CORN BY-PRODUCT DIVERSITY AND FEEDING VALUE TO NON-RUMINANTS

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INTRODUCTION

The rapid growth of the fuel ethanol industry in the U.S. has created increased supplies of corn by-products available for livestock and poultry feeds. Currently, there are approximately 88 ethanol plants in production or under construction/expansion in the U.S., which have the production capacity of 17 billion liters of ethanol per year (Renewable Fuels Association, December, 2004). Approximately 40% of fuel ethanol is produced by wet-mills after the starch is separated from the corn kernel, and these plants produce wet or dried corn gluten feed, corn gluten meal, and corn germ meal as the primary by-products. Dry-grind ethanol plants represent the fastest growing segment of the fuel ethanol industry in the U.S., and produce the majority (60%) of fuel ethanol. By-products from dry-grind ethanol plants include wet and dry distiller's grains, wet and dried distiller's grains with solubles, modified "wet cake" (a blend of wet and dry distiller's grains), and condensed distiller's solubles. Approximately 40% of the distiller's grains with solubles are marketed as a wet by-product for use in dairy operations and beef cattle feedlots located near ethanol plants. The remaining 60% of distiller's grains with solubles is dried (DDGS) and marketed domestically and internationally for use in dairy, beef, swine and poultry feeds. More than 7 million metric tonnes of DDGS will be produced in the year 2005. Some industry experts are predicting that DDGS production will reach 10 to 14 million metric tonnes by 2008. Corn is the primary grain used in wet mills and dry-grind ethanol plants because of its high fermentable starch content compared to other feed stocks. Schematic diagrams comparing the corn-wet-milling and the corn dry-grind processes, and the corn by-products produced from these types of ethanol plants are shown in Figure 1.

For each 100 kg of corn fermented in a dry-grind ethanol plant, approximately 36 liters of ethanol, 32 kg of DDGS, and 32 kg of carbon dioxide is produced. As a result, the nutrient content of corn DDGS can be estimated by multiplying the concentration of any nutrient in corn by a factor of three. However, some ethanol plants use sorghum, or blend corn with barley, wheat, or sorghum to make ethanol and distiller's grains with solubles, depending on geographical location, cost, and availability of these grains relative to corn. The beverage alcohol industry also produces grain by-products in the form of DDGS (whiskey distilleries) or brewer's grains (beer manufacturing). All of these by-products are nutritionally different and have different economic value in various types of animal and poultry feeds. Whiskey distilleries use a blend of corn, rye, and wheat to make DDGS, whereas brewer's grains are comprised primarily of barley. A comparison of the nutrient composition of common by-products from ethanol production is shown in Table 1. The high crude fat content of high quality corn DDGS distinguishes it from the other by-products, and the high availability of phosphorus in DDGS makes it an attractive and economical partial replacement for supplemental inorganic phosphorus sources in swine and poultry diets. Although there is a wide range of corn by-products that are used in livestock and poultry feeds, the focus of this paper is to identify and discuss differences in nutritional characteristics of corn DDGS among sources, as well as provide examples of new corn distiller's by-products and their potential application and value in diets for non-ruminants.

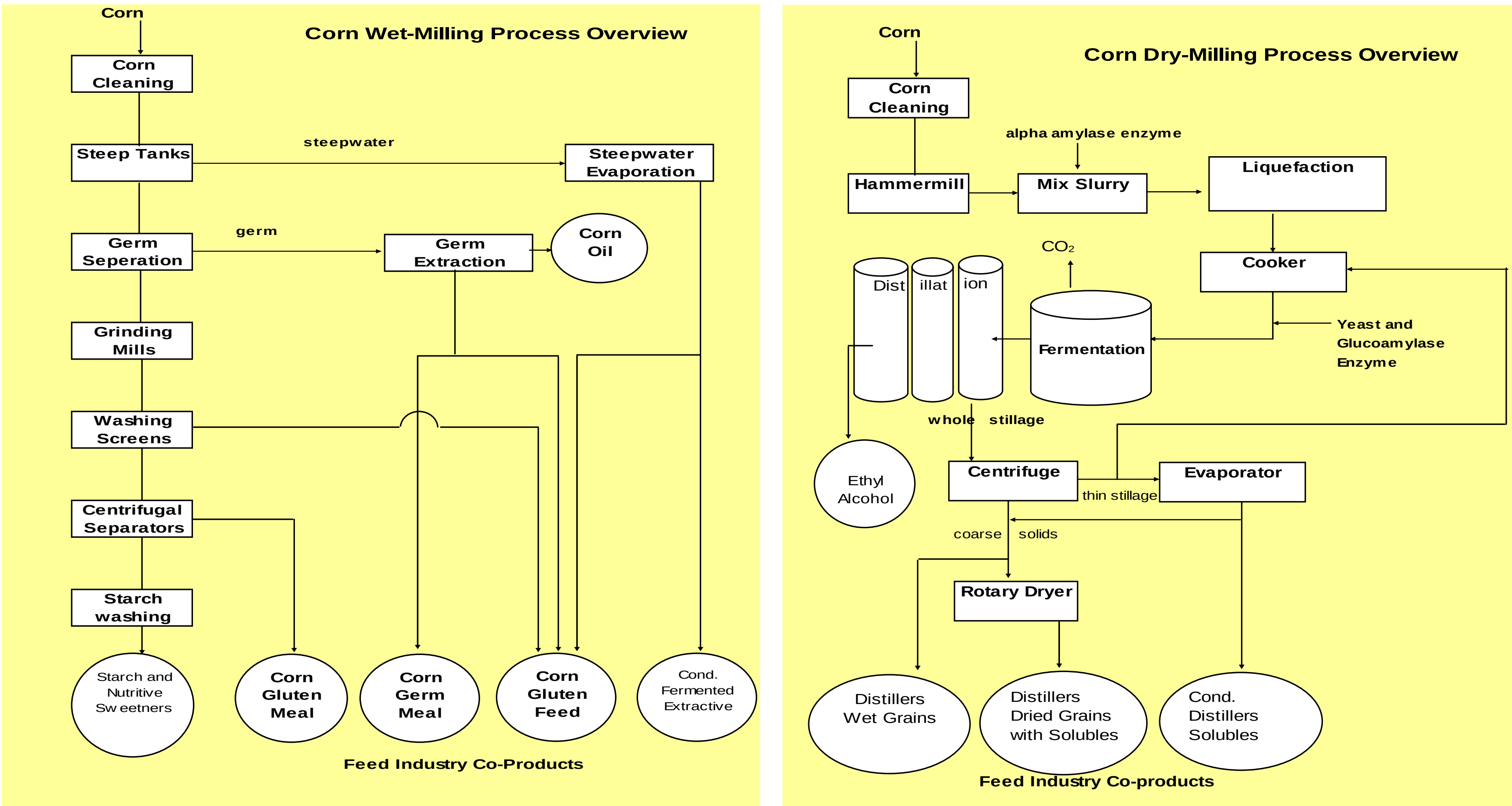


Figure 1. Comparison of corn wet-milling and dry-grind processes and the by-products produced.

Table 1. Comparison of the Nutrient Composition (100% Dry Matter Basis) of High Quality U.S. Corn DDGS, Corn Gluten Feed, Corn Gluten Meal, and Brewer's Dried Grains.

	High Quality U.S. Corn DDGS[1]	**Corn Gluten Feed[2]**	**Corn Gluten Meal[2]**	**Corn Germ Meal[3]**	**Brewer's Dried Grains[2]**
Crude protein, %	30.6	23.9	66.9	22.2	28.8
Crude fat, %	10.7	3.3	3.2	1.1	7.9
NDF, %	43.6	37.0	9.7	N/A	52.9
ADF, %	11.8	11.9	5.1	N/A	23.8
ME (swine), kcal/kg	3827	2894	4256	3222	2130
ME (poultry), kcal/kg	2830**	1944*	4133*	1889	2261*
Lysine, %	0.83	0.70	1.13	1.00	1.17
Methionine, %	0.55	0.39	1.59	0.67	0.49
Threonine, %	1.13	0.82	2.31	1.22	1.03
Tryptophan, %	0.24	0.08	0.34	0.22	0.28
Calcium, %	0.06	0.24	0.06	0.33	0.35
Phosphorus, %	0.89	0.83	0.44	0.50	0.56
P availability (swine), %	90	59	15	N/A	34
P availability (poultry), %	75***	N/A	28*	30	N/A

N/A = data not available.
[1] Data from Spiehs et al. (2002), University of Minnesota.
[2] Data from NRC (1998), Nutrient Requirements of Swine, 10th Revised Edition, National Academy Press.
[3] Data from Feedstuffs Reference Issue (2001).
* Data from NRC (1994), Nutrient Requirements of Poultry, 9th Revised Edition, National Academy Press.
**Determined as True Metabolizable Energy (Batal and Dale, 2004).
***Data from Martinez et al. (2004) and Lumpkins and Batal (2005).

DIFFERENCES IN NUTRIENT CONTENT AND FEEDING VALUE AMONG CORN DDGS SOURCES

Perhaps the biggest challenge of using corn DDGS in diets for non-ruminants is to know the nutrient content and amino acid digestibility of the source being used. The nutrient content of corn DDGS can vary among U.S. DDGS sources (Table 2), and been shown to vary over time within plant (Spiehs et al., 2002).

Table 2. Averages and Ranges in Composition of Selected Nutrients (100% Dry Matter Basis) Among 32 U.S. Corn DDGS Sources (www.ddgs.umn.edu).

Nutrient	Average (CV)	Range
Crude protein, %	30.9 (4.7)	28.7 - 32.9
Crude fat, %	10.7 (16.4)	8.8 - 12.4
Crude fiber, %	7.2 (18.0)	5.4 - 10.4
Ash, %	6.0 (26.6)	3.0 - 9.8
Calculated ME (swine), kcal/kg	3810 (3.5)	3504 – 4048
Lysine, %	0.90 (11.4)	0.61 - 1.06
Arginine, %	1.31 (7.4)	1.01 - 1.48
Tryptophan, %	0.24 (13.7)	0.18 - 0.28
Methionine, %	0.65 (8.4)	0.54 - 0.76
Phosphorus, %	0.75 (19.4)	0.42 - 0.99

Much of the variation in nutrient content of corn DDGS is likely due to the normal variation among varieties and geographic location where it is grown. Reese and Lewis (1989) showed that corn produced in Nebraska in 1988 ranged from 7.8 to 10.0% crude protein, 0.22 to 0.32% lysine, and 0.24 to 0.34% phosphorus. Therefore, as nutrients in DDGS become concentrated due to the fermentation of starch to produce ethanol, it is not surprising that the variability of nutrients among DDGS sources is also increased.

The ratio of blending condensed distiller's solubles with the grains fraction to produce DDGS also varies among plants. The typical nutrient content of each fraction is shown in Table 3. Because there are substantial differences in nutrient composition between these two fractions, it is understandable that the proportion of the grains and solubles blended together will have a significant effect on final nutrient composition of DDGS. The official AAFCO definition for DDGS is:

"Distillers Dried Grains with Solubles is the product obtained after the removal of ethyl alcohol by distillation from yeast fermentation of a grain or a grain mixture by condensing and drying at least ¾ of the solids of the resultant whole stillage by methods employed in the grain distilling industry."

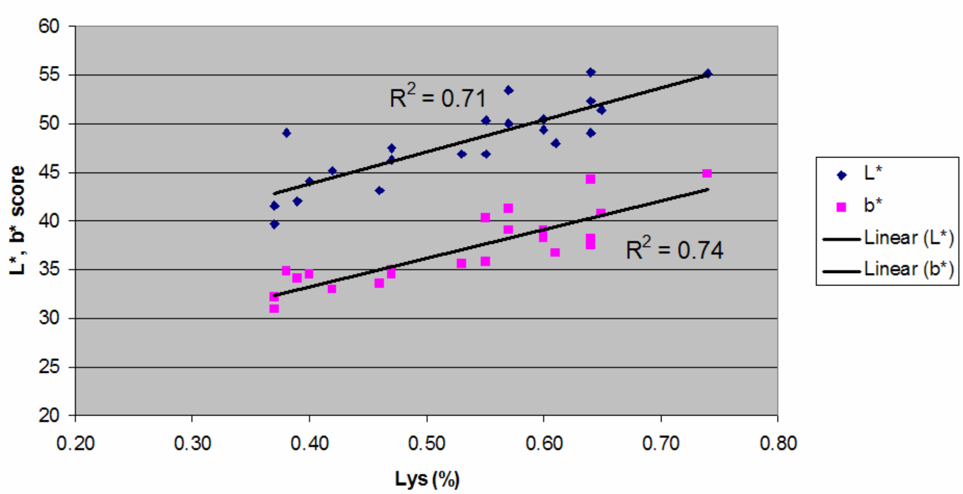
Some ethanol plants add all of the condensed solubles produced to the grains fraction, while others may add substantially less solubles to the grains fraction before drying. At least one ethanol plant is attempting to burn most, if not all of the solubles produced as a fuel source for the ethanol plant. This practice will substantially change the nutrient composition of the resulting by-product produced.

Table 3. Nutrient Content of Corn Distiller's Grains and Distiller's Solubles on (100% Dry Matter Basis).

Nutrient	**Distiller's Grains**	**Distiller's Solubles**
Crude protein, %	33.5	18.5
Crude fat, %	9.0	15.7
Crude fiber, %	9.5	2.5
Ash, %	3.0	8.4
Calcium, %	0.04	0.06
Phosphorus, %	0.54	1.28
Lysine, %	1.05	0.68
Methionine, %	0.66	0.27
Threonine, %	1.27	0.70
Tryptophan, %	0.29	0.20

Lightness and yellowness of color of DDGS appear to be reasonable predictors of digestible lysine content among golden corn DDGS sources for poultry (Figure 2; Ergul et al., 2003) and swine (Pederson et al., 2005). However, among sources of golden corn DDGS, Ergul et al., (2003) showed that true lysine digestibility coefficients ranged from 59 to 83% for poultry, and Stein et al. (2005) showed a similar range in true lysine digestibility coefficients for swine (44 to 63%). It is likely that much of the difference in lysine digestibility among golden DDGS sources is due to drying time and temperature used to produce DDGS. Dryer temperature can range from 260 to 1150º F., depending on the ethanol plant. Since amount and length of heating is highly correlated to lysine digestibility, it is not surprising that a fairly wide range in lysine digestibility exists among golden corn DDGS sources.

Figure 2. Regression of digestible lys (%) and color (L*, b*)



Some dry-grind ethanol plants use process modifications to produce ethanol and DDGS. For example, some plants use cookers to add heat for fermentation and use less enzymes, while other plants will use more enzymes and not rely on the use of cookers to facilitate fermentation. Theoretically, use of less heat could improve amino acid digestibility of DDGS, but no studies have been conducted to determine how these processes impact final nutrient composition and digestibility. Some ethanol plants partially de-germ the corn before fermentation. This results in a lower fat level in the final DDGS product. On the other hand, some ethanol plants market some of their wet distiller's grains resulting in a high proportion of solubles being added to the remaining grains fraction to produce DDGS. Because the solubles fraction is high in fat relative to the grains fraction, this results in a higher level than usual in the resulting DDGS. One company produces a pelleted DDGS primarily for the export market. In order to make a good quality pellet, about 20% soybean hulls are blended with DDGS before pelleting. However, the addition of soy hulls increases the fiber content of the product and dilutes all of the other nutrients. Whisky distilleries produce a slightly different type of DDGS as well, because of the mixture of grains used. Finally, there are examples of products labeled as "DDGS", but some of these are really corn gluten by-products or blends of different distiller's by-products. Generally, the distinguishing characteristic of typical corn DDGS from these other by-products are the high fat and phosphorus content.

A considerable amount of discussion has occurred over the past several years within the feed and ethanol industries regarding standardizing DDGS composition. The U.S. ethanol industry is comprised of a few very large producers and many small, independent ethanol plants. Many of the independent ethanol plants are unwilling to consider using standardized production processes because they are exploring product niches and technologies that will give them a greater competitive advantage. Attempts have been made in recent years to develop some type of system to differentiate quality and value among DDGS sources, but these attempts have failed. Unlike corn and other grains, there is no grading system to differentiate quality within ethanol by-product categories, and many ethanol plants and marketers are opposed to developing such a system. However, despite not having a grading system for DDGS, there is price differentiation based upon subjective color evaluation. In fact, it is not uncommon to find a \$20 to \$30/ton market price differential between "golden" DDGS and darker colored DDGS.

Because of differences in dry-grind production processes used to produce ethanol and DDGS among U.S. ethanol plants, it is important to identify specific ethanol plants that produce the type of DDGS with a nutrient profile and color that best matches the feeding application where it will be used. In order to assist customers in identifying U.S. corn DDGS sources and marketers, photos and nutrient profiles of DDGS samples produced by several U.S. ethanol plants can be found at www.ddgs.umn.edu under the "Nutrient Profiles" section.

Table 4. Comparison of the Nutrient Composition of Golden Corn DDGS Produced in Minnesota and South Dakota to Examples of Other "DDGS Sources" (100% Dry Matter Basis).

Nutrient	Golden Corn DDGS	"DDGS"	High Fat DDGS	Partial De-germed DDGS	Whiskey DDGS	Pelleted DDGS
Crude protein, %	31.8	29.3	31.6	30.1	29.9	27.0
Crude fat, %	11.3	3.5	15.3	8.9	8.8	9.0
Crude fiber, %	6.3	7.9	N/A	7.8	10.6	15.1
ADF, %	12.4	11.8	17.9	21.0	20.2	N/A
Ash, %	6.9	5.3	4.6	7.3	3.7	4.3
Calculated ME (swine), kcal/kg	3781	3577	N/A	3560	3789	N/A
Lysine, %	0.92	0.61	0.90	0.83	0.99	N/A
Methionine, %	0.62	0.54	0.54	0.66	0.61	N/A
Threonine, %	1.17	1.01	1.04	1.13	1.10	N/A
Tryptophan, %	0.25	0.18	0.23	0.25	0.27	N/A
Calcium, %	0.07	0.12	0.06	0.51	0.04	0.17
Phosphorus, %	0.77	0.78	0.89	0.68	0.57	0.62

DDGS FEEDING VALUE FOR SWINE

The swine industry is the fastest growing sector of DDGS use in the U.S. High quality corn DDGS has a digestible and metabolizable energy value equal to corn. However, like the low protein quality of corn, corn DDGS is also low in lysine relative to its crude protein level. Threonine is the second limiting amino acid after lysine, and should be monitored during diet formulation when using more than 10% corn DDGS in swine diets. Amino acid digestibility varies among corn DDGS sources. Whitney et al. (2000) showed that the apparent ileal digestibility coefficient for lysine was 53.6% for high quality, golden colored corn DDGS, and the lysine digestibility coefficient for a dark colored corn DDGS source was 0%. These results demonstrate that golden colored DDGS sources have much higher digestible lysine and other amino acids compared to darker colored, heat damaged DDGS sources. In order to ensure excellent pig performance when adding DDGS to swine diets, only light colored, golden sources should be used. Corn DDGS is an excellent source of available phosphorus for swine. Whitney et al. (2001) showed that relative phosphorus availability in corn DDGS was 90%, using dicalcium phosphate as the inorganic phosphorus reference source. Adding 10% high quality corn DDGS to a corn-soybean meal diet containing 3 lbs of L-lysine HCl for growing pigs, along with 0.15% limestone, will replace approximately 8.85% of the corn, 1% of the soybean meal, and 0.3% of the dicalcium phosphate in the diet.

U.S. pork producers that are using high quality, golden colored corn DDGS in their swine diets, are currently adding it at a level of 10% in gestating and lactating sow diets, as well as grow-finish pig diets, and achieve excellent performance. Some pork producers also add high quality corn DDGS to nursery diets at a level of 5% for pigs weighing at least 7 kg in body weight with excellent results. Research studies conducted at the University of Minnesota have demonstrated that much higher levels of corn DDGS can be added to swine diets without compromising performance or carcass quality. However, these recommendations assume that high quality DDGS is free from mycotoxins and diets are formulated on a digestible amino acid and available phosphorus basis. The risk of mycotoxins in corn DDGS is very low because many ethanol plants monitor incoming corn for the presence of mycotoxins as part of their quality control program. Based upon these research results obtained at the University of Minnesota, the maximum recommended feeding level for high quality corn DDGS in swine diets are shown in Table 5.

Table 5. Maximum Recommended Dietary Inclusion Rates for Golden Corn DDGS in Swine Diets.

Production Phase	Maximum Dietary Inclusion Rate
Weaned pigs (> 7 kg)	25%
Grow-finish	20%
Gestation	50%
Lactation	20%

Whitney and Shurson (2004) showed that if diets are formulated on a digestible amino acid basis, feeding up to 25% DDGS in Phase II and Phase III nursery diets will result in equivalent growth performance compared to feeding a diet containing no DDGS as long as the pigs weigh at least 7 kg when DDGS diets are initially fed. However, if DDGS is added to diet of pigs weighing less than 7 kg, growth rate and feed intake may be reduced.

Whitney et al. (2001) conducted a growth performance and carcass evaluation study where grow-finish pigs were fed diets containing 0, 10, 20, and 30% corn DDGS. Diets were formulated on a total lysine (amino acid) basis, and contained about 3% supplemental soybean oil as a supplemental fat source. Pigs fed diets containing 0 and 10% DDGS had equivalent growth performance, but pigs fed the 20 and 30% DDGS diets had lower average daily gain, but equivalent average daily feed intake, compared to pigs fed the 0 and 10% DDGS diets. Feed conversion was similar for pigs fed the 0, 10, and 20% DDGS diets, but was reduced when the 30% DDGS diets were fed. The reduction in growth rate of pigs fed the 20 and 30% DDGS diets was likely a result of inadequate threonine in the diets. This problem can be alleviated by formulating diets on a digestible amino acid basis and using other protein sources high in threonine. There were no differences in % carcass lean or muscle quality characteristics of pork carcasses from pigs fed increasing levels of DDGS. However, belly firmness declined linearly and iodine value (degree of unsaturated vs saturated fatty acids in pork fat) increased as increasing levels of DDGS were added to grow-finish diets. However, depending on the market, the effects of feeding DDGS on pork fat quality are generally not a concern.

Disease challenge studies have been conducted to study the effects of adding 10 or 20% DDGS to growing finishing pigs diets that were infected with *Lawsonia intracellularis*, on the length, incidence, and severity of intestinal lesions caused by this disease (Whitney et al., 2003). In one of these studies, adding 10% DDGS to the diet reduced the length, prevalence, and severity of gastrointestinal tract lesions similar to the response obtained by using a recommended BMD and chlortetracycline therapeutic regimen. However, there were no additive effects when both antimicrobials and DDGS were combined in the diet.

Wilson et al. (2003) conducted a study to evaluate previously recommended maximum inclusion rates of DDGS in gestation (50%) and lactation (20%) diets for sows over two reproductive cycles. Sows fed the DDGS diets weaned more pigs per litter during the second reproductive cycle compared to sows fed the control corn-soybean meal diets. This improvement in litter size weaned is similar to the litter size response observed in other studies where sows were fed high fiber diets. It is unknown if this response can be obtained when feeding gestation and lactation diets containing lower levels of DDGS.

Recent unpublished research results from studies conducted at the University of Minnesota have also shown that when nursery diets are formulated on an available phosphorus basis, and high quality corn DDGS is added to the diet, the concentration of manure phosphorus is reduced. However, dry matter digestibility of diets containing DDGS generally decreases slightly, resulting in a slight decrease, or no change in total manure phosphorus excretion. When adding corn DDGS and phytase to swine diets, manure phosphorus excretion will be dramatically reduced.

DDGS FEEDING VALUE FOR POULTRY

Corn DDGS can supply a significant amount of energy, amino acids, and phosphorus to poultry diets. Metabolizable energy values of 2865 kcal AME/kg, 2905 kcal TME/kg, and 2805 kcal TME/kg for DDGS have been used in feeding trials with turkeys (Noll et al., 2004), broilers (Lumpkins et al., 2004), and layers (Lumpkins et al., 2005), respectively, without negative effects on feed conversion with inclusion levels of 10%. Batal and Dale (2004) obtained an average TME of 2831 kcal/kg with roosters. Roberson (K. D. Roberson, Michigan State University, personal communication) determined AME values of 2760 and 2750 kcal/kg in turkey poults and laying hens, respectively. The experimentally derived AME value of 2750 kcal/kg was determined to be a more adequate estimate of the energy value of DDGS in market turkey toms when compared to that of the NRC (2480 kcal/kg), or an experimentally derived TME value of 2980 kcal/kg (Noll et al., 2005). Conservatively, then, a value of 2755 kcal ME/kg can be used to avoid overestimating the energy content of corn DDGS. Regardless, it is important to note that these recent estimates of energy are substantially higher than the value (2480 kcal ME/kg) reported in NRC (1994).

Recent research results have also shown that the amino acid content and digestibility of golden corn DDGS sources is higher than values reported in NRC (1994). For example, lysine digestibility of corn DDGS can be as high as 83% compared to the value reported in the poultry NRC (1994) of 65% (Ergul et al., 2003). Corn DDGS is also high in phosphorus (0.73%) (Noll et al., 2003). Unlike phosphorus availability in corn, phosphorus availability in corn DDGS is higher for poultry. Lumpkins and Batal (2005) obtained phosphorus availability estimates of 54 and 68%, whereas Martinez et al. 2004 obtained bioavailability estimates for phosphorous of 69, 75, 82, and 102% for different DDGS samples. The sodium content of corn DDGS can range from 0.01 to 0.48% averaging .11%. Therefore, dietary adjustments for sodium content may be necessary if the source of corn DDGS being used contains high levels of sodium, in order to avoid potential problems with wet litter and dirty eggs. Corn DDGS also contains as much as 40 ppm of xanthophyll. The xanthophyll content of corn DDGS has been shown in field and research trials to significantly increase egg yolk color when fed to laying hens (Shurson et al., 2003 and Roberson et al., 2005, respectively), and increase skin color of broilers when included at levels of 10% of the diet.

Current recommended maximum dietary inclusion levels for corn DDGS are 10% for meat birds and 15% for chicken layers. Higher levels of corn DDGS can be used successfully with appropriate diet formulation adjustments for energy and amino acids (Noll et al., 2004; Waldroup et al., 1981). When formulating diets containing corn DDGS, digestible amino acid values should be used especially for lysine, methionine, cystine, and threonine. Diets should also be formulated by setting minimum acceptable levels for tryptophan and arginine due to the second limiting nature of these amino acids in corn DDGS protein.

NEW DISTILLER'S DRIED GRAINS BY-PRODUCTS

Several ethanol production companies and other research groups have been developing a variety of modified processes to enhance ethanol yield and change the resulting by-products from dry grind ethanol plants. The most widely discussed processes involve using new enzyme technology to increase the crude protein content of DDGS, removing the germ and/or bran from corn prior to fermentation, and removing the phosphorus prior to producing DDGS. Although these modified processes may enhance ethanol yield, they may not enhance the nutritional and economic value of the by-products for monogastrics.

For example, feeding a high protein DDGS may initially appear to have improved feeding and economic value for swine and poultry. However, as crude protein increases, other nutrients must decrease in concentration. As shown in Table 6, Dakota Gold HP has 34% more crude protein than typical Dakota Gold DDGS, but curiously, the lysine content is not increased despite increases in other essential amino acids. Much of this increase in crude protein content is at the expense of fat (59% reduction) and phosphorus (42% reduction) in the high protein DDGS. In fact, the relative proportion of nutrients in the high protein DDGS is similar to that found in distiller's dried grains. Although NDF in the high protein DDGS is reduced, it would be expected that the reduction in fat content would substantially reduce the energy value for swine and poultry. However, the ME estimates provided in the nutrient specification sheets indicate that energy value is the same as typical DDGS, which is unlikely. Furthermore, since about 50% of the diet cost savings of using DDGS in swine diets is due to the reduced need for inorganic phosphorus supplementation, the large reduction in phosphorus content in the high protein DDGS will make it more difficult to provide the same degree of diet cost savings as provided by "typical" DDGS.

Table 6. Common Nutrient Specifications for DDGS and Compared to the Nutrient Content of Dakota Gold DDGS and Dakota Gold HP DDGS (100% Dry Matter Basis)

Nutrient	**DDGS Spec. 1**	**Dakota Gold DDGS Spec. 2**	**Dakota Gold HP**
Dry matter, %	88.0	90.0	90.0
Crude protein, %	30.7	29.2	39.2
Crude fat, %	10.9	11.6	4.8
ME (swine), kcal/kg	3759	3749	3749
ME (poultry), kcal/kg	3056	3065	3065
ADF, %	16.2	11.6	9.7
NDF, %	-	29.9	15.8
Ash, %	5.5	4.2	2.7
Calcium, %	0.06	0.04	0.04
Phosphorus, %	0.89	0.83	0.48
Lysine, %	0.83	1.06	1.06
Arginine, %	1.19	1.13	1.24
Tryptophan, %	0.24	0.21	0.24
Methionine, %	0.55	0.49	0.77
Cystine, %	0.58	0.41	0.70
Threonine, %	1.13	0.77	1.20

Source: Dakota Gold Marketing Nutrient Specifications (November, 2004).

Glutenol and CPC are two other examples of corn-based by-products resulting from a modified ethanol production processes. These products are produced post-fermentation after the germ and primary fiber components are physically removed prior to fermentation. The nutrient composition of these two products is shown in Table 7. Again, they are substantially higher in protein than typical DDGS, but lysine and other amino acids are not increased proportionately. The TME value for poultry appears to be overestimated because of the high crude protein content of these products and the low fat content. In fact, the high crude protein:lysine ratio may likely be detrimental to energy utilization because of the additional energy that will be expended by the pig or chick to remove excess nitrogen.

EFFECT OF USING DDGS AND NEW DISTILLER'S BY-PRODUCTS IN PRACTICAL SWINE AND POULTRY DIETS

Swine

In order to understand the feeding and relative economic value of typical corn DDGS to other new distiller's by-products, we formulated typical swine grower diets on an "as fed" basis using the following assumptions. For all of the distiller's by-products, it was assumed that digestibility coefficients for lysine, tryptophan, threonine, and methionine + cystine were 53, 64, 55, 52%, respectively. We also assumed that phosphorus availability in all distiller's by-products was 85%. Although the calculated ME values for high protein DDGS, glutenol and CPC suggest that energy value is relatively high, we adjusted these values lower because of the fat content of these products is substantially lower than the fat level in DDGS. The ME values we used were 1300, 1200, and 1258 for high protein DDGS, glutenol, and CPC respectively.

Table 7. Nutrient Composition of Glutenol and CPC (100% Dry Matter Basis).

Nutrient	**Glutenol**	**CPC**
Dry matter, %	90.0	90.0
Crude protein, %	59.8	50.0
Crude fat, %	1.91	3.6
Crude fiber, %	8.7	4.2
Ash, %	4.3	6.5
ADF, %	11.7	10.3
NDF, %	23.4	17.0
Poultry TME (kcal/kg)	3284	2989
Calcium, %	0.04	0.20
Phosphorus, %	0.57	1.07
Lysine, %	1.23 (83)[1]	0.90 (67)[1]
Arginine, %	2.13 (94)[1]	1.62 (87)[1]
Tryptophan, %	0.36 (88)[1]	0.29 (83)[1]
Methionine, %	1.23 (96)[1]	0.97 (91)[1]
Cystine, %	1.19 (85)[1]	0.88 (74)[1]
Threonine, %	2.17 (86)[1]	1.76 (73)[1]

[1] Values in parentheses are digestibility coefficients for poultry.

All diets contained 1553 kcal ME/lb, 1.0% lysine, 0.84% digestible lysine, a minimum of 0.48% digestible threonine and 0.14% digestible tryptophan, 0.58% calcium, and 0.26% available phosphorus. The minimum ratios of digestible methionine + cystine, digestible threonine, and digestible tryptophan to digestible lysine were 55, 58, and 16.6. In addition, all diets were formulated to contain equivalent amounts of salt, vitamins and minerals. Synthetic L-lysine HCl (78.8%), DL-methionine (99%), and L-threonine (98.5%) were used to meet minimum digestible amino acid requirements as needed. The feed ingredient prices used in the diet formulation comparisons are shown in Table 8.

Table 8. Feed Ingredient Prices Used in Diet Formulation Comparisons.

Ingredient	**$/cwt**
Corn	3.50
Soybean meal (47)	10.50
DDGS	4.00
Choice white grease	17.00
Dicalcium phosphate	13.00
Limestone	2.00
Salt	6.00
L-lysine HCl	80.00
L-threonine	145.00
DL-methionine	120.00
VTM premix	1.00

As a reference point, we formulated a standard corn-soybean meal grower diet (diet 1) containing 3 lbs of synthetic lysine, which is commonly used in the swine industry (Table 9). Diet 2 was formulated to contain 10% DDGS using the nutrient specifications shown for DDGS Spec. 1 in Table 5. L-lysine HCl was the only synthetic amino acid offered in the diet 2 formulation and 4.13 lbs of L-lysine HCl was used. Knowing that threonine is second limiting in corn-soybean meal-DDGS diets, we offered both L-lysine HCl and L-threonine for the formulation of DDGS diet 3. In this case, 5.78 lbs of L-lysine HCl and 0.65 lbs of L-threonine were added. Currently, there are limited data to indicate that acceptable growth performance can be achieved by using these high amounts of synthetic amino acids in swine diets. We then formulated an additional diet containing 10% DDGS using the nutrient profile for Spec. 2 DDGS shown in Table 5. This was done to compare diets 3 and 4 and show how important it is to know the source of DDGS being used, the need for accurate DDGS nutrient specifications, and how the nutrient specifications can affect the opportunity cost for DDGS.

Adding 10% DDGS and non-fixed amount of L-lysine HCl to a swine grower diet using nutrient spec. 1 DDGS replaces 146 lbs of corn, 55 lbs of soybean meal, and 6 lbs of dicalcium, while increasing the amount of choice white grease by 2 lbs, limestone by 3 lbs, and L-lysine HCl by about 1 lb in order to provide equivalent dietary ME, digestible lysine, calcium, and available phosphorus levels in the standard corn-soybean meal diet containing 3 lbs of L-lysine HCl (diet 1) per ton (Table 9). As a result, under current prices, adding 10% DDGS to a swine grower diet will reduce diet cost by $2.34/ton. When 10% DDGS (spec. 1) and a non-fixed amount of L-lysine HCl and L-threonine were added (diet 3), diet cost was reduced by an additional

$1.55/ton. However, adding high amounts of synthetic amino acids may be risky until we have data that show that satisfactory growth performance can be achieved using this formulation approach. If nutrient spec. 2 for DDGS is used (diet 4), and at the same price as nutrient spec. 1 for DDGS, diet cost actually increases $0.20/ton compared to diet 3 which used nutrient spec. 1 for DDGS. This demonstrates that the DDGS nutrient specifications affects opportunity cost since spec. 2 DDGS is worth $78/ton whereas spec. 1 DDGS is worth $80/ton because of differences in lysine, sulfur amino acids and threonine levels.

As shown in Table 10, the addition of 10% High Protein DDGS to a swine grower diet slightly reduces the amount of corn (- 20 lbs), soybean meal (- 5 lbs), L-threonine (- 0.4 lbs), DL-methionine (- 0.14 lbs), while increases the amount of choice white grease (+ 24 lbs) and dicalcium phosphate (+ 3 lbs) per ton of complete feed compared to the DDGS spec. 2 diet shown in Table 9. The increase in the amount of fat that was added is based upon our lower estimation of the actual ME value of high protein DDGS due to the lower fat content compared to typical DDGS. This clearly shows the importance of knowing the actual energy value of distiller's by-products because it has a substantial impact on the feeding and economic value in swine diets. Processes that reduce the fat content of distiller's by-products significantly reduce the energy value which makes them more difficult to economically fit into least cost formulations. Since phosphorus is the third most expensive nutrient added to swine diets, the lower phosphorus content of the High Protein DDGS also adversely affects its economic value because more dicalcium phosphate must be added to the diet to achieve the desired level of available P. In fact, using the price for DDGS at $80/ton, and the nutrient content assumptions for High Protein DDGS, one could afford to pay only $51/ton for the High Protein DDGS for swine diets.

Similarly, even though CPC and glutenol are even higher in crude protein content compared to High Protein DDGS, our estimated energy value and the poor protein quality (low lysine content) results in minimal reductions in corn and soybean meal use in swine diets compared to adding the same level of DDGS to the diet. In fact, an additional 0.7 to 0.8 lbs of L-lysine HCl needs to be added to the diets containing these products in order to achieve the desired level of digestible lysine. The slightly higher phosphorus content of CPC compared to DDGS is an economic advantage, but not for glutenol. As shown in Table 10, the economic value of CPC and glutenol in swine diets is $61.60/ton and $63.40/ton, respectively, which is substantially less than typical DDGS.

Table 9. Effect of Adding Synthetic Amino Acids and DDGS, with Two Different Nutrient Specifications, to a Practical Swine Grower Diet on Ingredient Use and Diet Cost.

Ingredient	**Corn + SBM + 3 lbs L-lysine (1)**	**10% DDGS (Spec. 1) + Lys (2)**	**10% DDGS (Spec. 1) + Lys & Thr (3)**	**DDGS (Spec. 2) + Lys, Thr, Met (4)**
	%	%	%	%
Corn	72.57	65.29	67.84	67.70
Soybean meal (47)	23.04	20.30	17.61	17.89
DDGS	0.00	10.00	10.00	10.00
Choice white grease	2.00	2.11	2.11	1.96
Dicalcium phosphate	1.07	0.76	0.78	0.79
Limestone	0.72	0.89	0.90	0.90
Salt	0.30	0.30	0.30	0.30
L-lysine HCl	0.15	0.21	0.29	0.27
L-threonine	0.00	0.00	0.03	0.05
DL-methionine	0.00	0.00	0.00	0.007
VTM premix	0.15	0.15	0.15	0.15
Total	**100.00**	**100.00**	**100.00**	**100.00**
Cost, $/ton	111.85	109.51	107.96	107.96
Opportunity cost of DDGS, $/ton	---	80.00	80.00	78.00
Nutrient Analysis				
ME, kcal/lb	1553	1553	1553	1553
Crude fat, %	4.73	5.52	5.60	5.53
Crude protein, %	17.5	18.3	17.4	17.4
Lysine, %	1.00	1.01	1.01	1.02
Dig. lysine, %	0.84	0.84	0.84	0.84
Met + cys, %	0.59	0.63	0.60	0.59
Dig. Met + cys, %	0.49	0.49	0.46	0.46
Threonine, %	0.65	0.68	0.67	0.65
Dig. threonine, %	0.48	0.48	0.48	0.48
Tryptophan, %	0.21	0.21	0.19	0.19
Dig. tryptophan, %	0.16	0.15	0.14	0.14
Calcium, %	0.58	0.58	0.58	0.58
Phosphorus, %	0.53	0.51	0.51	0.51
Avail. P, %	0.26	0.26	0.26	0.26

Table 10. Effect of Adding High Protein DDGS, CPC, or Glutenol to Growing Swine Diets on Ingredient Use.

Ingredient	**High Protein Dakota Gold DDGS**	**CPC**	**Glutenol**
	%	%	%
Corn	66.69	67.34	67.60
Soybean meal (47)	17.66	17.06	16.29
HP DDGS	10.00	0.00	0.00
CPC	0.00	10.00	0.00
Glutenol	0.00	0.00	10.00
Choice white grease	3.14	3.23	3.61
Dicalcium phosphate	0.94	0.70	0.91
Limestone	0.82	0.91	0.84
Salt	0.30	0.30	0.30
L-lysine HCl	0.27	0.30	0.31
L-threonine	0.03	0.009	0.00
DL-methionine	0.00	0.00	0.00
VTM premix	0.15	0.15	0.15
Total	**100.00**	**100.00**	**100.00**
Cost, $/ton	**107.95**	**107.95**	**107.95**
Opportunity cost of by-product, $/ton	**51.00**	**63.40**	**61.60**
Nutrient Analysis			
ME, kcal/lb	1553	1553	1553
Crude fat, %	6.06	6.06	6.29
Crude protein, %	18.1	18.9	19.4
Lysine, %	1.01	1.01	1.02
Dig. lysine, %	0.84	0.84	0.84
Met + cys, %	0.63	0.66	0.70
Dig. Met + cys, %	0.48	0.49	0.51
Threonine, %	0.67	0.69	0.71
Dig. threonine, %	0.48	0.48	0.48
Tryptophan, %	0.19	0.19	0.19
Dig. tryptophan, %	0.14	0.14	0.14
Calcium, %	0.58	0.58	0.58
Phosphorus, %	0.50	0.50	0.49
Avail. P, %	0.26	0.26	0.26

Poultry

A turkey grower tom diet (8-11 wks of age) was formulated with least cost software using the nutrient profile of the ingredients as listed in Tables 6 and 7, and ingredient costs as listed in Table 8. Digestible amino acid values were not available for the Dakota Gold products so average amino acid digestibility coefficients previously obtained from a survey of corn DDGS were used (Noll et al., 2003). Diets were formulated to contain 3150 kcal/kg ME (1428 kcal/lb) and a minimum digestible amino acid content for lysine (1.15%), methionine + cystine (.74%), and threonine (.74%). Calcium and inorganic phosphorus levels were set at 1.12 and .56%, respectively. Inclusion levels of the various products were limited to 10% of the diet. Supplements of lysine and methionine were available for use in all diets.

Table 11. Effect of Adding DDGS, CPC, or Glutenol to Turkey Grower Diets on Ingredient Use.

	Corn, Soy, Meat (CSM)	**With Dakota Gold DDGS**	**With High Protein DDGS**	**With CPC**	**With Glutenol**
	-------------------	-------------------	%	-------------------	-------------------
Corn	53.67	44.91	47.39	50.97	55.93
Soy	32.18	30.29	28.00	25.16	20.94
MBM	7.25	7.25	7.25	7.25	7.25
Dicalcium phosphate	1.04	.78	.92	.71	.92
DL-Methionine	.068	.054	.032	.028	.004
L-Lysine ·HCL	.041	.040	.109	.210	.289
Fat	4.44	5.26	4.91	4.35	3.23
Vitamin/minerals	++	++	++	++	++
Cost ($/ton)	146.48	146.13	142.89	138.29	130.64
Opportunity cost of DDGS ($/ton)	---	75.20	53.00	43.00	75.20
ME (kcal/kg)	3150	3150	3150	3150	3150
Crude Protein (%)	23.59	24.57	24.60	24.57	23.87
Crude fat (%)	7.72	9.24	8.32	7.71	6.52
Phosphorus, total (%)	.80	.798	.781	.784	.756
Phosphorus, available (%)	.560	.560	.560	.560	.560

Similar to the results obtained with the swine formulas, the standard DDGS and the glutenol product have the highest value based upon the opportunity cost assuming the energy values that were assigned to these ingredients are appropriate, and that a 10% dietary inclusion level results in similar performance. In all diets containing distiller's by-products, the usage of dicalcium phosphate and the total levels of phosphorus were decreased. Usage of supplemental fat increased in the diets containing the DDGS products and decreased in diets containing CPC and glutenol. The decrease in supplemental fat in the latter two diets was probably due to the high ingredient ME values and the concentration of protein allowing for a higher amount of corn in the diet, and a larger decrease in the amount of soybean meal needed.

In summary, ME content, amino acid level and digestibility, and available phosphorus content are the primary factors that influence suitability for use in swine and poultry diets and the economic value of distiller's by-products. However, based upon our assumptions for energy value the high protein DDGS and CPC by-products will have much higher value for ruminants because of the higher levels of nitrogen (crude protein), and lower levels of fat and phosphorus.

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