

# Feed and Alternative Uses for DDGS

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## Introduction

Fuel ethanol production is one of the fastest growing segments in American agriculture. Currently, there are 92 ethanol plants in production, with an additional 23 ethanol plants under construction ([www.ethanolrfa.org/industry/statistics](http://www.ethanolrfa.org/industry/statistics), November, 2005). These ethanol plants will have production capacity of 5.6 billion gallons of ethanol per year (Renewable Fuels Association, November, 2005). Approximately 40% of fuel ethanol is produced by wet-mills, 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" (blend of condensed distiller's solubles and dry distiller's grains), and condensed distiller's solubles. Of these dry-grind ethanol plant by-products, distiller's grains with solubles (DDGS) is the predominant by-product being marketed domestically. Several relatively new ethanol plants were designed and built without dryers. As a result, approximately 40% of the distiller's grains with solubles is marketed as a wet by-product for use in dairy operations and beef cattle feedlots. 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 within the next few years.

## Use of DDGS in Livestock and Poultry Feeds

Although there is significant interest among ethanol producers to find alternative uses for DDGS, the vast majority of this by-product is sold as a feed ingredient for livestock and poultry feeds. Corn is the primary grain used in wet mills and dry-grind ethanol plants because of its high fermentable starch content compared to other feedstocks. 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. 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 diets.

**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 <sup>1</sup>	Corn Gluten Feed <sup>2</sup>	Corn Gluten Meal <sup>2</sup>	Brewer's Dried Grains <sup>2</sup>
Crude protein, %	30.6	23.9	66.9	28.8
Crude fat, %	10.7	3.3	3.2	7.9
NDF, %	43.6	37.0	9.7	52.9
ADF, %	11.8	11.9	5.1	23.8
ME (swine), kcal/kg	3827	2894	4256	2130
Lysine, %	0.83	0.70	1.13	1.17
Methionine, %	0.55	0.39	1.59	0.49
Threonine, %	1.13	0.82	2.31	1.03
Tryptophan, %	0.24	0.08	0.34	0.28
Calcium, %	0.06	0.24	0.06	0.35
Phosphorus, %	0.89	0.83	0.44	0.56
P availability for swine, %	90	59	15	34

<sup>1</sup> Data from Spiels et al. (2002), University of Minnesota.

<sup>2</sup> Data from NRC (1998), Nutrient Requirements of Swine, 10<sup>th</sup> Revised Edition, National Academy Press.

Perhaps the biggest challenge of using corn DDGS in livestock and poultry diets is to have accurate information regarding 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 (Spiels 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](http://www.ddgs.umn.edu)).**

Nutrient	Average <sup>1</sup>	Range
Dry matter, %	89.3	87.3 – 92.4
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
Lysine, %	0.90 (11.4)	0.61 - 1.06
Phosphorus, %	0.75 (19.4)	0.42 - 0.99

<sup>1</sup> Values in parantheses are coefficients of variation among sources.

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:

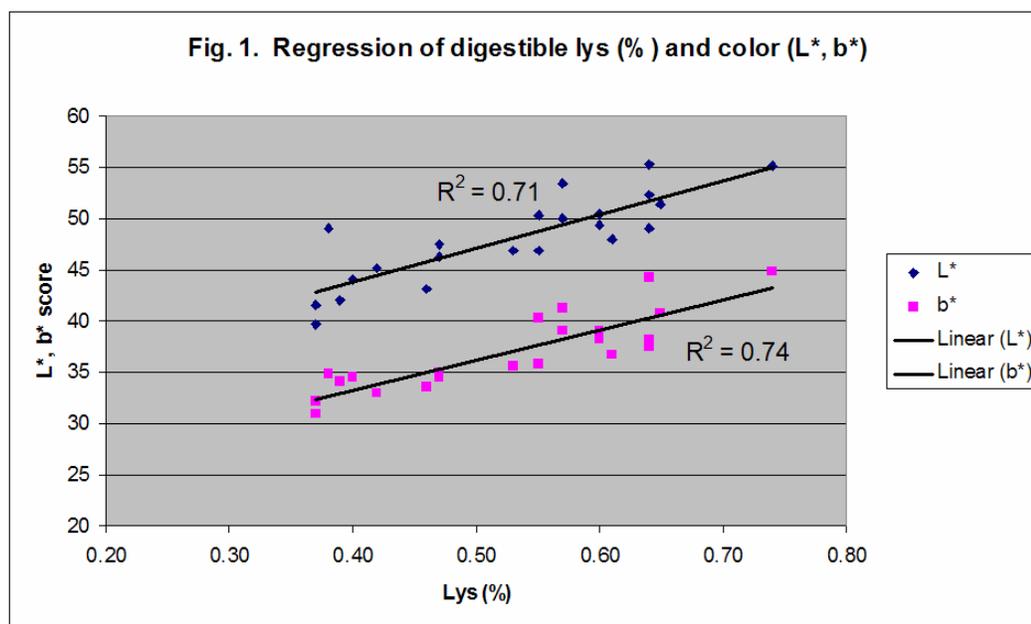
“Distillers Dried Grains with Solubles is the product obtained after the removal of ethyl alcohol by distillation from yeast fermentation of a grain or a grain mixture by condensing and drying at least ¾ of the solids of the resultant whole stillage by methods employed in the grain distilling industry.”

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 1; 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 1150° 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.



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](http://www.ddgs.umn.edu) under the "Nutrient Profiles" section.

### **Feeding Value of Corn DDGS for Dairy Cattle**

Corn DDGS is a very good protein source for dairy cows. The protein content in high quality corn DDGS is more than 30% of dry matter. Corn DDGS is a good source of ruminally undegradable protein (RUP), or by-pass protein, for cattle (Table 4). Most of the readily degradable proteins in corn are degraded during the fermentation process, resulting in a proportionately higher level of RUP than found in corn. The quality of protein in corn DDGS is fairly good, but as for most corn products, lysine is the first limiting amino acid. As a result, milk production can sometimes be increased when dairy cows are fed supplemental ruminally protected lysine and methionine, or when DDGS is blended with other protein supplements that contain more lysine. However, in most situations, milk production is as high, or higher, than when dairy cows are fed soybean meal as the protein source. It is important to recognize that dark colored corn DDGS usually indicates heat damage of the protein, which may lead to reduced milk production. In a study by Powers et al. (1995), dairy cows were fed diets containing dark colored DDGS had lower milk production than when cows were fed diets containing golden colored DDGS.

Therefore, it is important to use high quality sources of golden colored DDGS in dairy cows diets to achieve maximum milk production.

Corn DDGS is also a very good energy source for dairy cattle. Energy values for high quality DDGS are 10 to 15% higher than values previously reported in NRC (2001), and it contains more energy per kg than corn. Furthermore, because almost all of the starch in corn is converted to ethanol during the fermentation process, the fat and fiber concentrations in DDGS are increased by a factor of three compared to corn. Corn DDGS contains high amounts of NDF but low amounts of lignin. This makes DDGS a highly digestible fiber source for cattle, and reduces digestive upsets compared to when corn is fed. The highly digestible fiber in corn DDGS also allows it to serve as a partial replacement for forages and concentrates in diets for dairy and beef cattle.

The maximum recommended feeding level of corn DDGS in diets for lactating dairy cows is 20 % of the ration dry matter. This level corresponds to about 4.5 to 5.5 kg of DDGS in the diet per day, using typical feed intake levels of lactating dairy cows in the U.S. There are no palatability problems when feeding high quality DDGS to dairy cows, and nutritionists should be able to formulate nutritionally balanced diets up to that level. However, feeding at this maximum level may require the need to use some other protein supplements because of the lower protein quality (lysine) in DDGS. Furthermore, the diet will contain excess protein unless the forages used in the ration are primarily grasses. The phosphorus concentration of the diet may also be another factor to consider in order to minimize phosphorus excretion in the manure. Lastly, research studies have shown that as long as adequate amounts of fiber is provided by forages in the diet, feeding DDGS up to 20 % of dry matter intake will not affect milk fat concentration.

**Table 4. Nutrient Composition of High Quality U.S. Corn DDGS for Ruminants.**

<b>Nutrient</b>	<b>Corn DDGS (% of Dry Matter)</b>
Crude protein	30.1
RUP <sup>a</sup> % of crude protein	55.0
NE <sub>maintenance</sub> , Mcal/kg	2.07
NE <sub>gain</sub> , Mcal/kg	1.41
NE <sub>lactation</sub> , Mcal/kg	2.26
Neutral detergent fiber (NDF)	41.5
Acid detergent fiber (ADF)	16.1
Ether extract	10.7
Ash	5.2
Calcium	0.22
Phosphorus	0.83
Magnesium	0.33
Potassium	1.10
Sodium	0.30
Sulfur	0.44

<sup>a</sup>RUP = ruminally undegradable protein

Source: Schingoethe (2004)

### **Feeding Value of Corn DDGS for Beef Cattle**

In the U.S., finishing beef cattle have successfully been fed as much as 40% DDGS of ration dry matter as a replacement for corn grain. When adding corn DDGS to the diet at this level, it is used primarily as an energy source, and supplies more protein and phosphorus than required for finishing feedlot cattle. In one research study (Ham et al., 1994), the NE<sub>gain</sub> of corn DDGS for beef cattle was 21% higher than the value of dry-rolled corn. Conservatively, most nutritionists consider corn DDGS to have an apparent energy value equal to corn grain when fed to finishing cattle at levels ranging from 10 to 20% of total

ration dry matter. In many studies, feeding corn DDGS at levels of 15 to 20% of the diet dry matter improved growth rate and feed conversion of finishing beef cattle compared to when diets containing corn grain were fed. This performance improvement is often a result of reduced sub-acute acidosis and fewer problems with cattle going “off-feed”. Starch in corn grain is more likely to cause acidosis, laminitis, and fatty liver when fed at high levels to finishing beef cattle. However, these potential problems are greatly reduced when feeding corn DDGS because of the low residual starch content (< 2%) and the high amount of highly digestible fiber. Corn DDGS is very palatable and readily consumed by beef cattle. Furthermore, feeding DDGS does not change the quality or yield of beef carcasses, and it has no effect on the sensory or eating characteristics of beef.

Since DDGS goes through a drying process, there is potential for burning which can cause a chemical reaction called the Maillard reaction. When this reaction occurs, it renders some of the carbohydrate and protein unavailable to the animal. Therefore, bright, golden colored DDGS that has a sweet and fermented smell should be used to achieve the best feeding value and growth performance for beef cattle. Marketers of DDGS often discount the price of dark and heat damaged DDGS to account for the reduction in feeding value. Acid detergent insoluble nitrogen (ADIN) can be used to determine the extent of protein damage of DDGS. Once the ADIN value is determined in the laboratory, this value is multiplied by a factor of 6.25 to calculate the appropriate protein value for DDGS. This calculated protein value represents the amount of crude protein in DDGS that is unavailable and can be compared to the actual crude protein value to determine the extent of protein damage.

Corn DDGS is low in calcium but high in phosphorus and sulfur. Feeding diets containing corn DDGS may provide enough phosphorus to allow removal of all supplemental phosphorus sources from mineral supplements for beef cattle consuming forage based diets. Furthermore, to ensure adequate performance and to avoid urinary calculi, the calcium to phosphorus ratio of the diet should be equal to, or greater than 1.2:1, but not greater than 7:1. Supplemental calcium from feedstuffs high in calcium (e.g. limestone) should be used to stay within this recommended calcium to phosphorus ratio range. High levels of sulfur (greater than 0.4% of diet dry matter) from feed and water can cause polioencephalomalacia in cattle, and can interfere with copper absorption and metabolism. This antagonism with copper is worsened in the presence of molybdenum.

Less research has been conducted related to feeding corn DDGS to other ages of cattle. However, DDGS is an excellent feed ingredient to supplement energy and protein when cattle are fed low quality forages. When added to diets containing forages low in phosphorus, the phosphorus in DDGS will be of significant value. Other potential uses of DDGS include using it as a creep feed for calves nursing cows, a supplement for grazing cattle, and a supplement for low quality forages and crop residues that might be fed to growing calves, gestating beef cows, or developing beef heifers.

### **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. Tryptophan 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 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.**

<b>Production Phase</b>	<b>Maximum Dietary Inclusion Rate</b>
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 supplies a significant amount of energy, amino acids, and phosphorus to poultry diets. Metabolizable energy values of 2865 kcal ME/kg and 2975 kcal ME/kg for high quality, golden DDGS have been used in feeding trials with turkeys and broilers, and layers, respectively, without negative effects on feed conversion. Conservatively, a value of 2755 kcal ME/kg can be used to avoid overestimating the energy content of corn DDGS because the energy value varies among sources. However, it is important to note that these values are substantially higher than the value (2490 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%. Corn DDGS is also high in phosphorus (0.65 to 0.78%). Unlike phosphorus availability in corn, phosphorus availability in corn DDGS ranges from 54 to 68% for poultry. The sodium content of corn DDGS can range from 0.01 to 0.48%. 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 trials to significantly increase egg yolk color when fed to laying hens, 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 broilers and 15% for chicken layers. Higher levels of corn DDGS can be used successfully if with appropriate diet formulation adjustments for energy and amino acids. 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. In fact, using current feed ingredient prices, high protein DDGS would be valued at about 65% of the price of typical DDGS in swine and poultry diets.

Corn protein concentrate is another example of a corn-based by-product resulting from a modified ethanol production process. This product is produced post-fermentation after the germ and primary fiber components are physically removed prior to fermentation. This by-product is substantially higher in protein than typical DDGS, but lysine and other amino acids are not increased proportionately (Table 6). The high crude protein:lysine ratio may likely be detrimental to energy utilization in swine and poultry because of the additional energy that will be expended to remove excess nitrogen. However, the higher crude protein and lower fat is a significant nutritional and economic advantage in ruminant diets.

**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).**

<b>Nutrient</b>	<b>DDGS Spec. 1</b>	<b>Dakota Gold DDGS Spec.2</b>	<b>Dakota Gold HP</b>	<b>Corn Protein Concentrate</b>
Dry matter, %	88.0	90.0	90.0	90.0
Crude protein, %	30.7	29.2	39.2	50.0
Crude fat, %	10.9	11.6	4.8	3.6
ME (swine), kcal/kg	3759	3749	3749	No data
ME (poultry), kcal/kg	3056	3065	3065	2989
ADF, %	16.2	11.6	9.7	10.3
NDF, %	-	29.9	15.8	17.0
Ash, %	5.5	4.2	2.7	4.4
Calcium, %	0.06	0.04	0.04	0.20
Phosphorus, %	0.89	0.83	0.48	1.07
Lysine, %	0.83	1.06	1.06	0.90
Arginine, %	1.19	1.13	1.24	1.62
Tryptophan, %	0.24	0.21	0.24	0.29
Methionine, %	0.55	0.49	0.77	0.97
Cystine, %	0.58	0.41	0.70	0.88
Threonine, %	1.13	0.77	1.20	1.76

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

## Opportunities and Challenges for the Future

Most of the recent growth in the ethanol industry has occurred in the western Corn Belt of the U.S. where there is an abundance of corn and a high concentration of livestock and poultry operations. As a result, there is significant market growth potential for DDGS near these new ethanol plants. Currently, the U.S. ethanol industry is producing approximately 7 million metric tonnes of DDGS. On a theoretical basis, if every broiler, layer, and turkey in the U.S. ate 0.10 lbs of DDGS per day, 8 million metric tonnes of DDGS would be required. Likewise, if every pig in the U.S. ate 0.84 lbs of DDGS per day, or each beef steer, cow and calf ate an average of 4.8 lbs of DDGS per day, or if every dairy cow ate 8 lbs of DDGS per day, 8 million metric tonnes of DDGS would disappear. In other words, the livestock and poultry industries in the U.S. have the potential to consume all of the DDGS produced. However, many of these potential customers are often unfamiliar with the nutritional characteristics of DDGS and other distiller's by-products, and how to use them successfully in animal feeds. A significant amount of education and technical support is needed to help these inexperienced users develop feeding programs using DDGS. However, education alone will not be enough. The ethanol industry must understand their customer needs and address their concerns by modifying their production, quality management, and product technical support procedures if they want to maintain their markets. In particular, it is becoming increasingly critical that the issues related to variability in nutrient content, nutrient digestibility, variation in physical characteristics, multiple distiller's product characteristics, standard product testing procedures, certification and other quality concerns be addressed for long-term, sustained demand by domestic and international DDGS customers.

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