Use of Dried Distillers Grains with Solubles (DDGS) in Swine Diets

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Introduction

During the last 10 years, many new dry-grind fuel ethanol plants have been constructed and there are now approximately 165 plants in the U.S. that are projected to produce more than 18 million metric tons of DDGS in 2008 (Renewable Fuels Association, 2008). As a result of this dramatic increase in the production, a significant amount of research has been conducted during recent years to further evaluate the nutrient content, digestibility, feeding value, and unique properties associated with DDGS for swine. The objective of this paper is to summarize recent research results involving the nutritional and feeding value of DDGS in diets for weanling, growing-finishing, and reproducing swine, and its effects on gut health and manure management.

Nutritional value of DDGS for swine

High quality corn DDGS has a digestible and metabolizable energy value equal to or greater than corn. Spiehs et al. (1999) was the first to report that the digestible energy (DE) and metabolizable energy values were similar to energy values for corn (3.49 Mcal/kg and 3.37 Mcal/kg, respectively). Fu et al. (2004) reported that the ME and calculated net energy (NE) values for corn DDGS were 3.25 Mcal/kg and 2.61 Mcal/kg, respectively, whereas Hastad et al. (2004) reported much higher values for DE, ME, and calculated NE (3.87 Mcal/kg, 3.60 Mcal/kg, and 2.61 Mcal/kg, respectively). Stein et al. (2006) confirmed that the DE and ME value of corn DDGS for swine is equal to, or greater than corn (3,639 kcal DE/kg and 3,378 kcal ME/kg).

Corn is considered a low protein quality (low lysine and poor amino acid balance) feed ingredient. Similarly, corn DDGS is also a low protein quality feed ingredient for swine because of its low lysine content relative to its crude protein content. Threonine is the second limiting amino acid after lysine followed by tryptophan. These amino acids should be monitored during diet formulation when using more than 10% corn DDGS in swine diets. Amino acid digestibility can also vary among corn DDGS sources. Stein et al. (2006) showed that the range in true lysine digestibility coefficients for swine ranges from 43.9 to 63.0%. Fastinger and Mahan (2006) reported a similar range in standardized ileal lysine digestibility values (38.2% to 61.5%) among 5 DDGS sources. Lightness and yellowness of color of DDGS appear to be reasonable predictors of digestible lysine content among corn DDGS sources for swine (Pederson et al., 2005). Sources of DDGS that have a low lysine digestibility also often have a low concentration of lysine, which is the reason that the lysine to crude protein ratio gives an estimate of the quality of the lysine in a DDGS source (Stein, 2007). Stein (2007) recommended that selecting DDGS sources for swine feeding should be based on a calculated lysine to crude protein ratio of greater than 2.80% in order to avoid sources with low lysine digestibility. Furthermore, in order to ensure excellent pig performance when adding DDGS to swine diets, diets should be formulated on a digestible amino acid basis if more than 10% DDGS is included in the diet.

Corn DDGS is an excellent source of available phosphorus for swine. The concentration of P in DDGS is approximately 0.60% and the apparent total tract digestibility of P is approximately 59%, which is much greater than found in corn (Pedersen et al., 2007). Whitney et al. (2001) showed that relative phosphorus availability in corn DDGS was 90%, using dicalcium phosphate as the inorganic phosphorus reference source. Therefore, when DDGS is included in diets fed to swine, the utilization of organic P will increase and the need for supplemental inorganic P (i.e., dicalcium phosphate or monocalcium phosphate) will be reduced.

Use of DDGS in starter diets

The use of corn DDGS in weanling pig diets has been reported from 8 experiments. Whitney and Shurson (2004) conducted two experiments to determine the effects of increasing dietary levels (0 to 25%) of DDGS on growth performance of early-weaned pigs. Dietary treatments consisted of providing 0, 5, 10, 15, 20, or 25% DDGS during Phases 2 and 3 of a 3-phase nursery feeding program. Pigs in experiment 1 were slightly older (19.0 vs. 16.9 days of age) and heavier (7.10 vs. 5.26 kg) at the beginning of the experiment compared to pigs in experiment 2. All pigs were provided a commercial pelleted diet for the first 4 days post-weaning, and were then switched to their respective experimental Phase 2 diets (fed for a subsequent 14 days), followed by Phase 3 experimental diets (fed for an additional 21 days). Overall growth rate, ending body weight, and feed conversion of pigs were similar among dietary treatments regardless of dietary DDGS level fed for both experiments. In experiment 1, feed intake was unaffected by dietary treatment, but in experiment 2, increasing dietary DDGS level linearly decreased feed intake during Phase 2, and tended to decrease voluntary feed intake over the length of the experiment. These results suggest that high quality corn DDGS can be included in Phase 3 diets for nursery pigs at dietary levels up to 25%, without negatively affecting growth performance after a 2-week acclimation period. Satisfactory growth performance can also be achieved when adding up to 25% DDGS in Phase 2 diets for pigs weighing at least 7 kg in body weight. Including these high levels immediately post-weaning, however, may negatively influence feed intake, resulting in poorer initial growth performance.

Results from subsequent experiments have shown that inclusion of 10% DDGS in diets fed to weanling pigs beginning 10 days post-weaning (Linneen et al., 2008), and 30% DDGS beginning 3 weeks post-weaning did not influence pig performance (Gaines et al., 2006; Spencer et al., 2007; Burkey et al., 2008), but gain:feed was improved when DDGS was added to the diet in 2 experiments (Gaines et al., 2006; Spencer et al., 2007).

Three experiments have been conducted to evaluate dietary levels of sorghum DDGS for weanling pigs (Senne et al., 1995; Senne et al., 1996; Feoli et al., 2008a). Senne et al. (1995) fed pigs diets containing 0, 10, or 20% sorghum DDGS from d 7 to d 29 post-weaning and no differences in ADG, ADFI, or G:F were observed among treatments. In a subsequent experiment, pigs were fed diets containing 0, 15, 30, 45, or 60% sorghum DDGS from d 7 to d 29 post-weaning and quadratic reductions in ADG and gain:feed were observed (Senne et al., 1996). Performance of pigs fed up to 30% DDGS was similar to the performance of pigs fed the control diets, but adding 45 or 60% DDGS to the diet reduced ADG and G:F. The most recent results that have been reported have shown that inclusion of 30% sorghum DDGS in diets fed to weanling pigs negatively affected growth performance compared with pigs fed diets containing no DDGS (Feoli et al., 2008a). The reasons for different growth performance responses among these studies are unclear, but may be due to differences in the quality and nutrient digestibility of the DDGS source used.

In summary, adding up to 30% corn DDGS in diets for weanling pigs beginning approximately 3 weeks post-weaning will result in satisfactory growth performance, and it may be possible to include DDGS in phase 1 and phase 2 starter diets, but growth performance responses may vary. If sorghum DDGS is used, it may be necessary to use a dietary inclusion rate of less than 30% DDGS in order to avoid a reduction in pig performance.

Use of DDGS in grower-finisher diets

Twenty-five experiments have been conducted to compare growth performance of growing-finishing fed diets containing 5 to 40% corn DDGS with performance of pigs fed diets containing no DDGS. Average daily gain was improved in 1 experiment (Gowans et al., 2007), reduced in 10 experiments (Fu et al., 2004; Whitney et al., 2006c; Linneen et al., 2008; Weimer et al., 2008; Hinson et al., 2007; Stender and Honeyman, 2008; Widyartne and Zijlstra, 2007), and not affected in the remaining 14 experiments (Cromwell et al., 1983; Gralap et al. 2002; Cook et al., 2005; DeDecker et al., 2005; McEwen, 2006; Gaines et al., 2007a,b; Jenkin et al., 2007; Xu et al., 2007a; Linneen et al., 2008; McEwen, 2008, Widmer et al., 2008; Drescher et al., 2008). For the 10 experiments that reported a reduction in ADG, the reduction was observed only when DDGS was included at a level of 40% in the diet. Gain:feed ratio was improved in 6 experiments, reduced in 4 experiments, not affected by dietary treatments in 14 experiments, and not reported in 1 experiment. Average daily feed intake data were reported in 21 of these experiments and was improved in 1 experiment, reduced in 6 experiments, and not affected by the addition of DDGS to the diet in 14 experiments.

Based on the somewhat inconsistent performance responses among the 25 experiments reported, it is unclear why pig performance was maintained in most, but not all experiments where DDGS was included in the diets. In the experiments in which reduced performance was observed, the DDGS used may have been of a poorer quality (lower nutrient digestibility) than expected. Average daily feed intake was reduced in most of the experiments in which ADG was reduced, suggesting that the poorer performance was due to reduced palatability of the DDGS used in those diets. Hastad et al. (2005) demonstrated that when pigs are given a choice, they prefer to consume diets containing no DDGS. However, it is not known whether DDGS reduces palatability if pigs are offered only one diet.

When sorghum DDGS is added to grower-finisher diets at levels up to 30%, no differences in ADG, ADFI, and G:F have been observed (Senne et al., 1995; 1996), but when higher inclusion rates were used, ADG was reduced (Senne et al., 1996; 1998; Feoli et al., 2007b and c; 2008a, b, and c), ADFI was reduced (Senne et al., 1996; Feoli et al., 2007c; 2008b), and G:F may be reduced (Senne et al., 1998; Feoli et al., 2008a), but not in every case (Feoli et al., 2007c; 2008b and c). When 25% wheat DDGS was added to a wheat-field pea based diet, there were no effects on ADG or G:F (Widyaratne and Zijlstra, 2007). However, Thacker (2006) demonstrated that adding levels of 0, 5, 10, 15, 20, or 25% wheat DDGS in wheat-soybean meal based diets for growing pigs, linearly reduced ADG and ADFI, but G:F was not affected. In contrast, when Thacker (2006) reduced the dietary inclusion levels of wheat DDGS to 0, 3, 6, 9, 12, or 15% during the finishing phase, no differences in performance were observed. The differences in performance observed among these studies involving wheat DDGS were likely due to differences in diet formulation methods used. The diets fed by Widyaratne and Zijlstra (2007) were formulated using the concentrations of digestible amino acids determined for the specific batch of DDGS that was fed to the pigs, whereas the diets used by Thacker (2006) were formulated based on a total amino acid basis.

Carcass dressing percentage of pigs has been determined in 17 experiments where corn DDGS was included in the diets. No difference in dressing percentage was observed in 8 of these experiments (Fu et al., 2004; Xu et al., 2007b; McEwen, 2006; 2008; Drescher et al., 2008; Hill et al., 2008; Stender and Honeyman, 2008; Widmer et al., 2008), but dressing percentage was reduced in 9 experiments (Cook et al., 2005; Whitney et al., 2006c; Feoli et al., 2007b; Gaines et al., 2007 a,b; Hinson et al., 2007; Xu et al., 2007a; Linneen et al., 2008; Weimer et al., 2008). In studies where pigs were fed sorghum DDGS, dressing percentage increased in 1 experiment (Senne et al., 1996), was unaffected in 1 experiment (Senne et al., 2008), and was reduced in 5 experiments (Feoli et al., 2007b, c; 2008a, b, c). Dressing percentage was also reduced when wheat DDGS diets were fed (Thacker, 2006). It is unclear why dressing percentage was reduced by feeding DDGS diets in some experiments but not all studies. Researchers have speculated that the relatively high fiber content in DDGS may be a contributing factor to a reduction in dressing percentage because it has been shown that the addition of high fiber ingredients to diets fed to growing-finishing pigs reduces dressing percentage due to increased gut fill and increased intestinal mass (Kass et al., 1980).

Feeding diets containing corn DDGS generally has had no effect on backfat thickness (12 experiments), loin depth (9 experiments), and carcass lean percentage (12 experiments). However, results from one experiments showed a reduction in backfat (Weimer et al, 2008), loin depth was reduced in 2 experiments (Whitney et al., 2006c; Gaines et al., 2007b), and percentage carcass lean was reduced in one experiment (Gaines et al., 2007b) when corn DDGS was added to the diet. Loin depth was also reduced when wheat DDGS was included in the diet (Thacker, 2006). However, in experiments where loin depth was reduced, pigs fed the DDGS diets had lower ADG and were therefore, harvested at a lighter weight.

Belly thickness was linearly reduced when corn DDGS (Whitney et al., 2006c; Weimer et al., 2008) and sorghum DDGS was added to the diet (Feoli et al., 2008c). However, pigs fed DDGS containing diets from these studies also had reduced ADG, and as a result, were harvested at a lighter weight than pigs fed the control diets, which likely caused the reduction in belly thickness. Results from studies by Widmer et al. (2008) and Xu et al. (2008b) where there were no differences in the final BW of the pigs fed DDGS, there were no differences in belly thickness between pigs fed control or DDGS containing diets.

The adjusted belly firmness of pigs fed diets containing corn DDGS was reduced compared to pigs fed diets containing no DDGS (Whitney et al., 2006c; Xu et al., 2007a; Widmer et al., 2008), which is a result of increased iodine value of the belly fat when pigs are fed corn DDGS (Whitney et al., 2006c; White et al., 2007; Xu et al., 2007a; 2008b; Benz et al., 2008; Hill et al., 2008; Stender and Honeyman, 2008) and sorghum DDGS (Feoli et al., 2007c; 2008b, c). The increase in fat iodine values in pigs fed DDGS-containing diets is due to the relatively large quantities of unsaturated fatty acids, especially linoleic acid (C18:2), in corn and sorghum DDGS.

Carcass fat iodine values have been used as a measure of pork fat quality. Researchers have clearly established that feeding diets containing an unsaturated fat source can alter the degree of saturation in pork fat. Lea et al. (1970) indicated that adequately firm pork fat should have an iodine number below 70. Boyd (1997) suggested that the iodine value threshold for pork fat in the U.S. should be set at 74. As a result of the possible negative effects of feeding DDGS on pork fat quality, a few studies have been conducted to evaluate possible feeding strategies to reduce iodine values in pork fat when growing-finishing pigs are fed DDGS diets. Feoli et al. (2007c) showed that feeding diets containing up to 5% tallow and 40% sorghum DDGS did not reduce the iodine value in jowl fat, even though tallow contains a high proportion of saturated fatty acids. White et al., 2007) reported that adding 1% conjugated linoleic acid to diets containing 20 or 40% corn DDGS for 10 days before pig harvest reduced fat iodine values and the n6:n3 ratio. Removal of DDGS from the diet during the final 3 to 4 weeks prior to harvest will also reduce the negative impact of DDGS on carcass fat iodine values, and will result in pork carcasses that have acceptable iodine values (Hill et al., 2008; Xu et al., 2008b).

Muscle and fat color are one of the most important aspects of pork quality that influences the appearance and attractiveness of meat to consumers. Results from two studies have shown that loin subjective color was not affected by dietary DDGS level (Whitney et al., 2006c; Xu et al., 2008a), and the average loin muscle visual color score was approximately 3.0 which is a bright reddish-pink color. Xu et al., 2008a also showed that belly fat color (Minolta L*, a* and b*), and Japanese color scores were not affected when dietary levels of DDGS increased from 0 to 30%.

Despite the increase in unsaturated fatty acid content of pork fat when DDGS is fed, Xu et al. (2008a) showed that feeding diets containing up to 30% DDGS had no effect on loin fat oxidation (thiobarbituric acid method) at day 1, 14, 21 and 28 of storage. The most widely used method for assessing the extent of oxidative deterioration of lipids in meat is the 2-thiobarbituric (TBA) test (Shahidi, 1998).

Cooking loss and eating characteristics of loins and bacon have been shown to not be affected when feeding diets containing up to 30% corn DDGS to growing-finishing pigs (Xu et al., 2008a). Loin sensory tests for flavor, off-flavor, tenderness, juiciness and overall acceptability were similar for loins from pigs fed diets containing different levels of DDGS. Furthermore, cooking yield of bacon was similar among pigs fed different levels of DDGS, and flavor, off-favor, crispiness and overall liking were not influenced by dietary DDGS level.

Surprisingly, bacon fattiness and tenderness were linearly reduced with increasing dietary DDGS levels. Overall, results from the loin and bacon taste tests showed that feeding diets containing up to 30% DDGS had no detrimental effects on pork taste and eating characteristics.

Use of DDGS in gestation and lactation diets

Two early studies showed that feeding diets containing 40 to 80% DDGS to gestating sows had no effect on farrowing rate, feed intake, sow weight gain, litter size at farrowing, or litter weights at farrowing (Thong et al., 1978; Monegue et al., 1995). More recently, Wilson et al., (2003) confirmed that feeding a gestation diet containing 50% DDGS had no negative impacts on sow performance, and during the second parity of this two parity study, showed that litter size weaned may be improved. More research is necessary to determine if this response is repeatable, timing and the length of time DDGS diets must be fed, and if feeding high levels of DDGS are necessary to achieve an increase in litter size in sows.

Wilson et al. (2003) also evaluated sow lactation performance over two parities where sows were fed diets containing 0 or 50% DDGS in gestation, and 0 or 20% DDGS in lactation. Pre-weaning mortality was greater for sows fed the 50% DDGS gestation diet and 20% DDGS lactation diet compared with the other treatment combinations during the first reproductive cycle, but this was not the case during the second cycle. Sows that had been fed DDGS during the previous gestation period also had a lower wean to estrus interval than sows fed no DDGS in gestation or lactation. Sows that were fed DDGS in lactation, but not in gestation, had lower feed intake during the initial 7 days of the lactation period in the first reproductive cycle, but not in the second cycle. It was concluded from this experiment that DDGS may be included in lactation diets in amounts of at least 20%, but that feed intake may be depressed during the immediate post-partum period if no DDGS is included in gestation diets.

Two experiments were conducted to compare lactating sow performance when fed diets containing 15% DDGS, 5% sugar beet pulp, or a corn-soybean meal diet (Hill et al., 2005; 2006).

These researchers observed no differences in litter weight gain, pre-weaning pig mortality, or sow weight loss among dietary treatments.

Song et al. (2007a) and Greiner et al. (2008) fed lactating sows diets containing 0, 10, 20, or 30% DDGS during a 19-d lactation period and observed no differences among dietary treatments in feed intake, change in backfat thickness during lactation, piglet and litter weight gain, pre-weaning mortality, or wean to estrus intervals. In fact, Greiner et al. (2008) observed a linear increase in sow weight gain during lactation and a linear reduction in wean to estrus interval when DDGS was included in the diet, but these effects were not observed by Song et al. (2007a). Furthermore, Song et al., (2007b) showed that the inclusion of DDGS in the lactation diet had no effect on milk protein and fat levels, N digestibility, or N retention, but sows fed diets containing 20 or 30% DDGS had lower blood urea nitrogen levels than sows fed the control diet.

Therefore, these results suggest that DDGS may be included in gestation diets in amounts sufficient to replace all the dietary soybean meal without negatively affecting sow performance, and may increase litter size. Furthermore, lactation diets may contain up to 30% DDGS without negatively affecting sow or litter performance, but when DDGS is included in lactation diets, it may be necessary to acclimate them to DDGS containing diets during late gestation in order to avoid a potential reduction in feed intake when feeding DDGS diets during the first week post-partum.

DDGS and manure management

The addition of DDGS to swine diets reduces DM digestibility and increases fecal excretion in nursery aged pigs (Xu et al., 2006a, b, c) but not in growing-finishing pigs (Xu et al., 2006d). This response may be a result of older pigs having more lower gut fermentation and improved fiber utilization than younger pigs. Adding DDGS to growing pig diets reduces fecal P concentration, but total P excretion is generally not affected due to the increase in fecal excretion when DDGS diets are fed. The relatively high N concentration in DDGS relative to lysine suggests that N intake and fecal N excretion should increase with increasing dietary levels of DDGS. However, only Spiehs et al. (2002) reported this response. There is some disagreement among research results whether feeding DDGS diets increases odor emissions from manure. Gralapp et al. (2002) reported that increasing dietary DDGS level tended to increase odor concentration of swine manure, but Spiehs et al. (2000) showed that feeding diets containing 20% DDGS had no effect on H_2S, NH_3, or odor detection levels over a 10-week trial.

Effect of Feeding DDGS on Gut Health of Growing Pigs

Whitney et al. (2006a, b) conducted two experiments to determine if including DDGS in the diet of young growing pigs reduces the incidence or severity of clinical signs, fecal shedding, intestinal lesions, and/or cellular infection indicating porcine proliferative enteropathy (ileitis) after challenge with *Lawsonia intracellularis*. In the first experiment, 80 pigs were weaned at 17 days of age and were randomly allotted (blocked by sex and weight) to one of four treatment groups. A negative control group was unchallenged and fed a control corn-soybean meal diet. The remaining 3 groups were inoculated orally with 1.5×10^9 *L. intracellularis* per pig after a 4-week dietary adaptation period, and were fed either a control corn-soybean meal diet, or a similar diet containing 10 or 20% DDGS. On day 21 post-challenge, all pigs were euthanized and intestinal mucosa was examined for the presence of lesions. Ileal tissue samples were analyzed to determine presence and proliferation of *L. intracellularis*. Challenging pigs reduced ADFI, ADG, and G:F by 25, 55, and 40%, respectively, during the 3-week post-challenge period. Dietary treatment did not affect growth performance. Gross lesions were observed in 63% of challenged pigs compared to 0% in the negative control group. Including DDGS in the diet did not positively affect lesion prevalence and length, proliferation of *L. intracellularis*, or severity of lesions.

In the second experiment, 100 pigs were managed similar to the first experiment, except the *L. intracellularis* dosage rate for challenging pigs was reduced by 50%. Treatment groups consisted of a negative control group and 4 dietary treatments to test the effect of adding 10% DDGS to the diet with or without an antimicrobial regimen. Antimicrobial regimen consisted of providing 30 mg BMD®/kg diet (supplied continuously in the diet), with chlortetracycline (Aureomycin®) pulsed at 500 mg/kg from 3 days prior to 11 days post-challenge. Feeding diets containing 10% DDGS reduced ileum and colon lesion length and prevalence, and reduced the severity of lesions in the ileum and colon compared to other challenged pigs. Pigs fed the antimicrobial regimen reduced prevalence and severity of lesions in the jejunum, and tended to have reduced total tract lesion length. The combination of DDGS and antimicrobial resulted in no differences in length, severity, or prevalence of lesions, but fecal shedding of *L. intracellularis* was reduced on day 14 post-challenge. The proportion of intestinal cells infected with *L. intracellularis* was reduced when DDGS or antimicrobials were fed. In conclusion, it appears that dietary inclusion of DDGS may aid the young growing pig in resisting a moderate ileitis challenge similar to a U.S. approved antimicrobial regimen, but under more severe challenges, DDGS may not be effective.

Recommended Maximum Inclusion Rates of DDGS in Swine Diets

Based upon current research results, the maximum usage rate of DDGS in swine diets is as follows:

Production Phase	Maximum % of Diet
Nursery pigs (>7 kg)	30
Grow-finish pigs	30
Developing gilts	30
Gestating sows	50
Lactating sows	30
Boars	50

These recommendations assume that high quality DDGS is free of mycotoxins. Phase 2 and phase 3 nursery diets containing up to 30% DDGS will support growth performance equivalent to feeding pigs fed corn-soybean meal based diets provided that diets are formulated on a digestible amino acid and available phosphorus basis. Similarly, grower-finisher and gilt development diets containing levels up to 30% DDGS should provide equivalent growth performance compared to pigs fed corn-soybean meal diets if they are formulated on a digestible amino acid and available phosphorus basis. However, depending on pork fat quality standards used by various pork processors, feeding diets containing more than 20% DDGS to growing-finishing pigs will reduce belly firmness unless DDGS is withdrawn from the diet 3 to 4 weeks prior to slaughter. Once conjugated linoleic acid becomes commercially available, it appears that it would be effective for meeting pork fat quality standards when feeding high (> 20%) dietary levels of DDGS.

For sows, up to 50% DDGS can be successfully added to gestation diets, and 30% DDGS can be added to the lactation diet if DDGS is free of mycotoxins. However, a short adaptation period may be necessary when switching sows from a corn-soybean meal diet to diets containing high levels of DDGS in lactation.

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