meal diets + 18.07% Sorghum DDGS 3

DDGS = distillers dried grains with solubles

Appendix Table 2

Analysis of average daily gain, average daily feed intake, gain:feed, and phosphorus intake (Experiment 1).

		Mean Squares			
Source	df	ADG, g	ADFI, kg	G:F	P Intake, g
Total	34				
Treatment	6	8044.677	0.002	0.004	3.872
Rep	4	3954.785	0.164	0.017	2.917
MSP linear	1	17904.323	0.011	0.012	11.925
MSP Quad	1	561.091	0.001	0.000	0.009
CDDGS vs HMSP	1	50.028	0.002	0.000	0.013
SDDGS vs HMSP	1	1150.144	0.009	0.000	0.000
CDDGS vs SDDGS	1	637.617	0.001	0.000	0.018
DDGS vs HMPS	1	812.603	0.005	0.000	0.002

MSP = monosodium phosphate; CDDGS = Corn distillers dried grains with solubles; SDDGS = sorghum distillers dried grains with solubles; HMSP = high monosodium phosphate

Appendix Table 3

Pigs means for metacarpal (MC)/metatarsal (MT) bone breaking strength, femur bone breaking strength, and metacarpal (MC) ash % (Experiment 1).

Pen	Trt	Rep	MC/MT, kg	Femur, kg	MC ash, %
1	6	1	71.92	241.16	55.02
2	5	1	102.77	244.38	53.50
3	3	1	100.22	280.03	54.80
4	1	1	81.97	218.78	51.48
5	2	1	.	.	.
6	7	1	73.04	212.20	52.48
7	4	1	.	243.36	51.10
19	7	2	68.47	267.83	50.93
20	5	2	78.62	264.41	54.21
21	6	2	78.36	283.94	52.69
22	2	2	84.74	239.23	52.07
23	3	2	84.73	250.20	53.39
24	1	2	63.12	182.12	20.30
25	4	2	100.22	280.03	52.37
8	3	3	.	.	.
9	4	3	79.95	200.53	52.55
10	2	3	80.01	200.53	53.72
11	7	3	75.25	227.96	52.10
12	6	3	71.84	231.37	51.91
13	1	3	63.51	178.81	51.47
14	5	3	87.82	226.28	53.13
26	4	4	107.13	243.36	53.99
27	1	4	77.73	215.21	52.21
28	7	4	99.11	252.18	53.04
29	6	4	90.58	264.21	52.95
30	2	4	84.49	190.18	53.33
31	5	4	96.70	217.76	53.48
32	3	4	97.99	270.53	54.54

Appendix Table 3 (continued)

Pen	Trt	Rep	MC/MT, kg	Femur, kg	MC ash, %
15	6	5	86.80	206.14	52.97
16	5	5	83.09	217.76	53.03
17	1	5	55.13	155.76	51.53
18	7	5	77.54	244.73	53.37
33	3	5	.	.	.
34	4	5	76.44	223.32	.
35	2	5	79.56	197.01	50.13

Trt 1: Corn starch-dextrose-soybean meal diets + 0% monosodium phosphate

Trt 2: Corn starch-dextrose-soybean meal diets + 0.075% monosodium phosphate

Trt 3: Corn starch-dextrose-soybean meal diets + 0.15% monosodium phosphate

Trt 4: Corn starch-dextrose-soybean meal diets + 19.48% Corn DDGS

Trt 5: Corn starch-dextrose-soybean meal diets + 18.07% Sorghum DDGS 1

Trt 6: Corn starch-dextrose-soybean meal diets + 18.07% Sorghum DDGS 2

Trt 7: Corn starch-dextrose-soybean meal diets + 18.07% Sorghum DDGS 3

DDGS = distillers dried grains with solubles

Appendix Table 4

Analysis of metacarpal (MC)/metatarsal (MT) bone breaking strength, femur bone breaking strength, and metacarpal (MC) ash % (Experiment 1).

		Mean Squares		
Source	df	MC/MT, kg	Femur, kg	MC ash, %
Total	36			
Treatment	6	347.655	2731.433	3.232
Rep	4	308.420	1747.642	1.018
MSP linear	1	891.403	7700.094	11.114
MSP Quad	1	37.260	530.421	1.082
CDDGS vs. HMSP	1	3.498	548.452	2.283
SDDGS vs. HMSP	1	143.006	563.006	2.843
CDDGS vs. SDDGS	1	263.027	15.541	0.015
DDGS vs. HMPS	1	72.038	625.399	3.064

MSP = monosodium phosphate; CDDGS = Corn distillers dried grains with solubles; SDDGS = sorghum distillers dried grains with solubles; HMSP = high monosodium phosphate

Appendix Table 5

Pigs means for fecal concentrations of dry matter, nitrogen, phosphorus, and ash (Experiment 1).

Pen	Trt	Rep	DM, %	N, %	P, %	Ash, %
1	6	1	89.13	10.47	1.21	3.70
2	5	1	88.92	13.19	1.68	3.29
3	3	1	89.89	11.46	1.36	2.70
4	1	1	88.53	11.19	0.77	2.23
5	2	1	89.12	10.18	1.08	2.94
6	7	1	88.59	12.37	1.46	3.55
7	4	1	88.47	12.92	1.39	3.16
19	7	2	89.61	11.84	1.20	3.57
20	5	2	89.76	10.12	1.17	2.80
21	6	2	89.47	10.21	1.30	3.30
22	2	2	90.51	12.72	0.95	2.40
23	3	2	90.50	12.56	1.52	2.47
24	1	2	90.38	10.76	0.84	2.42
25	4	2	91.31	9.22	2.08	2.69
8	3	3	89.30	12.82	1.04	2.83
9	4	3	88.56	12.53	1.39	2.81
10	2	3	89.20	8.62	0.84	2.33
11	7	3	88.54	10.38	1.64	3.83
12	6	3	88.37	10.46	1.21	3.22
13	1	3	89.06	9.26	0.70	2.46
14	5	3	88.33	11.13	1.43	2.71
26	4	4	88.23	13.48	0.69	4.07
27	1	4	90.30	7.86	1.06	2.05
28	7	4	88.86	10.36	1.34	4.52
29	6	4	89.85	10.28	1.19	3.05
30	2	4	90.36	11.64	1.19	2.73
31	5	4	89.95	8.86	1.11	3.12
32	3	4	89.74	12.71	1.40	2.57

Appendix 5 (continued)

Pen	Trt	Rep	DM, %	N, %	P, %	Ash, %
15	6	5	88.08	12.32	1.47	3.92
16	5	5	89.06	12.32	1.53	2.79
17	1	5	90.14	8.23	0.68	2.26
18	7	5	89.58	10.73	1.26	4.06
33	3	5	.	.	.	.
34	4	5	90.15	11.21	1.39	2.97
35	2	5	90.81	7.14	0.86	2.01

Trt 1: Corn starch-dextrose-soybean meal diets + 0% monosodium phosphate

Trt 2: Corn starch-dextrose-soybean meal diets + 0.075% monosodium phosphate

Trt 3: Corn starch-dextrose-soybean meal diets + 0.15% monosodium phosphate

Trt 4: Corn starch-dextrose-soybean meal diets + 19.48% Corn DDGS

Trt 5: Corn starch-dextrose-soybean meal diets + 18.07% Sorghum DDGS 1

Trt 6: Corn starch-dextrose-soybean meal diets + 18.07% Sorghum DDGS 2

Trt 7: Corn starch-dextrose-soybean meal diets + 18.07% Sorghum DDGS 3

DDGS = distillers dried grains with solubles

Appendix Table 6

Analysis of fecal concentration of dry matter, nitrogen, phosphorus, and ash (Experiment 1).

		Mean Squares			
Source	df	DM, %	N, %	P, %	Ash, %
Total	36				
Treatment	6	0.792	1.598	0.264	4.681
Rep	4	2.442	0.144	0.030	1.345
MSP linear	1	0.127	0.269	0.587	17.417
MSP Quad	1	0.124	0.002	0.023	2.100
CDDGS vs. HMSP	1	0.732	0.557	0.008	0.373
SDDGS vs. HMSP	1	2.222	1.939	0.001	5.063
CDDGS vs. SDDGS	1	0.275	0.312	0.006	2.834
DDGS vs HMPS	1	1.984	1.689	0.003	3.681

MSP = monosodium phosphate; CDDGS = Corn distillers dried grains with solubles; SDDGS = sorghum distillers dried grains with solubles; HMSP = high monosodium phosphate

Appendix Table 7

Pigs means for fecal concentrations of dry matter, gross energy, nitrogen, and phosphorus (Experiment 2).

Pen	Trt	Rep	DM, %	GE, kcal/kg	N, %	P, %
2	5	1	64.42	4686.52	3.26	2.64
3	2	1	42.37	4252.61	3.32	2.15
9	4	1	31.51	4407.03	3.35	2.08
11	1	1	43.70	4104.76	3.09	2.11
12	3	1	46.68	4720.66	3.28	2.06
1	1	2	60.81	4168.99	2.66	3.08
4	3	2	36.33	4227.29	3.27	2.29
5	5	2	27.42	4694.04	3.61	2.33
7	4	2	27.17	4470.66	2.88	2.17
8	2	2	41.47	4113.51	3.43	2.18
15	4	3	42.32	4586.45	4.10	1.60
19	5	3	41.57	4852.29	4.18	2.05
20	3	3	48.47	4156.45	3.75	1.96
21	1	3	44.38	4719.23	3.48	2.09
23	2	3	39.04	4578.99	3.41	1.93
13	3	4	46.73	4596.20	3.34	2.16
14	2	4	37.87	4464.61	3.22	2.13
16	1	4	36.46	4505.78	3.28	2.27
17	5	4	33.28	4918.65	4.23	2.13
22	4	4	43.40	4392.95	3.73	1.76
6	3	5	39.13	4194.66	3.16	1.85
10	4	5	41.69	4930.66	3.18	2.16
18	1	5	38.41	4649.60	3.72	2.57
24	5	5	39.01	4620.96	4.14	1.82
25	2	5	.	.	.	.

Trt 1: Corn-soybean meal diet + 0% DDGS

Trt 2: Corn-soybean meal diet + 20% Corn DDGS

Trt 3: Corn-soybean meal diet + 20% Sorghum DDGS 1

Trt 4: Corn-soybean meal diet + 20% Sorghum DDGS 2

Trt: 5: Corn-soybean meal diet + 20% Sorghum DDGS 3

DDGS = distillers dried grains with solubles

Appendix Table 8

Analysis of fecal concentrations of dry matter, gross energy, nitrogen, and phosphorus (Experiment 2).

		Mean Squares			
Source	df	DM, %	GE, kcal/kg	N, %	P, %
Total	24				
Trt	4	42.807	131326.142	0.308	0.156
Rep	4	45.912	58444.817	0.303	0.160
Control vs DDGS	1	75.519	28795.348	0.281	0.483
Control vs CDDGS	1	55.921	7798.061	0.029	0.252
Control vs SDDGS	1	64.377	67361.803	0.379	0.468
CDDGS vs SDDGS	1	2.697	114433.499	0.125	0.001

CDDGS = Corn distillers dried grains with solubles; SDDGS = sorghum distillers dried grains with solubles

Appendix Table 9

Pigs means for dry matter intake, excretion, and digestibility (Experiment 2).

Pen	Trt	Rep	DM intake, g/d	DM excretion, g/d	DM digestibility, %
2	5	1	1032.43	105.17	89.81
3	2	1	1041.68	129.39	87.58
9	4	1	1003.90	125.72	87.48
11	1	1	968.65	113.62	88.27
12	3	1	1031.15	127.96	87.59
1	1	2	1037.94	85.59	91.75
4	3	2	1042.90	131.31	87.41
5	5	2	1021.39	118.99	88.35
7	4	2	1035.46	125.20	87.91
8	2	2	1045.74	138.67	86.74
15	4	3	1137.21	168.48	85.19
19	5	3	1151.51	135.79	88.21
20	3	3	1155.56	144.54	87.49
21	1	3	1122.98	105.60	90.60
23	2	3	1151.43	128.38	88.85
13	3	4	1137.88	145.38	87.22
14	2	4	1084.58	135.04	87.55
16	1	4	1121.59	143.08	87.24
17	5	4	1154.76	149.11	87.09
22	4	4	1156.32	160.26	86.14
6	3	5	1030.09	161.11	84.36
10	4	5	1049.39	133.95	87.23
18	1	5	1142.37	116.85	89.77
24	5	5	1130.14	163.15	85.56
25	2	5	.	.	.

Trt 1: Corn-soybean meal diet + 0% DDGS

Trt 2: Corn-soybean meal diet + 20% Corn DDGS

Trt 3: Corn-soybean meal diet + 20% Sorghum DDGS 1

Trt 4: Corn-soybean meal diet + 20% Sorghum DDGS 2

Trt: 5: Corn-soybean meal diet + 20% Sorghum DDGS 3

DDGS = distillers dried grains with solubles

Appendix Table 10

Analysis of dry matter intake, excretion, and digestibility (Experiment 2).

		Mean Squares		
Source	df	DM intake, g/d	DM excretion, g/d	DM digestibility, %
Total	24			
Trt	4	379.064	725.969	6.195
Rep	4	15881.813	779.176	2.628
Control vs DDGS	1	111.213	2610.559	21.138
Control vs CDDGS	1	24.346	1104.590	9.507
Control vs SDDGS	1	133.504	2692.060	21.420
CDDGS vs SDDGS	1	20.712	53.356	0.261

CDDGS = Corn distillers dried grains with solubles; SDDGS = sorghum distillers dried grains with solubles

Appendix Table 11

Pigs means for gross energy intake, excretion, and digestibility (Experiment 2).

Pen	Trt	Rep	GE intake, kcal/d	GE excretion, kcal/d	GE digestibility, %
2	5	1	4737.32	492.88	89.60
3	2	1	4833.02	550.24	88.62
9	4	1	4622.70	554.06	88.01
11	1	1	4274.34	466.37	89.09
12	3	1	4705.04	604.04	87.16
1	1	2	4580.11	356.81	92.21
4	3	2	4758.68	555.08	88.34
5	5	2	4686.68	558.56	88.08
7	4	2	4768.04	559.70	88.26
8	2	2	4851.87	570.44	88.24
15	4	3	5236.58	772.72	85.24
19	5	3	5283.75	658.92	87.53
20	3	3	5272.73	600.79	88.61
21	1	3	4955.36	498.34	89.94
23	2	3	5342.24	587.85	89.00
13	3	4	5192.06	668.19	87.13
14	2	4	5032.05	602.92	88.02
16	1	4	4949.22	644.70	86.97
17	5	4	5298.64	733.40	86.16
22	4	4	5324.54	704.03	86.78
6	3	5	4700.24	675.82	85.62
10	4	5	4832.16	660.49	86.33
18	1	5	5040.89	543.32	89.22
24	5	5	5185.67	753.91	85.46
25	2	5	.	.	.

Trt 1: Corn-soybean meal diet + 0% DDGS

Trt 2: Corn-soybean meal diet + 20% Corn DDGS

Trt 3: Corn-soybean meal diet + 20% Sorghum DDGS 1

Trt 4: Corn-soybean meal diet + 20% Sorghum DDGS 2

Trt: 5: Corn-soybean meal diet + 20% Sorghum DDGS 3

DDGS = distillers dried grains with solubles

Appendix Table 12

Analysis of gross energy intake, excretion, and digestibility (Experiment 2).

		Mean Squares		
Source	df	GE intake, kcal/d	GE excretion, kcal/d	GE digestibility, %
Total	24			
Trt	4	58718.301	18154.038	5.365
Rep	4	329462.221	23418.599	4.332
Control vs DDGS	1	199695.167	60208.647	16.128
Control vs CDDGS	1	145810.039	17425.716	3.645
Control vs SDDGS	1	171207.895	68274.243	19.245
CDDGS vs SDDGS	1	6432.629	6194.957	2.841

CDDGS = Corn distillers dried grains with solubles; SDDGS = sorghum distillers dried grains with solubles

Appendix Table 13

Pigs means for nitrogen intake, excretion, and digestibility (Experiment 2).

Pen	Trt	Rep	N intake, g/d	N excretion, g/d	N digestibility, %
2	5	1	37.30	3.43	90.82
3	2	1	34.90	4.29	87.70
9	4	1	35.95	4.21	88.28
11	1	1	30.57	3.51	88.52
12	3	1	35.47	4.20	88.16
1	1	2	32.76	2.28	93.04
4	3	2	35.87	4.29	88.03
5	5	2	36.90	4.29	88.36
7	4	2	37.08	3.60	90.28
8	2	2	35.04	4.76	86.42
15	4	3	40.72	6.90	83.05
19	5	3	41.60	5.68	86.35
20	3	3	39.75	5.42	86.36
21	1	3	35.45	3.68	89.62
23	2	3	38.58	4.37	88.66
13	3	4	39.14	4.86	87.59
14	2	4	36.34	4.34	88.04
16	1	4	35.40	4.69	86.76
17	5	4	41.72	6.31	84.87
22	4	4	41.40	5.97	85.57
6	3	5	35.43	5.08	85.65
10	4	5	37.57	4.26	88.67
18	1	5	36.06	4.34	87.96
24	5	5	40.83	6.75	83.46
25	2	5	.	.	.

Trt 1: Corn-soybean meal diet + 0% DDGS

Trt 2: Corn-soybean meal diet + 20% Corn DDGS

Trt 3: Corn-soybean meal diet + 20% Sorghum DDGS 1

Trt 4: Corn-soybean meal diet + 20% Sorghum DDGS 2

Trt: 5: Corn-soybean meal diet + 20% Sorghum DDGS 3

DDGS = distillers dried grains with solubles

Appendix Table 14

Analysis of nitrogen intake, excretion, and digestibility (Experiment 2).

		Mean Squares		
Source	df	N intake, g/d	N excretion, g/d	N digestibility, %
Total	24			
Trt	4	23.269	1.848	4.463
Rep	4	18.727	2.456	8.286
Control vs DDGS	1	58.378	5.660	16.546
Control vs CDDGS	1	10.446	1.544	6.688
Control vs SDDGS	1	72.622	6.501	17.281
CDDGS vs SDDGS	1	14.739	0.676	0.457

CDDGS = Corn distillers dried grains with solubles; SDDGS = sorghum distillers dried grains with solubles

Appendix Table 15

Pigs means for phosphorus intake, excretion, and digestibility (Experiment 2).

Pen	Trt	Rep	P intake, g/d	P excretion, g/d	P digestibility, %
2	5	1	6.37	2.77	56.47
3	2	1	6.53	2.78	57.47
9	4	1	6.07	2.62	56.84
11	1	1	5.49	2.40	56.34
12	3	1	6.50	2.63	59.48
1	1	2	5.88	2.63	55.24
4	3	2	6.58	3.01	54.24
5	5	2	6.30	2.77	56.07
7	4	2	6.26	2.71	56.65
8	2	2	6.55	3.03	53.84
15	4	3	6.88	2.69	60.90
19	5	3	7.11	2.78	60.83
20	3	3	7.29	2.83	61.21
21	1	3	6.37	2.21	65.31
23	2	3	7.22	2.48	65.61
13	3	4	7.18	3.14	56.24
14	2	4	6.80	2.88	57.59
16	1	4	6.36	3.25	48.89
17	5	4	7.13	3.17	55.45
22	4	4	6.99	2.82	59.70
6	3	5	6.50	2.99	54.04
10	4	5	6.35	2.89	54.50
18	1	5	6.48	3.00	53.67
24	5	5	6.97	2.97	57.47
25	2	5	.	.	.

Trt 1: Corn-soybean meal diet + 0% DDGS

Trt 2: Corn-soybean meal diet + 20% Corn DDGS

Trt 3: Corn-soybean meal diet + 20% Sorghum DDGS 1

Trt 4: Corn-soybean meal diet + 20% Sorghum DDGS 2

Trt: 5: Corn-soybean meal diet + 20% Sorghum DDGS 3

DDGS = distillers dried grains with solubles

Appendix Table 16

Analysis of phosphorus intake, excretion, and digestibility (Experiment 2).

		Mean Squares		
Source	df	P intake, g/d	P excretion, g/d	P digestibility, %
Total	24			
Trt	4	0.427	0.045	4.537
Rep	4	0.592	0.189	51.037
Control vs DDGS	1	1.433	0.087	10.629
Control vs CDDGS	1	0.985	0.037	10.687
Control vs SDDGS	1	1.273	0.090	7.877
CDDGS vs SDDGS	1	0.020	0.002	1.820

CDDGS = Corn distillers dried grains with solubles; SDDGS = sorghum distillers dried grains with solubles

VITA

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Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF CORN OR SORGHUM DISTILLERS DRIED GRAINS WITH SOLUBLES ON APPARENT NUTRIENT DIGESTIBILITY OF GROWING PIGS.

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Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: EFFECTS OF CORN OR SORGHUM DISTILLERS DRIED GRAINS WITH SOLUBLES ON APPARENT NUTRIENT DIGESTIBILITY OF GROWING PIGS.

Pages in Study: 84 Candidate for the Degree of Master of Science

Major Field: Animal Science

Scope and Method of Study: The purpose of this study was to examine the effects of corn and sorghum distillers dried grains with solubles (DDGS) on nutrient digestibility of growing pigs. This study included two experiments with a total of 35 Yorkshire barrows with an average body weight of 29.6 kg for the first experiment and 25 crossbred pigs with an average body of 27.5 kg for the second experiment. In both experiments pigs were blocked by body weight and ancestry and randomly allotted to dietary treatments with five pigs per treatment in a randomized complete block design. One corn DDGS and three sorghum DDGS sources were used in the experimental diets. Data was analyzed as a randomized complete block design with initial weight as the blocking criterion. The model included the effects of block, treatment and block by treatment (error). In all cases, pig served as experimental units.

Findings and Conclusions: Corn and sorghum DDGS did not negatively affect growth performance or bone characteristics. Phosphorus bioavailability was 77% for corn DDGS and 64 to 70% for sorghum DDGS, respectively. Bioavailability was determined using a slope ratio assay. Nutrient digestibility of nitrogen and gross energy decreased with inclusion of DDGS sources. Phosphorus digestibility was similar for pigs fed the control versus DDGS dietary treatments. There was no difference for phosphorus, and gross energy apparent digestibility among DDGS diets. Apparent digestibility of nutrients in DDGS sources can be expected to range from 77.1 to 80.3% for nitrogen, 61.6 to 66.9% for phosphorus, and 76.65 to 82.9% for gross energy. In conclusion, distillers dried grains with solubles is an excellent source of nutrients and available phosphorus. There are variations among DDGS sources that must be considered when formulating diets for growing pigs.

ADVISER’S APPROVAL: Scott Carter