



A GUIDE TO Distiller's Dried Grains with Solubles (DDGS)

Third Edition



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Executive Summary

This 3rd Edition of the DDGS User Handbook updates our previous editions with information on recent research and experience on DDGS use. This edition also includes several new chapters discussing low fat DDGS now being produced in many U.S. ethanol plants.

The U.S. ethanol industry includes several different plant designs and production technologies, and uses several different grains as feedstocks for ethanol production – including a wide diversity of corn varieties and sources. With the evolving technology for corn fractionation and for oil extraction, the industry produces many different products as DDGS. As a result, no single DDGS commodity exists. This Handbook gives buyers tools they need in developing relationships with U.S. DDGS sellers, so that buyers can be confident of the value of the DDGS they purchase.

This version of the Handbook is divided into numerous short chapters, which enable readers to find quickly the specific information they are seeking. Those chapters are summarized below --

Introduction to U.S. DDGS – An Excellent Ingredient for Use in Animal Feeds –

Recent record high feed ingredient prices around the world are causing animal nutritionists to search for lower cost alternative feed ingredients to minimize the cost of food animal production. U.S. dried distiller's grain with solubles (DDGS) is an excellent, lower cost alternative feed ingredient that continues to be produced in large quantities by the dry-grind fuel ethanol industry. The high energy, mid-protein, and high digestible phosphorus content of DDGS make it a very attractive, partial replacement for some of the more expensive, traditional energy (corn), protein (soybean meal), and phosphorus (mono- or dicalcium phosphate) used in animal feeds. When DDGS is added to properly formulated feeds, it results in excellent animal health, performance, and food product quality. These attributes, and others, have made DDGS one of the most popular feed ingredients for use in animal feeds around the world.

Ethanol Production and Its Co-Products – Dry-Grind and Wet Milling Processes –

Most ethanol plants in the United States are dry-grind facilities which use starch from corn to produce ethanol and the remainder of the corn kernel is used to produce a variety of wet and dried distillers grains co-products including DDGS. In dry-grind ethanol production, each bushel of corn (25.4 kg) produces about 11.8 liters of ethanol, 7.7 kg of DDGS, and carbon dioxide. Wet mills represent a significant, but smaller proportion of the U.S. ethanol industry and produce corn gluten feed, corn gluten meal, and corn germ meal as the primary co-products.

Ethanol Production and Its Co-Products – Front-End Fractionation and Back-End Oil Extraction Technologies –

Corn fractionation has been used for many years to produce specialized industrial and food grade products. A relatively small number of dry-grind ethanol plants implemented “front-end” fractionation technologies to separate the endosperm (starch rich fraction) from the non-fermentable fractions including the germ and bran. Several new corn co-products, including high-protein DDGS were produced using these technologies, but because of poor long-term economic viability of using these technologies, very few U.S. dry-grind ethanol plants are using “front-end” fractionation technologies today. However, recently “back-end” oil extraction technologies have become widely adopted by the majority of U.S. dry-

grind ethanol plants. In this process, approximately one-third of the corn oil is removed from thin stillage prior to producing a “reduced-oil” DDGS. The resulting DDGS from this process contains 7 to 9 percent crude fat, and has slightly more crude protein and fiber than DDGS produced without oil extraction. Limited scientific information has been published evaluating the impact of reduced-oil on energy content, but all of the currently available information on this topic is summarized for beef, dairy, poultry, and swine in Chapters 15,18, 20, and 22 of this Handbook.

Nutrient Composition and Digestibility of DDGS: Variability and *In Vitro* Measurement – The variability in nutrient content and digestibility among DDGS sources can be a challenge when determining economic and feeding value for livestock and poultry. However, new nutritional “tools” have been developed, including metabolizable energy (ME) prediction equations for DDGS in swine and poultry diets and equations as well as chemical procedures for estimating digestible amino acid content for poultry and swine. Some commercial companies have developed nutritional “tools” to rapidly, accurately and inexpensively estimate total and digestible nutrient content of specific DDGS sources.

Recommended Laboratory Analytical Procedures for DDGS – Laboratory analysis of feed ingredients, including DDGS, is important to verify that guaranteed nutritional specifications are met, determine nutrient composition for accurate feed formulation, and to determine the presence and concentration of any potential contaminants. Chapter 5 of this Handbook describes recommended analytical procedures to use when verifying contract specifications for moisture, crude protein, crude fat and crude fiber in DDGS. Recommend laboratory analysis procedures are also described for use in determining concentrations of several nutrients of importance in diet formulations as well as methods for determining the presence of potential contaminants such as mycotoxins.

Comparison of Different Grain DDGS Sources – Nutrient Composition and Animal Performance – A variety of feedstocks are used to produce ethanol and DDGS around the world. Grains, such as corn, wheat, and barley vary in starch content, and those with the greatest amount of starch (e.g. corn) are used to a greater extent because they provide the greatest ethanol yield. Since the nutrient composition of grains used to produce ethanol varies, the nutrient composition of the resulting distiller’s grains also varies and must be considered when using DDGS produced from different grains sources.

Physical and Chemical Characteristics Related to Handling and Storage of DDGS – Physical and chemical properties of DDGS vary among sources and can influence its feeding value, handling, and storage characteristics. These include color, smell, particle size, bulk density, pH, flowability, shelf-life stability, and hygroscopicity. Considerable research has been conducted during the past few years to measure various physical properties, particularly focused on flowability of DDGS. Moisture content of DDGS is important in order to minimize transportation costs, reduce flowability problems, and the risk of microbiological spoilage. Bulk density is an important factor in determining the storage volume of transport vehicles, vessels, containers, totes, and bags, as well as transport and storage costs.

Is Color the Only or Best Indicator of DDGS Quality? – Currently, there are no grading systems that define and regulate the quality standards for DDGS like those existing for corn and other grains exported from the U.S. Color of feed ingredients has historically been used as a subjective indicator of the amount of heat damage, and consequently amino acid digestibility. As a result, color has become a quality assessment factor for some DDGS buyers in the export market. Although a darker colored DDGS sample may indicate reduced amino acid digestibility for poultry and swine, it is not always the case. Many factors influence the color of DDGS, and other measurements of quality should be used in order to obtain an accurate assessment of DDGS quality.

Antibiotic Use in DDGS Production – Antibiotics have been used in relatively small quantities to control bacterial infections during fermentation in ethanol production for many years, and virginiamycin and penicillin have been most commonly used. The U.S. FDA has approved the use of virginiamycin in ethanol production, and the scientific evidence available indicates that there are no concerns for residues or risks to animal and human health. A recent survey conducted by the University of Minnesota shows that less than 1 percent of distillers grains samples had penicillin or tetracycline residues, no samples had tylosin residues, and 1.3 percent had detectable levels of virginiamycin residues, which were below the 1 ppm level of being Generally Recognized as Safe. Erythromycin residues were found in 10 percent of the 159 samples, but concentrations were less than 0.8 ppm. Only one sample from this survey showed some inhibition to a sentinel strain of *E. coli*, but that sample had no detectable concentrations of the 5 antibiotics tested. These results indicate that the prevalence and concentrations of antibiotic residues are very low, and residues appear to be inactivated during the DDGS production process. Therefore, DDGS continues to be a safe feed ingredient for use in all animal feeds.

Mycotoxins in DDGS – Like many grain-based feed ingredients, DDGS may contain amounts of mycotoxins that can negatively affect animal performance or be produced and stored under conditions that cause mold growth and mycotoxin production. Mycotoxins can be present in DDGS if the grain delivered to an ethanol plant is contaminated with them. Mycotoxins are not destroyed during the ethanol production process, nor are they destroyed during the drying process used to produce DDGS. If mycotoxins are present in corn, their concentration in DDGS will be increased by 3 times. However, the risk of mycotoxins in DDGS is very low because it is uncommon for most of the major corn producing region in the U.S. to have adverse weather and climatic conditions that lead to mycotoxin production in corn. Furthermore, most ethanol plants monitor grain quality and reject corn sources that are contaminated with mycotoxins. Only approved mycotoxin testing procedures should be used when determining the presence and concentration of mycotoxins in DDGS.

Mycotoxin Situation with the 2011 U.S. Corn Crop and 2012 DDGS Production – In 2011, a few states (Ohio, Michigan, Indiana, and Nebraska) in the U.S. Corn Belt had corn growing and harvesting weather conditions conducive to vomitoxin production. Although DDGS produced in these states may have higher concentrations of vomitoxin than DDGS produced in other Midwestern U.S. states, the majority of DDGS produced in 2012 will contain less than 1

ppm vomitoxin. Some DDGS samples produced in 2012 may also contain zearalenone, aflatoxins, and T-2 toxin, but the frequency and concentrations will be low.

Sulfur Concerns and Benefits in DDGS – When excess sulfur (greater than 0.40 percent of diet dry matter) is present in ruminant diets neurological problems caused by polioencephalomalacia can occur. Sulfur is reduced to hydrogen sulfide by rumen bacteria and accumulates in the rumen causing toxicity. Some DDGS sources contain high concentrations of sulfur, and if DDGS is fed at a high dietary inclusion rate, depending on the sulfur concentrations in other dietary ingredients and water, polioencephalomalacia can occur. Supplementation of ruminant diets with copper or thiamine may alleviate this problem if high sulfur diets are fed. However, recent research conducted at the University of Minnesota has shown that high sulfur content in DDGS fed to pigs protects against oxidized oil, found occasionally in DDGS sources, by increasing sulfur-containing antioxidants in pigs.

Use of DDGS in Beef Cattle Diets – Corn DDGS is an excellent energy and protein source for beef cattle in all phases of production. It has 102 percent to 127 percent the energy value of dry-rolled corn and can be effectively used as an energy source and fed up to 40 percent of ration dry matter intake for finishing cattle with excellent growth performance and carcass and meat quality. However, at this high DDGS feeding rate, cattle will consume excess protein and phosphorus. The best applications for using DDGS in beef cow diets are in situations where 1) supplemental protein is needed (especially when feeding low quality forages) to replace corn gluten feed or soybean meal, 2) a low starch, high fiber energy source is needed to replace corn gluten feed or soy hulls, and 3) when a source of supplemental fat is needed. For growing heifers, adding urea to meet the degradable protein intake requirement is not necessary when DDGS is used as an energy source in forage based diets. DDGS can be an effective forage supplement to increase growth at times when availability of forage may be limited for growing heifers.

Use of Reduced-Oil DDGS in Beef Cattle Diets – One study has been conducted at the University of Nebraska to evaluate feeding diets containing 35 percent (dry matter basis) reduced-oil wet distillers grains with solubles (6.7percent crude fat) compared to wet distillers grains containing 12.9 percent crude fat. Feeding the reduced-oil distillers grains reduced growth rate and feed conversion compared to cattle fed the 12.9 percent wet distillers grains diet. Although the energy value (NEg) is reduced by 1.3 percent for each 1 percent reduction in oil content, reduced-oil DDGS had an energy value equal to corn and is still an excellent energy source for beef feedlot cattle.

Is There a Connection Between Feeding DDGS and E. coli O157:H7 Shedding in Beef Cattle? – Consumption of ground beef is the most frequently implicated cause of E. coli O157:H7 outbreaks in humans and food products from cattle have been linked to 75 percent of these outbreaks. Some feedstuffs appear to alter the shedding levels of E. coli O157:H7, but these effects have not been consistently shown. Fasting and feeding poor quality forages have been shown to increase shedding of E. coli O157:H7 in cattle, but abruptly switching cattle from a high grain diet to a high quality hay-based diets has been shown to reduce E. coli O157:H7 populations. Currently, there is no scientific evidence that indicates that feeding DDGS causes E. coli O157:H7 contamination in ground beef. If there is a possible connection between

feeding cattle DDGS and increased shedding of *E. coli* O157:H7, the mechanism has not been identified.

Use of DDGS in Dairy Cattle Diets – Corn DDGS can be included in dairy cow diets up to 20 percent of the diet without decreasing dry matter intake, milk production, and percentage milk fat and protein. Adding 20 to 30 percent DDGS to a lactating cow diet also results in milk production being equal to, or greater than when diets containing no DDGS are fed. Milk fat percentage varies among various studies, but was not significantly changed by the inclusion of distiller's grains in the diet. Milk protein percentage is decreased when more than 30 percent DDGS is added to the diet. When formulating diets containing DDGS for lactating dairy cows, consideration should be given to type of forage, forage to concentrate ratio, crude fat content of DDGS, and the need for supplemental crystalline lysine to achieve optimal performance. Corn DDGS can be effectively used in a total mixed ration by lactating dairy cows under heat-stressed climatic conditions making it a valuable feed ingredient for use in dairy rations in sub-tropical and tropical regions of the world. Although there has been limited research to evaluate feeding DDGS to growing dairy heifers, diets containing up to 40 percent DDGS have been used to achieve excellent growth rate and feed conversion in growing beef cattle rations.

Use of Reduced-Oil DDGS in Dairy Cattle Diets – One study has been conducted to evaluate the effects of feeding reduced-oil DDGS (3.5 percent crude fat) on milk production and composition of lactating dairy cows. Researchers at South Dakota State University fed diets containing 0, 10, 20, or 30 percent reduced-oil DDGS (replacing soybean meal) to cows and found no effect of increasing levels of reduced-oil DDGS on dry matter intake, crude protein intake, or milk production. Milk production efficiency, milk fat percentage, milk fat yield, and total milk solids increased linearly. Milk protein percentage responded quadratically and no effects were observed for efficiency of nitrogen utilization and milk protein yield when increasing levels of reduced-oil DDGS were fed. These results indicated that feeding a very low oil DDGS source had some positive effects with no negative effects on lactation performance of dairy cows.

Use of DDGS in Poultry Diets – Corn DDGS is an excellent feed ingredient for use in layer, broiler, duck, and turkey diets and contains approximately 85 percent of the energy value of corn for poultry. Conservatively, DDGS can be added at 5 to 8 percent of starter diets for broilers and turkeys, and 12 to 15 percent of diets for layers and growing-finishing diets for broilers, ducks, and turkeys when diets are not formulated on a digestible amino acid basis, and achieve excellent performance and egg and meat quality. Recent research studies have shown that DDGS can be added to poultry diets at even higher dietary inclusion rates (25 percent for layers and broilers) to achieve excellent performance and egg and meat quality provided that accurate nutrient profiles specific to the DDGS source are used, and diets are formulated on a digestible amino acid basis.

Use of Reduced-Oil DDGS in Poultry Diets – One study has been conducted at Auburn University to estimate the AME_n content of a variety of corn co-products with variable nutrient content including crude fat concentrations. The following energy prediction equation can be used to estimate the energy content of reduced-oil DDGS for broilers: AME_n (kcal/kg of dry matter) = 3,517 – (33.27 x % hemicellulose, dry matter basis) + (46.02 x % crude fat, DM basis)

– (82.47 x % ash, DM basis). No performance, egg, or meat quality studies have been published related to feeding reduced-oil DDGS to poultry.

Use of DDGS in Swine Diets – Corn DDGS is an excellent for use in swine diets in all phases of production. Maximum recommended dietary DDGS inclusion rates to support excellent performance are up to 30 percent for nursery pigs weighing more than 7 kg, growing-finishing pigs, and lactating sows, and levels of up to 50 percent of the diet for gestating sows. These recommendations are based on the assumption that diets are formulated on a digestible amino acid basis. Feeding diets containing more than 20 percent DDGS causes pork fat to become less firm. Therefore, depending on pork fat quality standards in a given country, some markets may require feeding no more than 20 percent DDGS throughout the grower-finisher phase, or withdrawing it from the diet 3 to 4 weeks before harvest to achieve desired pork fat quality.

Use of Reduced-Oil DDGS in Swine Diets – One study has been conducted at the University of Minnesota to determine the relationship between crude fat and metabolizable energy (ME) content of DDGS, as well as develop prediction equations to estimate ME content using key nutrient fractions from chemical analysis. Results from this study showed a very poor relationship between crude fat and ME content of DDGS ranging from 5 to 13 percent crude fat (dry matter basis). Fiber content (measured as neutral detergent fiber-NDF, acid detergent fiber-ADF, or total dietary fiber-TDF) and gross energy (GE) content of reduced-oil DDGS are more important factors that determine ME content. The following equations can be used to accurately estimate ME content in DDGS regardless of crude fat content:

$$\text{ME kcal/kg DM} = 1,352 + (0.757 \times \text{GE kcal/kg}) - (51.4 \times \% \text{TDF})$$

$$\text{ME kcal/kg DM} = 4,440 - (68.3 \times \% \text{ADF})$$

$$\text{ME kcal/kg DM} = 3,711 - (21.9 \times \% \text{NDF}) + (48.7 \times \% \text{Crude fat})$$

Managing Pork Fat Quality When Feeding High Amounts of DDGS to Growing-Finishing Pigs – It is well established that the amount and composition of fatty acids in a grower-finisher swine diet directly affects the fatty acid composition and firmness of pork fat. Pork fat firmness is an important overall characteristic of pork quality and affects shelf-life, flavor, processing characteristics, and consumer acceptance. Feeding corn-soybean meal diets containing increasing dietary levels of DDGS linearly reduces pork fat firmness because of the high concentration of polyunsaturated fatty acids in the corn oil present in DDGS. In countries where pork fat quality is a concern, no more than 20 percent DDGS should be included in grower-finisher swine diets. Alternatively, higher (> 20 percent) dietary DDGS inclusion rates can be used if 1) DDGS is removed from the diet 3 to 4 weeks before harvest, 2) reduced-oil DDGS is used, 3) diets are formulated based on iodine value product, and 4) barley and/or wheat are used as the predominant grain sources in grower-finisher diets containing DDGS.

Use of Enzymes in DDGS Diets for Poultry and Swine – Most of the starch is removed from corn during ethanol production resulting in concentrated levels of protein, oil, fiber, and minerals in DDGS. Poultry and swine can only utilize moderate amounts of dietary fiber for energy, but DDGS contains more gross energy than corn. Therefore, there is considerable interest in using carbohydrase enzymes to improve the energy value of DDGS for poultry and swine. Most commercial enzyme products have been targeted toward poultry and swine and

can be effective in diets containing small grains other than corn. However, in corn-based diets, the addition of commercial carbohydrases and proteases has resulted in inconsistent or no improvements in energy and nutrient digestibility. Poultry tend to derive more consistent benefits from carbohydrases than swine, presumably because of differences in digesta viscosity between the two different types of gastrointestinal tracts. Addition of phytase enzymes to DDGS diets have little added benefit of improving phosphorus digestibility in DDGS, but dramatically improve phosphorus digestibility in other ingredients such as corn and soybean meal.

Use of DDGS in Aquaculture Diets – Aquaculture is one of the fastest growing food producing industries in the world. Traditionally, fish meal has been used as the predominant protein source in most aquaculture diets, but high cost and reduced supply availability have caused fish nutritionists to use less expensive plant-based protein sources like DDGS. As a result, there is increasing interest in using DDGS in aquaculture diets around the world due to its moderately high protein content, relatively low phosphorus content, and low cost compared to fish meal. Furthermore, DDGS does not contain anti-nutritional factors found in other protein sources such as soybean meal (trypsin inhibitors) or cottonseed meal (gossypol). Limited studies have been conducted to evaluate the addition of DDGS to catfish, rainbow trout, tilapia, sunshine bass, Pacific white shrimp, and freshwater prawns. Adding 10 percent DDGS to all aquaculture feeds can result in excellent performance, and DDGS levels up to 20 to 30 percent can also result in excellent performance if adequate additions of some crystalline amino acids (e.g. lysine, methionine, tryptophan) are added, or other complementary protein sources containing higher levels of amino acids are included in fish feeds.

Use of DDGS in Sheep and Goat Diets – While limited studies have been conducted to evaluate the effects of feeding DDGS to sheep and goats compared with other species, DDGS is an economical and excellent feed ingredient in diets for sheep and goats. The high fiber and low starch content of DDGS provides diet formulation flexibility and allows it to safely partially replace a portion of the forage or grain in diets with reduced risk of rumen acidosis compared to feeding grain-based diets. Dried distillers grains with solubles can be an excellent protein and energy supplement for ewes and growing-finishing lambs to replace a portion of the corn and soybean meal in the diet. Like cattle, sulfur content of the diet should be monitored and managed, especially when feeding high levels of DDGS with moderate to high sulfur levels. Conservatively, adding DDGS at a level of 20 percent of growing-finishing lamb diets and 25 percent of lactating ewe diets will provide good performance results, although some studies have shown that DDGS can be added at levels up to 50 percent of the ration of growing-finishing lambs without affecting growth performance or carcass quality.

Use of DDGS in Horse and Companion Animal Diets – Very little research has been conducted related to feeding diets containing DDGS to horses and other companion animals. However, because of the increasing supply and availability of high quality and relatively low cost U.S. DDGS produced today, it is becoming a more popular ingredient for use in horse feeds and commercial pet foods. Based upon the limited research information available, it appears DDGS is a very suitable ingredient at inclusion rates up to 20 percent of the diet for horses, rabbits, and dogs.

Impact of Diet Formulation Methods and Tools on Assessing Value of DDGS –

One of the challenges of obtaining the best economic and nutritional value from U.S. DDGS is to know actual nutrient content and digestibility of the DDGS source being used. Several DDGS value calculator tools have been developed to determine DDGS feeding value for livestock and poultry. These tools are extremely useful for determining the actual economic value of DDGS in specific livestock and poultry diets. They should be used when evaluating whether the current price for DDGS is economical relative to its nutrient contributions and price relative to other competing ingredients. Depending on the nutrient composition of the DDGS source being used, and the diet formulation methods chosen, the relative economic and nutritional value of DDGS can vary substantially. Using accurate energy, amino acid, and phosphorus digestibility values for DDGS can reduce excessive feeding of nutrients, avoid nutrient deficiencies, and reduce diet costs while supporting optimal animal performance.

Factors that Affect DDGS Pricing and Transportation Logistics –

One of the biggest factors for determining whether DDGS is an economical animal feed ingredient in the international market is the cost of transportation and logistics to import DDGS. A number of factors can affect DDGS pricing including: 1) U.S. demand for DDGS, 2) price of corn and soybean meal, 3) availability of supply for export, 4) seasonality of domestic DDGS consumption, 5) fluctuating transportation costs, and 5) import tariffs imposed by many countries. DDGS price follows the corn market more closely than the soybean meal market. Overall trends in both the corn and soybean meal markets affect the DDGS price, but daily volatility in the corn or soybean meal market on the Chicago Board of Trade does not always translate into daily volatility in the DDGS market. Ocean freight rates have varied dramatically over the past 5 years. The high volatility in charter vessel freight has a major impact on the cost of obtaining DDGS for international customers. The United States is currently the world's largest container importer, and shipping DDGS via containers is an excellent option for the discriminating buyer who is looking to purchase DDGS from a limited number of sources or ethanol plants. It is essential that DDGS importers know and trust their supplier. Importers should understand the exporting company's logistical and transportation capabilities. Freight spreads change. Exporters that have facilities and capabilities via multiple transit ways (Great Lakes, major rivers, Gulf of Mexico, Pacific Northwest) have a better ability to serve the export market around the globe. Purchasing DDGS at the lowest freight costs will require working with companies that have multiple transportation and loading options and flexibility.

Summary of U.S. Grains Council Sponsored International DDGS Feeding Trials –

The effects of feeding U.S. DDGS to livestock, poultry, and fish have been evaluated by feed industry leaders and animal production companies from many countries. Feeding trials sponsored by the U.S. Grains Council have been conducted in Australia, Indonesia, Japan, Korea, Mexico, Taiwan, Thailand, and Vietnam. Results from these feeding trials involving various food animal species, using common diets found in these countries, have consistently shown positive performance and cost savings benefits of adding DDGS to animal feeds.

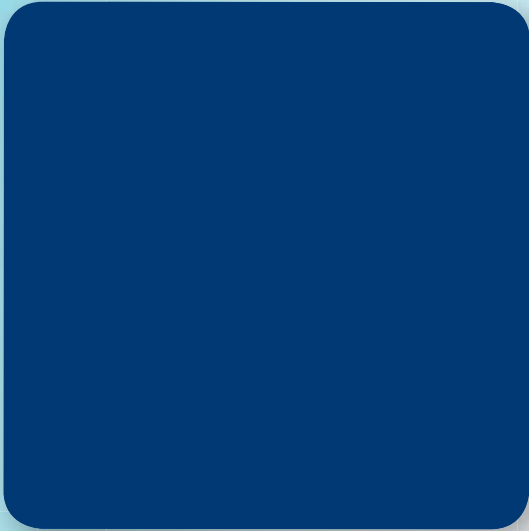
U.S. Suppliers of DDGS –

There are over 36 experienced U.S. DDGS exporters listed in Chapter 32 of this Handbook who have DDGS supply available, transportation and logistics capabilities, and are eager to provide pricing information to current and potential DDGS

customers around the world. Contact anyone of them for current prices and information about their capabilities to meet your DDGS supply needs.

CHAPTER 1

Introduction to U.S. DDGS



Chapter 1

Introduction to U.S. DDGS – An Excellent Ingredient for Use in Animal Feeds

This 3rd Edition of the *U.S. Grains Council DDGS User Handbook* was developed to provide nutritionists, feed ingredient purchasers, feed manufacturers, and animal producers with the most up to date, scientifically based information available related to distiller's dried grains with solubles (DDGS). The Handbook includes:

- Detailed information on the production process, as well as new processes affecting nutrient composition of corn distillers co-products, which affect nutrient content, digestibility, and variability among sources. An added feature of this updated Handbook is inclusion of new studies relating to low fat DDGS;
- Comparisons of corn DDGS to other grain sources used to produce DDGS;
- Physical characteristics of DDGS and recommended laboratory analysis methods for evaluating quality and nutrient content;
- Comprehensive summaries of research information related to establishing maximum recommended dietary inclusion rates to achieve optimal animal performance for dairy and beef cattle, sheep and goats, swine, poultry, fish and companion animals; and
- Results from U.S. Grains Council sponsored DDGS feeding trials conducted in many countries around the world are also included.

By providing this comprehensive scientific review of DDGS information, we hope that it will give new and existing DDGS users the knowledge and understanding to provide a high level of confidence when purchasing and using this high quality feeding ingredient to obtain the best nutritional and economic value in animal feeds.



Recent record high feed ingredient prices around the world have caused animal nutritionists to search for lower cost alternative feed ingredients to minimize the cost of food animal production. **U.S. DDGS is an excellent, lower cost alternative feed ingredient that continues to be produced in large quantities by the dry-grind fuel ethanol industry.** The high energy, protein, and phosphorus content of DDGS make it a very attractive partial replacement for some of the more expensive traditional energy (corn), protein (soybean meal), and phosphorus (mono- or dicalcium phosphate) ingredients used in animal feeds. When DDGS is added to animal feeds that are properly formulated, it provides excellent animal health, performance, and food product quality. These attributes, and others, have made DDGS one of the most popular feed ingredients to use in animal feeds around the world.

Due to the large supply of U.S. DDGS currently being produced, the quantity available for export has also increased in recent years. Likewise, the demand for U.S. DDGS has increased dramatically because end-users have obtained diet cost saving and many other positive benefits of using DDGS in animal feeds. Yet for many nutritionists, feed manufacturers, and animal producers around the world, DDGS is considered to be a new and unfamiliar feed ingredient. As with any new feed ingredient introduced to the market, there are many technical questions about the benefits and limitations to use DDGS successfully. Generally, the topics of most interest to DDGS end-users include: variability in nutrient content and digestibility among sources, physical characteristics (e.g. color, particle size, effects on pellet quality), dietary inclusion rates for various animals, effects on animal performance, and feed safety. All of these topics and more are discussed in detail in this revised *U.S. Grains Council DDGS User Handbook – 3rd Edition*.

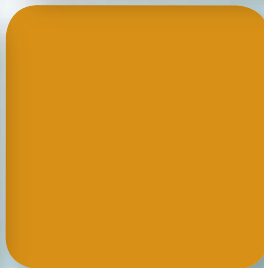
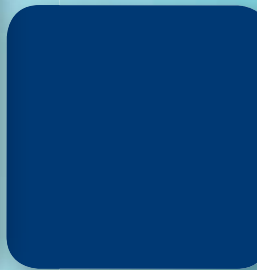
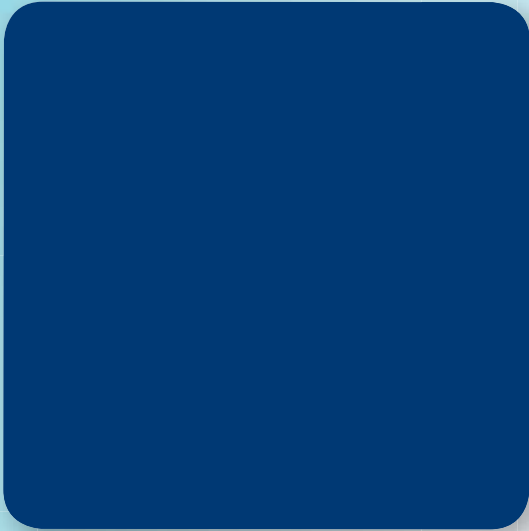
The U.S. Grains Council (USGC) provides this comprehensive summary of nutritional information about DDGS to assist current and potential buyers in understanding its nutritional characteristics, recommended maximum dietary inclusion rates, and benefits and limitations for its use in animal feeds. As for any feed ingredient, end users of DDGS should consult, and seek assistance and advice from a qualified nutritionist when formulating diets and developing feeding recommendations. The USGC has no control over the nutritional content of any specific ingredient that may be selected for feeding. The USGC makes no warranties that these recommendations are suitable for any particular herd, flock, or animal. The USGC disclaims any liability for itself or its members for any problems encountered in the use of these recommendations. By reviewing this material, buyers agree to these limitations and waive any claims against USGC for liability arising out of this information.

For more information, please contact the U.S. Grains Council at 202-789-0789 or email grains@grains.org. You may also visit our website at www.grains.org.



CHAPTER 2

Ethanol Production and Its Co-Products – Dry-Grind and Wet Milling Processes



Chapter 2

Ethanol Production and its Co-Products Dry-Grind and Wet Milling Processes

Introduction

This chapter described the basic principles of ethanol production in order to provide a better understanding of the nutritional characteristics and feeding value of the corn co-products produced by the fuel ethanol industry.

Conversion of Glucose to Ethanol

In the U.S., corn is the predominant source of starch (glucose) used to produce ethanol. With the exception of sugar cane, corn provides the highest ethanol yields compared to any other feedstock being used (**Table 2**). However, research is underway to develop methods to convert carbohydrates from cellulosic feedstocks such as softwood (Arwa et al., 2005), non-starch polysaccharides (Arthur, 2006), as well as using sugar beets (Savvides et al., 2000) to glucose for use in producing ethanol. The nutrient composition of the feedstock used to produce ethanol determines the nutrient profile of the distiller's co-products produced.

Table 2. Starch content and ethanol yield of various feedstocks.

Feedstock	Moisture (%)	Starch (%)	Ethanol Yield (L/MT)
Starch	-	100.0	720
Sugar cane	-	-	654
Barley	9.7	67.1	399
Corn	13.8	71.8	408
Oats	10.9	44.7	262
Wheat	10.9	63.8	375

Source: Saskatchewan Agriculture and Food (1993).

The energetic efficiency of converting glucose to ethanol is about 51.4%, while 48.6% is attributed to the production of carbon dioxide. The efficiency of producing ethanol from moisture-free starch is about 56.7%.

Dry-grind Ethanol Production

Particle size reduction of grain

As shown in **Figure 3**, the initial step in ethanol production using dry-grind technology is to reduce the particle size of corn by grinding it with a hammer mill. Hammer mills crush the corn grain by high speed, rotating hammer tips. The fineness of the ground corn is determined mainly by the rotor volume, hammer tip speed, number of hammers, and the screen opening size (Dupin et al., 1997). The screens used in the hammermill are normally in the range of 3 to 5 mm in diameter. Particle size of the grain can affect ethanol yield (Kelsall and Lyons, 1999), and therefore, ethanol producers tend to use finely ground corn to maximize ethanol yield. As shown in **Table 3**, an extra 0.20 gallons (0.85 liters) of ethanol can be produced if the corn is ground through a 5mm screen compared to an 8 mm screen.

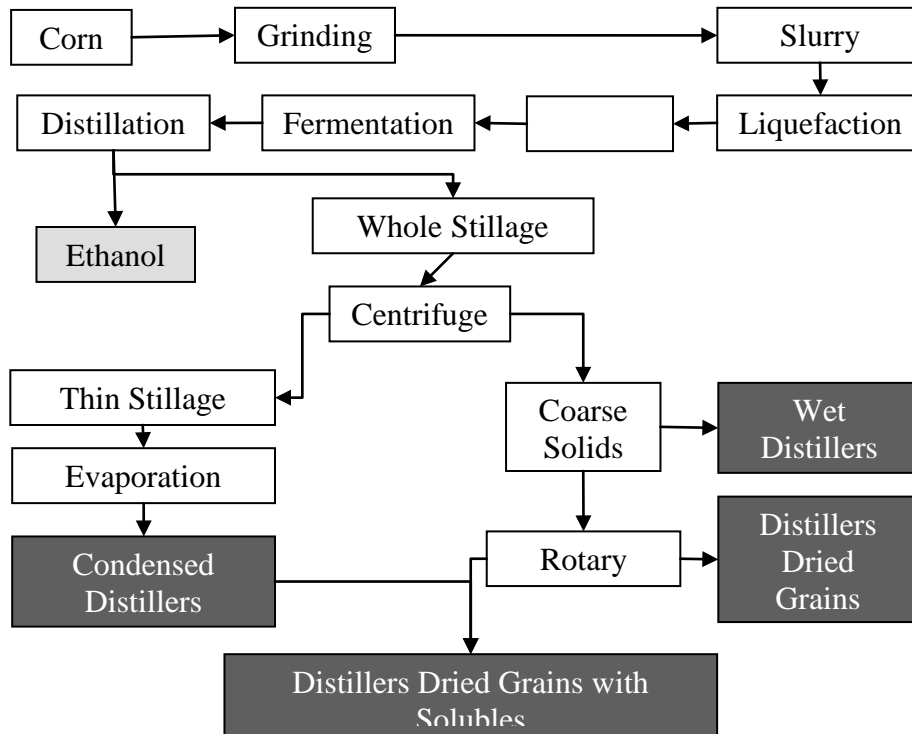


Figure 3. Dry-grind ethanol production processes and by-products
(Erickson et al., 2005)

Table 3. Ethanol yield from ground corn of different particle size.¹

Particle Size	Ethanol Yield (gallons/bushel)
Fine grind corn, 5 mm screen	2.65
Coarse grind corn, 8 mm screen	2.45

¹ Kelsall and Lyons, 1999.

Cooking and saccharification

Water and recycled stillage are added to the ground corn, which act as conditioners to begin leaching of soluble protein, sugars, and non-starch bound lipids (Chen et al. 1999). Cooking is then used to hydrolyze starch into glucose along with the addition of amylolytic enzymes in order for yeast (*Saccharomyces cerevisiae*) to convert glucose to ethanol. Temperatures typically used during the cooking process are 40-60°C in the pre-mixing tank, 90-165°C for cooking, and 60°C for liquefaction (Kelsall and Lyons, 1999). Gelatinization of starch starts to occur between 50 and 70°C. A critical step in converting starch to glucose involves the completeness of starch gelatinization (Lin and Tanaka, 2006). During gelatinization, nearly all of the amylose in the starch granules is leached out (Han and Hamaker, 2001), which increases viscosity due to swollen granules and gels consisting of solubilized amylose (Hermansson and Kidman, 1995).

Complete hydrolysis of the starch polymer requires a combination of enzymes. Amylases are the most widely used, thermostable enzymes in the starch industry (Sarikaya et al., 2000). These include α -amylases or glucoamylase (Poonam and Dalel, 1995). Enzymes must be thermostable in order for starch hydrolysis to occur immediately after gelatinization. Enzyme use accounts for about 10-20% of the ethanol production cost (Gregg et al., 1998).

Some ethanol plants use batch cooking systems whereas others use continuous cooking systems (Kelsall and Lyons, 1999). In a batch cooking system, a known quantity of corn meal is mixed with a known quantity of water and recycled stillage. In the continuous cooking process, corn meal, water, and recycled stillage are continuously added into a premix tank. The temperature of the premix tank is maintained just below that needed for gelatinization, and the mash is continuously pumped through a jet cooker. The temperature of the cooker is set at 120°C. From the cooker, the mash passes into the top of a vertical column, and moves down the column in about 20 minutes, it is then passed into a flash chamber for liquefaction at 80-90°C. High temperature-tolerant amylase is added at 0.05-0.08% w/w cereal to bring about liquefaction. The retention time in the liquefaction/flash chamber is about 30 minutes. The pH of the system is controlled to be within 6.0-6.5. Batch systems use less enzymes compared to continuous systems and are also more energy efficient. The main disadvantage of batch systems is reduced productivity or feedstock utilization per unit of time.

Fermentation

Fermentation is the process where yeast convert sugars to alcohol. The most commonly used yeast is *Saccharomyces cerevisiae* (Pretorius, 2000) because it can produce ethanol to a

concentration as high as 18% in the fermentation broth. *Saccharomyces* is also generally recognized as safe (GRAS) as a food additive for human consumption (Lin and Tanaka, 2006). In ideal fermentation, about 95% of sugar is converted to ethanol and carbon dioxide, 1% is converted into cellular matter of the yeast cells, and 4% is converted into other products such as glycerol (Boulton et al., 1996). Yeast use accounts for about 10% of the ethanol production cost (Wingren et al., 2003).

Pre-fermentation is used to achieve the desired number of yeast cells for fermentation and is a process that involves agitation for 10-12 hours to achieve 300 to 500 million cells/ml. Fermentation takes place at a temperature of about 33°C (Thomas et al., 1996), at a pH of about 4.0 (Neish and Blackwood, 1951), and lasts between 48-72 hours (Ingledew, 1998). In addition to ethanol, carbon dioxide is produced and can either be collected or is released into the air.

The control of normal yeast growth is a key factor in efficient ethanol production. The activity of the yeasts is highly dependent on the temperature of the fermentation system. Torija et al. (2003) reported that the optimum temperature for reproduction and fermentation in yeast is 28 and 32°C, respectively. Fermentation efficiency of *S. cerevisiae* at high temperatures (above 35°C) is low (Banat et al., 1998). Therefore, a cooling mechanism is required in fermentation systems.

One challenge of managing fermenters in an ethanol plant is preventing contamination with other microbes. Microbial contamination causes reduced ethanol yield and ethanol plant productivity (Barbour and Priest, 1988). The most common organisms associated with microbial contamination are lactobacilli and wild yeasts. These microbes compete with *Saccharomyces cerevisiae* for nutrients (trace minerals, vitamins, glucose, and free amino nitrogen) and produce inhibitory end-products such as acetic and/or lactic acid. *Dekkera/Brettanomyces* wild yeasts have become a concern in fuel alcohol production (Abbott and Ingledew, 2005). A reduction in lactic acid bacterial contamination is currently achieved by using antibiotics in fuel ethanol plants (Narendranath and Power, 2005).

Distillation of ethanol

After fermentation, ethanol is collected using distillation columns. Ethanol collected from the fermenters is contaminated with water, and is purified using a molecular sieve system to remove the water and produce pure ethanol.

Corn oil extraction

Crude corn oil can be produced at corn ethanol plants by extracting the oil from the thin stillage portion of the DDGS production process (CEPA, 2011). Corn oil extraction from thin stillage occurs after fermentation and distillation, and before the drying to produce DDGS. Corn oil extraction systems have been added to existing ethanol plants to increase the energy efficiency of the plant as well as increase the total amount of fuel that is produced per metric tonne of corn processed. The installation of corn oil extraction equipment in an existing ethanol plant

facilitates the production of a biodiesel feedstock without affecting ethanol production volumes. Different corn oil extraction technologies are available commercially to the ethanol industry.

Most of the ethanol industry is using a “Step 1” extraction process where corn oil is extracted from thin stillage after it is removed from the whole stillage using centrifugation (CEPA, 2011). The resulting partially concentrated thin stillage is heated and the corn oil is extracted by a second centrifuge. Heat exchangers use steam to raise the temperature of the thin stillage to facilitate extraction, so that after corn oil is extracted, thermal energy from the stillage is recovered in heat exchangers to heat the incoming stillage.

Thin stillage contains approximately 30% of the oil available in the corn, of which most can be recovered using this “Step 1” process, depending on individual ethanol plant conditions (CEPA, 2011). In general, a typical ethanol plant uses corn that contains approximately 4% corn oil (weight basis) which ends up in DDGS if oil extraction is not used. For example, a dry-grind ethanol plant with an annual production capacity of 190 million liters can recover 5.7 million liters of corn oil per year.

The “Step 2” process has not yet been implemented in most U.S. ethanol plants, but is an additional extraction process that can capture an additional 30% of the corn oil that is bound in the whole stillage prior to the centrifuge separation of the wet grains and thin stillage (CEPA, 2011). Since more than 40% of the total oil in corn is trapped within the wet cake, the wet cake is “washed” to liberate this oil so that it can be extracted in the “Step 1” system. The additional oil made available to the “Step 1” extraction process generally doubles the production of corn oil. Therefore, the combination of using both “Step 1” and “Step 2” processes, 60 to 70% of the corn oil present in the distiller’s co-products can be extracted. As a result, these technologies allow the extraction of 23 to 27 liters of corn oil for every 380 liters of ethanol produced.

For every 3.8 liters of ethanol produced, 2.4 kg of DDGS is produced without the use of corn oil extraction (CEPA, 2011). However, with corn oil extraction, DDGS yield is reduced by approximately 0.06 kg per liter of ethanol produced, representing a 9.4% reduction in DDGS yield. Removal of corn oil affects the nutritional profile of the DDGS, primarily by reducing the fat and energy content, and increasing the protein concentration. For some food animal species such as swine, poultry, and fish, high fat and energy content of DDGS is very important, whereas dairy and beef cattle can use the reduced-oil DDGS more effectively. Refer to **Chapters 15, 18, 20, and 22** for more information about the effects of feeding reduced-oil DDGS to beef cattle, dairy cattle, poultry, and swine, respectively.

Co-product production

The water and solids remaining after distillation of ethanol are called whole stillage. Whole stillage is comprised primarily of water, fiber, protein, and fat. This mixture is centrifuged to separate coarse solids from liquid. The liquid, called thin stillage, goes through an evaporator to remove additional moisture resulting in condensed distiller’s solubles (syrup) which contains approximately 30% dry matter. Condensed distillers solubles can be sold locally to cattle feeders or combined with the coarse solids fraction and dried to produce dried distiller’s grains

with solubles. The coarse solids are also called wet cake and contain about 35% dry matter. Wet cake can be sold to local cattle feeders without drying, dried to produce dried distiller's grains, or mixed with condensed distiller's solubles and dried to produce distillers dried grains with solubles (88% dry matter).

Wet Milling

Unlike dry-grind ethanol plants that ferment the entire ground corn kernel, wet mills separate the corn kernel into various fractions, which allows for the production of multiple food and industrial products including ethanol. The corn wet milling industry was developed in the early 19th century with the primary purpose of producing starch for use in food and laundry products (Kerr, 1950). In the 1920's wet mills began producing crystalline dextrose (Newkirk, 1923), and after World War II, began producing ethanol. In the early 1990's, wet mills began producing high fructose corn syrup in addition to other products. A majority of wet mill plants have been built in the last few decades (Johnson and May, 2003). An overview of the wet milling process is shown in **Figure 4**.

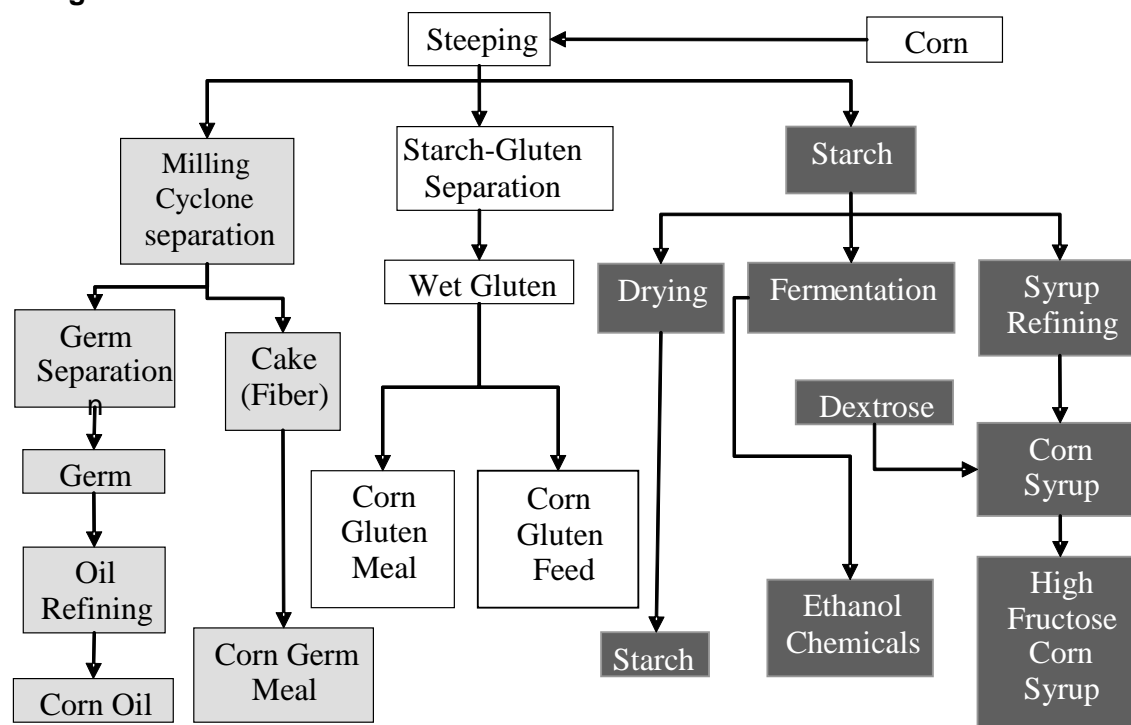


Figure 4. Wet milling processes and by-products

(Erickson et al., 2005)

Grain cleaning

Corn is initially cleaned to remove broken kernels, chaff, pieces of cobs, and foreign material. This process is important because broken kernels can release starch in steep water, which can gelatinize leading to undesirable viscosity during evaporation of steep water into steep liquor (May, 1987).

Steeping

Steeping involves soaking of the corn kernels under the controlled temperature (48-50°C), time (35-50 hours), concentration of SO₂ (0.1-0.2%), and lactic acid (Watson, 1984). Water acts as a conditioner so that milling can be performed under optimal conditions (Bass, 1988). Steeping aids in softening the corn kernel for milling, inhibits microbial growth, and enhances pure starch recovery (Bartling, 1940).

Milling

After soaking, the corn germ becomes soft and rubbery. Hydrocyclones with counter rotating discs and intermeshing fingers tear apart the corn kernels and separate the germ (May, 1987). Since the germ is lighter in weight than the rest of corn kernel it can be easily separated by centrifugal force. Once removed, the germ is purified to remove starch and protein extracts by washing with water. Oil is then extracted from the germ to produce corn oil.

Fiber is separated by pumping the slurry (starch, gluten, fiber, and kernel fragments) with considerable force on 120° wedge-wire screen. Fiber particles are large in shape and are screened out to leave starch and protein.

Gluten is separated by high speed centrifuges due to the fact that protein is lighter in weight compared to starch (May, 1987). Gluten is then thickened in centrifuges, dewatered to contain 42% solids by vacuum filtration, and dried to 88% solids for sale as corn gluten meal (Jackson and Shandera, 1995).

Starch processing

Impurities, in the form of proteins, are removed by washing the starch in fresh water using a countercurrent process in the centrifuges. The purified starch contains less than 0.4% protein with less than 0.01% free protein (May, 1987). The protein that is removed consists primarily of starch-protein complexes that are recycled back to the primary separation step. Purified starch can then be dried, fermented to produce ethanol, or refined to produce corn syrup. The procedure used to produce ethanol from starch in wet mills is similar to that previously described for dry-grind ethanol plants.

Co-product production

Corn steep liquor is a high-energy liquid feed ingredient. It contains about 25% crude protein on a 50% dry matter basis. This product is sometimes combined with corn gluten feed, or may be sold separately as a liquid protein source for beef or dairy rations. It also can be used as a pellet binder and is a source of B-vitamins and minerals.

Corn germ meal contains 20% protein, 2% fat, and 9.5% fiber. It has an amino acid balance that makes it valuable in poultry and swine diets.

Corn gluten feed is a medium protein ingredient composed of the bran and fibrous portions of the corn kernel. It may, or may not, contain the condensed corn extractives. This by-product can be sold as a wet or dry feed ingredient. The bran and condensed extractives (sometimes called germ meal) are combined and dried in a rotary dryer. The dried corn gluten feed is made into pellets to facilitate handling. It typically contains about 21% protein, 2.5% fat, and 8% fiber. Wet corn gluten feed (45% dry matter) is perishable in 6-10 days and must be fed within that time period or stored in an anaerobic environment. Corn gluten feed is primarily used in dairy and beef cattle rations.

Corn gluten meal is a high protein concentrate, which typically contains 60% protein, 2.5% fat, and 1% fiber. It is a valuable source of methionine. Corn gluten meal also has a high level of xanthophylls, which makes it an attractive ingredient in poultry diets as a source of yellow pigment.

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CHAPTER 3

Ethanol Production and Its Co-Products - Front-End Fractionation and Back-End Oil Extraction Technologies



Chapter 3

Ethanol Production and its Co-Products

Front-End Fractionation and Back-End Oil Extraction Technologies

Introduction

Although the majority of corn co-products produced by the dry-grind ethanol industry are dried distiller's grains with solubles, limited quantities of new corn co-products are being produced, most notably high-protein DDG. Interest by the U.S. ethanol industry in implementing front-end fractionation technologies has decreased dramatically from a few years ago, and this can be attributed to the high capital investment required and disappointing improvements in ethanol production efficiency. There are several reasons why fractionation technologies were being considered a few years ago in the U.S. ethanol industry. Some of these reasons include increased ethanol yield, less enzyme use during fermentation, lower production of co-product mass that requires drying, reduced drying costs and heat damage to proteins in co-products, less energy and water use, reduced need for frequent cleaning of the system to remove oil, ability to market or use the corn oil for other high value applications, and increased number of fractionated co-products to potentially add value and create new markets for corn co-products. Unfortunately, many of these potential advantages were never realized.

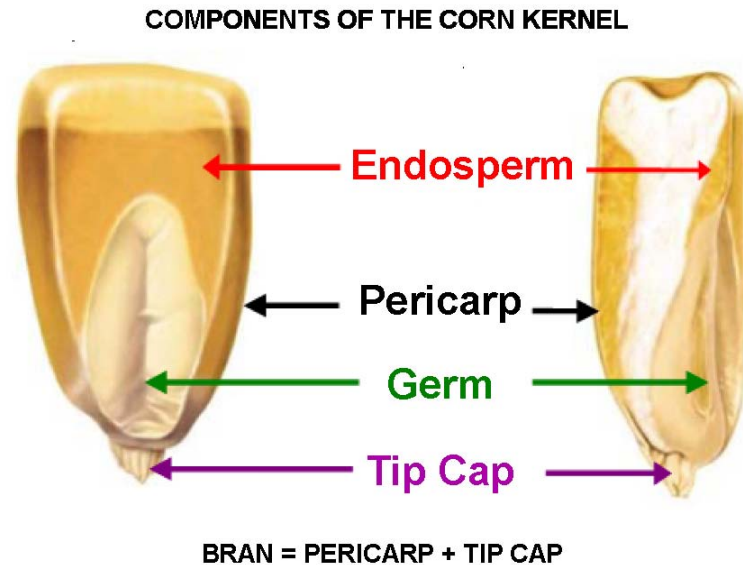
Therefore, almost all of the front-end fractionation technologies described in this chapter are not currently being used. It is uncertain if these technologies, and the new corn co-products produced from these processes, will be considered again in the future. Therefore, the purpose of this chapter is to provide an understanding of the wide array of front-end and back-end ethanol and distillers co-product technology that has been developed, and the research that has begun to determine the potential use of these co-products in animal feeds.

Overview of Front-End Fractionation and Back-End Oil Extraction

Fractionation involves separating the corn kernel into three components; the endosperm, germ, and bran (tip and pericarp). The endosperm represents about 83% of the corn kernel and is primarily composed of starch, whereas the germ (about 12% of the kernel) is high in oil, protein, ash, and non-fermentable carbohydrates. The remaining bran portion is almost exclusively composed of fiber (non-fermentable carbohydrates).

Front-end fractionation involves separating the endosperm, germ, and bran fractions before fermentation. The endosperm fraction (rich in starch) is fermented to produce ethanol and a corn co-product. Corn oil is extracted from the germ fraction and marketed or utilized for various industrial applications, leaving a corn germ meal as a feed co-product. The bran fraction is also separated and used as a high fiber feed primarily for ruminants.

In contrast to front-end fractionation, back-end oil extraction has become the most popular new technology in the U.S. ethanol industry, where more than 50% of ethanol plants are extracting corn oil. Most of the ethanol industry is using a “Step 1” extraction process where corn oil is extracted from thin stillage after it is removed from the whole stillage using centrifugation (CEPA, 2011). The resulting partially concentrated thin stillage is heated and the corn oil is



extracted by a second centrifuge. Heat exchangers use steam to raise the temperature of the thin stillage to facilitate extraction, so that after corn oil is extracted, thermal energy from the stillage is recovered in heat exchangers to heat the incoming stillage.

Thin stillage contains approximately 30% of the oil available in the corn, of which most can be recovered using this “Step 1” process, depending on individual ethanol plant conditions (CEPA, 2011). In general, a typical ethanol plant uses corn that contains approximately 4% corn oil (weight basis) which ends up in DDGS if oil extraction is not used. For example, a dry-grind ethanol plant with an annual production capacity of 190 million liters can recover 5.7 million liters of corn oil per year.

The “Step 2” process has not yet been implemented in most U.S. ethanol plants, but is an additional extraction process that can capture an additional 30% of the corn oil that is bound in the whole stillage prior to the centrifuge separation of the wet grains and thin stillage (CEPA, 2011). Since more than 40% of the total oil in corn is trapped within the wet cake, the wet cake is “washed” to liberate this oil so that it can be extracted in the “Step 1” system. The additional oil made available to the “Step 1” extraction process generally doubles the production of corn oil. Therefore, the combination of using both “Step 1” and “Step 2” processes, 60 to 70% of the corn oil present in the distiller’s co-products can be extracted. As a result, these technologies allow the extraction of 23 to 27 liters of corn oil for every 380 liters of ethanol produced.

For every 3.8 liters of ethanol produced, 2.4 kg of DDGS is produced without the use of corn oil extraction (CEPA, 2011). However, with corn oil extraction, DDGS yield is reduced by approximately 0.06 kg per liter of ethanol produced, representing a 9.4% reduction in DDGS yield. Removal of corn oil affects the nutritional profile of the DDGS, primarily by reducing the

fat and energy content, and increasing the protein concentration. Refer to **Chapters 15, 18, 20, and 22** for more information about the effects of feeding reduced-oil DDGS to beef cattle, dairy cattle, poultry, and swine, respectively.

There are a number of fractionation and oil extraction technologies being developed and evaluated, but they have not been widely implemented for ethanol and co-product production. The following are examples of the types of technologies being researched and developed to improve ethanol yield, resulting in a variety of co-products with different nutrient composition that will eventually be available for feed use:

1. Efforts to improve the efficiency of fermentation and ethanol production of corn
 - a) adding proteases in addition to carbohydrases (Wang et al., 2009)
 - b) comparison of raw starch hydrolyzing enzyme with conventional liquefaction and saccharification enzymes (Wang et al., 2007)
 - c) use of endogenous liquefaction enzymes (Singh et al., 2006)
 - d) comparison of enzymatic (E-Mill) and conventional dry-grind corn processes using a granular starch hydrolyzing enzyme (Wang et al., 2005)
2. Pre-treatments and fermentation of DDGS components to increase ethanol yield
 - a) pre-treatment protein separation (Brehmer et al., 2008)
 - b) pre-treatment and enzymatic hydrolysis (Perkis et al., 2008)
 - c) fermentation of DDGS hydrolysates to solvents and value-added products by solventogenic clostridia (Ezeji and Blaschek, 2008)
 - d) use of hot water and ammonia to expand fiber components in DDGS (Dien et al., 2008; Kim et al., 2008a, b; Lau et al., 2008)
 - e) water solubilization of DDGS using phosphate esters (Oshel et al., 2008)
 - f) use of solid-state fermentation products grown on DDGS (Hoskins and Lyons, 2009)
3. Fiber separation to enhance ethanol yield
 - a) from DDG and DDGS (Srinivasan et al., 2005, 2007a,b, 2008 a,b, 2009; Srinivasan and Singh, 2006;)
 - b) decortication (Corredor et al., 2006)
 - c) quick germ, quick fiber, and enzymatic milling comparisons with the conventional dry-grind corn process (Singh et al., 2005)
 - d) dry de-germ and de-fiber to separate germ and pericarp fiber of corn prior to fermentation of the endosperm fraction fermentation, and lipid removal (Murthy et al., 2006)
4. Oil extraction efficiencies
 - a) corn processing methods (Wang et al., 2009)
 - b) supercritical CO₂ and hexane extraction of lipids from DDGS (Wang et al., 2008; 2007)



- c) *in situ* transesterification for the production of fatty acid esters from DDGS (Haas et al., 2007)
- 5. Integrated production of ethanol and biodiesel from DDGS (Balan et al., 2009)
- 6. Zein extraction from DDGS (Xu et al., 2007)

Nutrient Composition of New Corn Co-products

Because fractionation is a new and emerging technology in fuel ethanol production, there are limited nutrient composition data for the resulting co-products. Dry matter, crude protein, crude fat, crude fiber, and ash concentrations for most of the known fractionated co-products are shown in **Table 1**.

Table 1. Nutrient composition of new, fractionated corn distiller's co-products (dry matter basis).

Company co-product	Dry matter, %	Crude protein, %	Crude fat, %	Crude fiber, %	Ash, %
Typical corn DDGS	89.3	30.9	10.7	7.2	6.0
Poet Dakota Gold HP	91.6	44.8	3.9	7.3	2.1
Poet Dakota Bran	ND ¹	14.6	9.8	3.8	4.6
Poet Dehydrated Corn Germ	93.2	16.9	18.9	5.5	5.8
Maize Processing Innovators Quick Germ/Quick Fiber DDGS	ND	49.3	3.9	6.8	3.2
Maize Processing Innovators E-Mill DDGS	ND	58.5	4.5	2.0	3.2
Cereal Process Technologies Hi-Protein DDGS	ND	35.0-37.0	4.0-6.0	4.0-6.0	ND
Renssen Enhanced DDGS	ND	40.0-50.0	2.5-4.0	7.0-11.0	ND
Solaris NeutraGerm	97.0	17.5	45.0	6.0	1.9
Solaris Probran	90.0	9.5	2.0	16.6	1.0
Solaris Glutenol	90.0	45.0	3.3	3.8	4.0
Solaris Energia	90.0	30.0	2.5	8.2	2.5
FWS Technologies Enhanced DDGS	ND	35.0-37.0	6.5	ND	3.8
De-Oiled DDGS	89.9	31.3	2.3	ND	6.2
J. Jireh Products Dried Condensed Solubles	93.4	21.6	4.7	3.1	8.3

¹ ND = not determined.

In general, most fractionated corn co-products are higher in crude protein and crude fiber than DDGS, and are lower in crude fat. Although the amino acid concentration may slightly increase in many of the high protein fractionated co-products, the protein quality (amino acid balance) is still poor relative to the requirements of monogastric animals. The reduced fat and increased fiber content of these fractions may result in lower energy value for swine and poultry. Therefore, their feeding and economic value may be reduced compared to DDGS for swine, poultry, and aquaculture. However, based on the nutrient composition of these co-products,

they would generally have greater value in ruminant diets because the amino acid balance of corn protein is not as critical in ruminant diets as it is in swine, poultry, and aquaculture diets. Furthermore, the increased amount of readily fermentable fiber can provide a good source of energy for ruminants, and the lower fat content may allow higher dietary inclusion rates for lactating dairy cows and reduce concerns of milk fat depression at high feeding levels.

Nutrient Digestibility of Selected New Corn Co-products

References for scientific publications with results from feeding new, fractionated corn co-products to various livestock and poultry species are summarized in **Table 2**. The majority of these studies have evaluated nutrient content and digestibility, but not maximum dietary inclusion rates or determined their effects on animal performance.

Table 2. Summary of published studies involving feeding new fractionated corn co-products to livestock and poultry.

Species	HP-DDG	De-oiled DDG	Corn Germ	Corn Bran	Other
Beef feedlot cattle				Bremer et al. (2006) Berger and Singh (2009)	Partial DDGS fractionation (Deppenbusch et al., 2008)
Lactating dairy cows	Kelzer et al. (2007) Mjoun et al. (2009b)	Mjoun et al. (2009a, b)	Kelzer et al. (2007) Abdelqader et al., (2006)	Kelzer et al. (2007) Janicek et al. (2007)	
Growing-finishing swine	Widmer et al. (2007) Widmer et al. (2008) Gutierrez et al. (2009a,b) Anderson et al. (2009)	Anderson et al. (2009)	Widmer et al. (2007) Widmer et al. (2008) Anderson et al. (2009)	Anderson et al. (2009)	Yeast product-Stein et al. (2005) Dried condensed soluble and dehydrated, degermed corn co-products -Anderson et al. (2009) Helembai et al. (2006)
Broilers	Batal (2007) Kim et al. (2008)		Batal (2007) Kim et al. (2008)	Batal (2007)	
Layers	Batal (2007) Kim et al. (2008)		Batal (2007) Kim et al. (2008)	Batal (2007)	
Turkeys	Batal (2007) Kim et al. (2008)		Batal (2007) Kim et al. (2008)	Batal (2007)	High protein hydrolyzed corn co-product (Abe et al., 2004)

Poultry

A high protein hydrolyzed corn co-product obtained from the National Renewable Energy Laboratory was evaluated for nutrient content and digestibility, and its feeding value in turkey starter diets (Abe et al., 2004). Dry matter, ash, fat, fiber, protein, starch, and sugar content were 95.9, 1.43, 10.7, 3.9, 57.8, 1.6, and 2.0%, respectively. The lysine, arginine, tryptophan, threonine, cystine, and methionine content as a % of crude protein were 1.99, 2.63, 0.34, 3.14, 2.1% respectively, and digestibility coefficients were 68.1, 79.0, 64.0, 75.2, 78.3, and 85.9%, respectively. The nitrogen-corrected true metabolizable energy (TME_n) was 2,692 kcal/kg (as-fed basis). When 0, 5, 10, 15, and 20% of this co-product were added to the diets and fed from 3 to 18 days of age, there was a linear decrease in ADG at day 11, and a cubic effect from day 11 to 18. These results suggest that up to 10% of this co-product can be used effectively up to day 14, and higher inclusion rates may provide satisfactory growth for turkeys older than two weeks.

Batal (2007) determined the nutrient digestibility of DDGS, high protein corn distillers dried grains with solubles (HP-DDGS), dehydrated corn germ and corn bran for poultry (**Table 3**). These results indicate that new fractionation technologies used in ethanol production result in co-products that have unique nutritional properties and knowledge of their nutritional value is essential in order to assess their economic and feeding value.

Table 3. Nutrient content and digestibility of DDGS, HP-DDGS, dehydrated corn germ, and corn bran for poultry.¹

Nutrient	DDGS	HP-DDGS	Dehydrated corn germ	Bran cake
Crude protein, %	27.0	44.0	15.5	11.6
Crude fiber, %	7.0	7.0	4.5	4.5
Crude fat, %	10.0	3.0	17.0	7.8
TME _n , kcal/kg	2,829	2,700	2,965	2,912
Lysine, %	0.79	1.03	0.83	0.43
Lysine availability, %	81	72	80	68
Lysine as a % of CP	2.9	2.3	5.4	3.7
Phosphorus, %	0.77	0.35	1.18	No data
P bioavailability, %	60	47	31	No data

¹ Batal, 2007.

High protein DDGS (33% protein, 0.33% phosphorus on a 90% dry matter basis) and corn germ meal (14% crude protein and 1.22% phosphorus) were fed to chicks and precision-fed roosters to determine nitrogen-corrected TME_n, amino acid digestibility, and phosphorus bioavailability for poultry (Kim et al., 2008). The TME_n and amino acid digestibility in corn germ meal was significantly higher compared to HP-DDGS, while P bioavailability was similar between DDGS and HP-DDGS (60 vs. 58%, respectively), but lower for corn germ meal (25%). These results suggest that corn germ meal is a better source of energy with higher amino acids digestibility than HP-DDGS, but DDGS and HP-DDGS are better sources of bioavailable phosphorus than corn germ meal for poultry.

Rochelle et al. (2011) used stepwise regression analysis to develop a prediction equation to estimate AME_n from a using nutrient composition data and *in vivo* AME_n from a diverse collection of corn co-products. AME_n can be predicted ($R^2 = 0.89$, SEM =191, P < 0.01) as follows:

$$\text{AME}_n \text{ (kcal/kg of dry matter)} = 3,517 - (33.27 \times \% \text{ hemicellulose, dry matter basis}) + (46.02 \times \% \text{ crude fat, DM basis}) - (82.47 \times \% \text{ ash, DM basis})$$

Swine

Widmer et al. (2007) conducted three experiments to determine energy, phosphorus, and amino acid digestibility in HP-DDG and corn germ, compared with corn. The digestible and metabolizable energy content of corn on a DM basis (4,056 and 3,972 kcal/kg, respectively) was similar to that of corn germ (3,979 and 3,866 kcal/kg, respectively), but were surprisingly lower than HP-DDG (4,763 and 4,476 kcal/kg, respectively). True total tract digestibility of phosphorus was higher in HP-DDG (69%) compared to corn germ (34%), and similar to values obtained by Kim et al. (2008) in poultry. Standardized ileal digestibility for crude protein and all amino acids except arginine, lysine, glycine, and proline were higher in HP-DDG than in corn germ. Therefore, HP-DDG appears to have higher levels of digestible energy, phosphorus and most amino acids than corn germ for swine.

Stein et al. (2005) conducted two studies to determine the digestibility of energy, crude protein, and amino acids from a yeast product extracted from ethanol co-product streams. The concentration of digestible and metabolizable energy in the yeast product was 5,600 and 5,350 kcal/kg of DM, respectively, which is 138 to 134% of the value found in corn (4,071 and 3,992 kcal/kg, respectively). The standardized ileal digestibility coefficients were also high for crude protein (74.8%), lysine (82.2%), methionine (88.6%), threonine (71.1%), tryptophan (82.2%), isoleucine (79.5%), leucine (84.0%) and valine (74.5%). These



results suggest that this yeast product can be an excellent source of energy and digestible amino acids in swine diets.

Helembai et al. (2006) evaluated the apparent digestibility of nutrient and nitrogen retention of corn gluten feed, DDGS, and yeast hydrolysate-based NuPro in growing pigs. Apparent digestibility of crude protein (82.7%) and nitrogen retention (53.3%) was highest in NuPro at the 20% dietary inclusion level. Crude protein digestibility of DDGS was 75.8% and a lower nitrogen retention (44.03%), whereas the crude protein digestibility of corn gluten feed was high (82.9%), but the nitrogen retention was low (24.9%). Crude fat apparent digestibility was similar in all three corn co-products (68.0, 67.4 and 68.1%, respectively). Despite differences in nitrogen retention, all of these co-products had high apparent digestible nitrogen-free extract (85.2, 81.4 and 82.2%, respectively) and organic matter (86.4, 80.6 and 82.6%, respectively) and are highly digestible.

In a recent study, Anderson et al. (2012) evaluated several corn co-products (**Table 4**), which varied substantially in nutrient content, to determine their DE and ME content for finishing pigs. Ingredients evaluated included those low in fiber (starch, oil, dried solubles, and dehulled, degermed corn), DDGS (n = 7), high in protein (HP-DDG; n = 3, and corn gluten meal), and high in fiber (bran, n = 2; corn germ meal, n = 2; and corn gluten feed). Most ingredients were obtained from various dry-grind ethanol plants with the exception of gluten meal, gluten feed, and one source of corn germ meal, which were obtained from corn wet milling plants. One feedstuff, dehulled, degermed corn is a co-product from a fractionated dry-grind process.

Table 4. Sources of corn co-products used to determine DE and ME for finishing pigs.¹

Feedstuff	Vendor
Corn gluten feed	Tate & Lyle, Ft. Dodge, IA
Corn bran	ICM/Lifeline Foods, St. Joseph, MO
Corn bran w/solubles	Poet Biorefining, Glenville, MN
DDGS	Ace Ethanol, Racine, WI
DDGS – drum dry	Cellencor, Heron Lake, MN
DDGS – microwave dry	Cellencor, Heron Lake, MN
DDGS	Hawkeye Renewables, Iowa Falls, IA
DDGS- Dakota Gold BPX	Poet Biorefining, Groton, SD
DDGS	VeraSun Energy Corporation, Aurora, SD
DDGS – oil extracted	VeraSun Energy Corporation, Aurora, SD
Corn gluten meal	Archer Daniels Midland, Cedar Rapids, IA
HP-DDG	ICM/Lifeline Foods, St. Joseph, MO
HP-DDG	MOR Technology, Cape Girardeau, MO
HP-DDG	Poet Biorefining, Coon Rapids, IA
Corn germ, dehydrated	Poet, Coon Rapids, IA
Corn germ meal	Cargill, Eddyville, IA
Corn dried distillers solubles	Pulse Combustion Systems, Payson, AZ
Dehulled, degermed corn	Bunge North America, Atchison, KS
Corn starch	Archer Daniels Midland, Clinton, IA
Corn oil	Mazola, ACH Food Co., Memphis, TN

¹ Anderson, 2009.

The variable nutrient composition of the corn co-products is shown in **Table 5**. Corn starch and oil were included in the study to serve as reference standards to determine ME, however, they were not included in chemical analysis. All values were calculated on a DM basis. The nutrient concentrations ranged from 8.3 to 66.3%, 0.5 to 100%, 0.08 to 11.5%, 2.6 to 53.6%, 2.3 to 61.1%, 0.5 to 25.4%, 0.8 to 22.6%, 0.3 to 3.5%, 0.5 to 14.1% for crude protein, starch, crude fiber, total dietary fiber (TDF), neutral detergent fiber (NDF), acid detergent fiber (ADF), cellulose, lignin, and crude fat, respectively.

As expected, the ME content varied substantially among corn co-products (**Table 6**). The low fiber co-products (starch, oil, dried solubles and dehulled, degermed corn) differed in ME from 4,080 to 8,755 kcal/kg DM, respectively. The seven DDGS samples differed in ME from 3,414 to 4,141 kcal/kg DM, respectively. The high protein co-products (corn gluten meal and three sources of HP-DDG) ranged in ME from 3,676 to 4,606 kcal/kg DM for HP-DDG (ICM) and HP-DDG (MOR), respectively. The remaining fibrous feedstuffs (two sources of bran and germ meal, and one source of corn gluten feed) ranged from 2,334 to 3,692 kcal/kg DM.

Stepwise regression analysis using chemical composition of feed ingredients was used to develop prediction equations for ME. The equation was significant ($P < 0.01$) and provided a good estimate ($r^2 = 0.95$) for estimating actual ME of the corn co-products evaluated in this study. Gross energy had a positive effect on the estimate for ME while TDF and ash had negative effects on estimating ME content.



Table 5. Nutrient composition of corn co-products.^{1,2}

DM BASIS	DDGS (WI)	DDGS (IA)	DDGS (Verasun)	RO-DDGS (Verasun)	DDGS (BPX)	DDGS (MNdm)	DDGS (MNmc)	Dried solubles	Corn gluten feed
Bulk density, g/cm ³	0.581	0.470	0.487	0.494	0.467	0.530	0.396	0.330	0.499
Particle size, microns	1054	784	579	480	330	568	866	WNP	571
Moisture	6.82	9.75	13.41	12.64	10.87	11.43	12.95	22.3	4.14
OM digestibility	74.22	62.25	64.7	57.14	65.43	63.85	62.97	93.48	60.99
Gross energy	5314	5375	5434	5076	5547	5550	5502	54.76	4539
Crude protein	29.62	29.65	31.94	34.74	29.49	32.69	34.12	23.75	24.29
Alanine	2.07	2.09	2.38	2.48	2.09	2.38	2.47	1.47	1.52
Arginine	1.33	1.46	1.49	1.44	1.37	1.47	1.55	1.20	1.13
Aspartic acid	1.87	1.96	2.11	2.19	1.93	2.24	2.22	1.48	1.45
Cysteine	0.53	0.57	0.60	0.61	0.59	0.64	0.61	0.39	0.52
Glutamic acid	4.41	4.50	5.20	5.43	4.70	5.11	5.33	2.79	3.70
Glycine	1.18	1.24	1.34	1.39	1.22	1.38	1.38	1.26	1.03
Histidine	0.77	0.83	0.90	0.89	0.82	0.90	0.94	0.60	0.72
Isoleucine	1.06	1.14	1.19	1.25	1.11	1.23	1.29	0.68	0.70
Leucine	3.47	3.45	3.90	4.12	3.37	3.88	4.08	1.58	2.03
Lysine	1.03	1.21	1.19	1.00	1.10	1.20	1.29	1.09	0.67
Methionine	0.56	0.58	0.65	0.64	0.54	0.64	0.65	0.32	0.30
Phenylalanine	1.29	1.61	1.48	1.51	1.31	1.48	1.55	0.53	0.77
Proline	2.08	2.23	2.52	2.54	2.29	2.44	2.57	1.29	1.87
Serine	1.37	1.32	1.52	1.58	1.30	1.47	1.53	0.90	0.88
Threonine	1.11	1.10	1.22	1.26	1.09	1.25	1.26	0.81	0.78
Tryptophan	0.21	0.19	0.20	0.18	0.21	0.23	0.23	0.21	0.13
Tyrosine	1.04	1.17	1.19	1.22	1.05	1.16	1.22	0.62	0.65
Valine	1.49	1.57	1.69	1.76	1.53	1.73	1.80	1.08	1.11
Starch	7.85	3.47	6.24	3.04	4.94	2.12	1.05	6.34	12.57
Crude fiber	7.05	7.76	7.56	8.69	7.95	7.93	8.35	0.08	8.56
Total dietary fiber	30.34	38.14	35.69	37.20	35.90	35.38	43.18	16.07	40.07
NDF	34.61	40.13	40.12	50.96	33.41	44.87	49.12	2.33	42.66
ADF	11.25	10.55	14.42	15.82	8.62	13.16	14.66	0.49	9.90
Cellulose	10.64	10.12	11.72	12.72	8.21	11.95	13.37	0.79	9.17
Lignin	1.21	1.06	3.16	3.49	1.00	1.72	1.92	0.31	1.05
Crude fat	11.45	10.89	10.16	3.15	11.71	12.10	11.98	11.81	2.70
Ash	4.16	4.43	4.46	5.16	5.41	4.55	4.04	14.08	6.81
Calcium(mg/kg)	204	248	475	652	663	240	230	1699	683
Copper (mg/kg)	6	6	5	8	6	5	5	9	8
Iron (mg/kg)	81	72	125	288	90	104	132	129	125
Magnesium (mg/kg)	3485	3023	3456	3986	3710	3736	3125	11389	5192
Manganese (mg/kg)	21	13	16	23	15	20	18	40	34
Phosphorus (mg/kg)	7913	8582	7527	8373	9613	8377	7394	24356	11979
Potassium (mg/kg)	11465	10974	10069	11232	13140	11758	10172	38597	19862
Selenium (mg/kg)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Sodium (mg/kg)	172	1287	2414	3776	2659	1361	1324	4259	364
Sulfur (mg/kg)	8475	7940	7616	9772	11087	7288	6982	18069	4907
Zinc (mg/kg)	63	55	59	67	89	82	75	95	120

¹ Identity of individual feedstuffs described in Table 1. BDL = below detection limit and WNP = would not pass. All values based on DM basis except particle size and bulk densities which are based on as-is basis. Values on a percentage basis unless listed otherwise.

² Anderson, 2009.

Table 5 (continued). Nutrient composition of corn co-products.^{1,2}

DM BASIS	DH-DG corn	corn germ dehydrated	corn germ meal	corn bran (ICM)	corn bran (Poet)	corn gluten meal	HP-DDG (MOR)	HP-DDG (Poet)	HP-DDG (ICM)
Bulk density, g/cm ³	0.687	0.435	0.465	0.158	0.346	0.677	0.636	0.576	0.604
Particle size, microns	477	1175	483	1841	2166	577	471	587	783
Moisture	12.78	9.44	10.87	12.62	9.18	8.51	8.3	5.95	12.31
OM digestibility	93.15	75.54	56.98	32.32	73.32	79.95	61.46	71.54	54.36
Gross energy	4397	5224	4767	4847	4982	5467	58.11	53.21	5464
Crude protein	8.28	17.54	23.64	10.94	15.17	66.30	57.45	43.83	39.98
Alanine	0.66	1.05	1.41	0.78	1.04	5.54	4.65	3.49	2.92
Arginine	0.28	1.31	1.67	0.65	0.77	2.38	2.26	1.63	1.68
Aspartic acid	0.48	1.35	1.68	0.81	1.02	4.23	3.75	2.82	2.44
Cysteine	0.17	0.34	0.37	0.22	0.30	1.08	1.13	0.81	0.74
Glutamic acid	1.74	2.47	3.22	1.67	1.95	13.51	10.88	7.88	6.84
Glycine	0.25	0.91	1.31	0.55	0.77	1.93	1.93	1.51	1.46
Histidine	0.22	0.51	0.72	0.31	0.44	1.41	1.36	1.17	1.07
Isoleucine	0.31	0.53	0.84	0.38	0.50	2.83	2.33	1.86	1.53
Leucine	1.25	1.27	1.91	1.10	1.30	10.67	8.57	6.37	5.12
Lysine	0.17	0.97	1.17	0.58	0.62	1.39	1.58	1.33	1.20
Methionine	0.16	0.28	0.42	0.18	0.23	1.41	1.44	0.94	0.81
Phenylalanine	0.45	0.66	1.02	0.50	0.55	4.14	3.13	2.37	1.96
Proline	0.77	1.07	1.20	0.82	1.08	5.59	4.77	3.79	3.06
Serine	0.39	0.68	1.00	0.53	0.65	2.91	2.86	2.02	1.68
Threonine	0.26	0.57	0.88	0.50	0.61	2.12	2.14	1.61	1.33
Tryptophan	0.06	0.17	0.20	0.06	0.09	0.24	0.29	0.14	0.19
Tyrosine	0.25	0.53	0.71	0.37	0.41	3.16	2.61	1.77	1.46
Valine	0.38	0.86	1.37	0.56	0.76	3.18	2.88	2.32	2.02
Starch	87.96	25.00	15.29	23.25	25.73	11.08	0.51	7.30	5.10
Crude fiber	0.60	4.87	10.69	11.54	4.80	1.44	8.14	9.42	7.87
Total dietary fiber	2.61	24.78	47.76	53.60	26.65	9.24	28.80	31.28	36.75
NDF	4.27	27.37	61.05	56.86	25.21	12.25	43.52	32.00	51.09
ADF	0.49	6.13	12.49	13.14	5.35	7.57	25.42	12.61	15.11
Cellulose	0.77	5.21	11.71	12.78	5.38	5.95	22.55	12.05	14.25
Lignin	0.33	1.28	1.22	0.89	0.55	2.24	3.40	0.95	1.44
Crude fat	0.17	18.45	2.38	5.14	9.68	1.34	4.12	2.86	6.97
Ash	0.49	6.46	2.70	2.33	5.31	3.99	1.10	2.05	2.09
Calcium (mg/kg)	13	159	359	164	314	6408	173	114	78
Copper (mg/kg)	1	7	36	5	5	18	6	4	4
Iron (mg/kg)	15	90	122	54	98	242	102	53	61
Magnesium (mg/kg)	268	5626	1905	1675	3277	1039	456	1110	936
Manganese (mg/kg)	1	22	11	15	17	25	17	6	5
Phosphorus (mg/kg)	879	15187	6496	4379	7578	6318	2486	4185	5029
Potassium (mg/kg)	1449	16593	4093	6464	13682	4596	1700	4389	3028
Selenium (mg/kg)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Sodium (mg/kg)	115	83	839	63	4270	1029	231	1260	563
Sulfur (mg/kg)	1048	2141	3274	1460	9506	9051	7178	9034	7002
Zinc (mg/kg)	5	85	77	39	195	42	71	28	37

¹ Identity of individual feedstuffs described in Table 1. BDL = below detection limit. All values based on DM basis except particle size and bulk densities which are based on as-is basis. Values on a percentage basis unless listed otherwise.

² Anderson, 2009.

Table 6. Digestible and metabolizable energy values of corn co-products in finishing pigs.¹

Corn Co-product	Energy, kcal/kg	
	DE ³	ME ³
Gluten feed	2517	2334
Bran (ICM)	3004	2957
Bran (Poet)	3282	3031
DDGS (ACE)	4332	4141
DDGS (MNdrum)	4116	3876
DDGS (MNmicro)	4016	3713
DDGS (Hawk)	3841	3659
DDGS (Poet)	3705	3414
DDGS (VS)	4164	3937
RO-DDGS (VS)	3868	3650
Gluten meal	5047	4598
HP-DDG (ICM)	3994	3676
HP-DDG (MOR)	4955	4606
HP-DDG (Poet)	4210	3823
DCG (Poet)	3889	3692
Germ meal	3521	3417
Solubles (20%)	4762	4525
DH-DG corn	4401	4316
Starch	4082	4080
Oil (10%)	8988	8755
Mean	4250	4028
SD	362.5	413.0

Stepwise regression analysis using chemical composition of feed ingredients was used to develop prediction equations for ME (**Table 7**). The equation was significant ($P < 0.01$) and provided a good estimate ($r^2 = 0.95$) for estimating actual ME of the corn co-products evaluated in this study. Gross energy had a positive effect on the estimate for ME while TDF and ash had negative effects on the estimating ME content.

Table 7. Equation for predicting ME from chemical analysis of corn co-products in finishing pigs.

Equation ¹	R ²	SE	P-value
ME = 0.949 × GE – 32.238 × TDF – 40.175 × Ash	0.95	306	< 0.01

¹ ME = kcal/kg DM; GE = kcal/kg DM; TDF = %; Ash = %.

Dairy

Kelzer et al. (2007) conducted a study to determine protein fractions and evaluate differences in rumen undegradable protein (RUP), RUP digestibility (dRUP), and amino acid concentrations in corn germ, corn bran, HP-DDGS, two sources of DDG, wet corn gluten feed, and wet distillers grains. A comparison of the nutrient concentrations in these corn co-products are shown in **Table 8**. Concentrations of RUP, dRUP, lysine, and methionine were different among corn milling co-product sources.

Table 8. Comparison of protein fraction concentrations as a % of crude protein among seven corn co-products.¹

Protein Fraction, % CP	Corn Germ	Corn Bran	High Protein DDGS	DDGS 1	DDGS 2	Wet Corn Gluten Feed	Wet Distillers Grains
Crude protein, % DM	16.3	13.5	47.2	30.1	28.9	26.7	29.9
Non-protein nitrogen	30.0	33.5	7.4	17.0	17.9	36.6	18.6
Rapidly degradable true protein	15.0	4.0	0.6	7.0	2.1	15.9	2.4
Moderately degradable true protein	38.1	54.3	82.4	67.0	41.0	33.2	53.1
Slowly degradable true protein	13.5	6.0	8.8	4.8	11.1	10.1	11.0
Undegraded true protein	3.4	2.2	0.8	4.2	27.9	4.1	14.9
Rumen undegraded protein	16.5	20.7	55.2	33.2	56.3	11.5	44.7
RUP digestibility	66.8	65.8	97.7	92.0	91.9	51.0	93.1
Lysine	2.9	3.2	2.0	1.9	1.9	3.5	1.9
Methionine	1.9	1.4	3.2	2.0	2.4	1.6	2.3

¹ Kelzer et al., 2007.

Beef

Bremer et al. (2006) evaluated a low protein corn co-product (Dakota Bran Cake – DBRAN) on feedlot performance and carcass characteristics for finishing cattle. Results from this study showed that feeding DBRAN up to 45% of the diet improves growth performance with no effects on carcass characteristics and it has approximately 100 to 108% the energy value of corn.

Feeding Value of New, Fractionated Corn Co-Products to Livestock and Poultry

Because most new fractionation technologies have not been fully implemented and are being evaluated, limited quantities of fractionated corn co-products are being produced and available commercially. As a result, there are limited published data on the efficiency and quality of these fractionated corn co-products in livestock and poultry feeds. Until such data is available, it is difficult to determine their comparative feeding value, dietary inclusion rates, and comparative nutritional and economic values.

Table 9 shows a summary of the maximum dietary inclusion rates of some fractionated corn co-products based on results from only a few animal feeding trials designed to determine animal growth/milk production responses.

Table 9. Maximum dietary inclusion rates of selected corn co-products for various species based on animal performance trials.

	Dairy	Beef	Swine	Poultry
HP-DDG	NA	NA	20%-30%	NA
De-oiled DDG	NA	NA	NA	NA
Corn bran	25%	45%	NA	NA
Corn germ	14%	NA	10%	NA

NA = not available.

Poultry

No performance trials have been conducted to evaluate the effects of feeding corn bran, corn germ, HP-DDGS, and de-oiled DDGS on growth performance of broilers and turkeys, and egg production of layers. Without this information, we assume no change in bird performance when calculating displacement ratios for these ingredients.

Swine

One study (Widmer et al., 2008) evaluated the effects of feeding DDGS (10 or 20% of the diet), HP DDG (replaced 50 or 100% of soybean meal), and corn germ (5 or 10% of the diet) to growing-finishing pigs on growth performance, carcass quality, and palatability of pork. Results from this study showed that feeding diets containing 20% DDGS or high dietary inclusion rates of HP-DDG had no negative effect on growth performance, carcass composition, muscle quality, and eating characteristics of bacon and pork chops, but may decrease pork fat quality. Similarly, feeding diets containing up to 10% corn germ had no negative effects on growth performance, carcass composition, carcass quality or eating characteristics of bacon and pork loins, but increased final body weight and improved bacon fat quality (reduced iodine value). Similar to preliminary results of feeding some of the fractionated corn co-products to dairy and beef cattle, there appear to be no negative effects, and potentially positive effects, on feeding

diets containing HP-DDGS and corn germ to grower-finisher pigs, and the reduced oil in these co-products may improve pork quality.

Dairy

Corn germ and corn bran are the only fractionated co-products that have been evaluated in performance trials to date. Adding 14% corn germ to the concentrate portion of a 55:45 forage to concentrate diet for lactating dairy cows will increase milk and milk fat yield, but at 21%, will decrease the concentration of milk fat (Abdelqader et al., 2006). Janicek et al. (2007) showed that when corn bran increased from 10 to 25% of the diet, there were no effects on dry matter intake and milk fat yield, but increased milk yield, milk protein yield, and feed conversion. The decrease in milk fat concentration with increasing levels of corn bran, coupled with the increase in total milk yield resulted in no differences between dietary treatments in 3.5% fat-corrected milk. Based on the results of these two studies, we conservatively assume in our calculation of displacement ratios for all co-products (including corn germ and corn bran) that milk yield and feed efficiency are unaffected although preliminary results from these two studies suggest improved performance.

Beef

Currently, only corn bran has been evaluated in a beef feedlot performance and carcass trial. Bremer et al. (2006) evaluated Dakota Bran Cake (DBRAN) on feedlot performance and carcass characteristics for finishing cattle and observed that feeding DBRAN up to 45% of the diet improves growth performance with no effects on carcass characteristics. Although, this study showed an improvement in cattle growth performance, it is the only study conducted and we have chosen to conservatively assume no change in growth performance when calculating displacement ratios for fractionated corn co-products fed to beef feedlot cattle.

Conclusions

Corn fractionation has been used for many years to produce specialized industrial and food grade products. Very few ethanol plants are using “front-end” fractionation technologies to separate the endosperm (starch rich fraction) from the non-fermentable fractions including the germ and bran. In contrast, over half of the ethanol industry is using “back-end” oil extraction to capture some of the corn oil from the co-product streams resulting in higher protein and fiber, but lower oil content of the resulting co-products. Limited scientific studies have been published evaluating fractionated and reduced-oil corn co-products in livestock and poultry feeds, but results from available published studies are summarized. Until more research is conducted to evaluate the feeding value of these co-products, it is difficult to determine their comparative feeding value, dietary inclusion rates, and comparative nutritional and economic value of these co-products. However, all of the new fractionated co-products that have been produced have some nutritional value and feeding applications in animal feeds.

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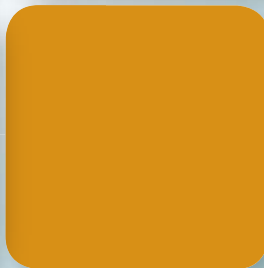
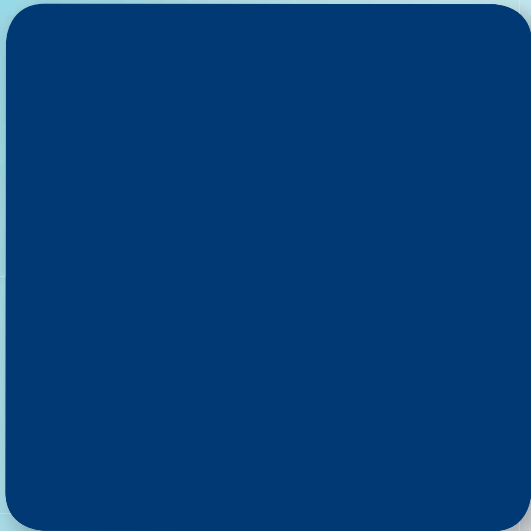
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CHAPTER 4

Nutrient Composition and Digestibility of DDGS: Variability and *In Vitro* Measurement



Chapter 4

Nutrient Composition and Digestibility of DDGS: Variability and *In Vitro* Measurement

Introduction

One of the challenges of using corn DDGS in animal feeds is to know the nutrient content and digestibility of the source being fed. Several studies have described variability in nutrient content and digestibility for various animal species (Spiehs et al., 2002; Tjardes and Wright, 2002; Waldroup et al., 2007; Stein and Shurson, 2009) and it is well documented that the nutrient content of corn DDGS can vary among U.S. DDGS sources (**Table 1**), and has been shown to vary over time within plants (Spiehs et al., 2002).

Table 1. Averages and ranges in composition of selected nutrients (100% dry matter basis) among 32 U.S. corn DDGS sources.¹

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

¹ www.ddgs.umn.edu.

Nutritionists want consistency and predictability of nutrient content and digestibility in the feed ingredients they purchase and use. As shown in **Table 1**, the nutrients most variable among DDGS sources are fat, fiber, ash, lysine, tryptophan, and phosphorus. With some ethanol plants using front-end fractionation and back-end oil extraction technologies, the nutrient composition of distiller's co-products is becoming more diverse and confusing because the term "DDGS" is often misused when describing these nutritionally different corn co-products that are becoming available in the feed ingredient market (e.g. high protein DDGS). As a result, DDGS is less of a "commodity" compared to other feed ingredients such as corn and soybean meal.

To manage the diversity among DDGS sources, some commercial feed manufacturers are requiring identity preservation of their choices of DDGS sources, and are limiting the number of DDGS sources on feed company's preferred suppliers list. Use of commercially available nutritional "tools" such as Value Added Science and Technologies (<http://v-ast.com/services.htm>) "Illuminate" can greatly improve purchaser and end-user capabilities to identify DDGS sources that provide the best nutritional and economic value, as well as provide accurate nutrient loading values for specific DDGS sources in order to improve livestock and poultry diet formulations. These tools are commercially available to DDGS end users. Other U.S. commercial feed manufacturers have developed and are using other systems of determining relative value and nutrient loading values of DDGS sources for their customers.

Olentine (1986) listed a number of variables in the raw materials and processing factors that contribute to variation in nutrient composition of distiller's by-products (**Table 2**). 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 1987 ranged from 7.8 to 10.0% crude protein, 0.22 to 0.32% lysine, and 0.24 to 0.34% phosphorus.

The ratio of blending condensed distiller's solubles with the grains fraction to produce DDGS also varies among plants. 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 the final nutrient composition of DDGS. Noll et al. (2006) evaluated the nutrient composition and digestibility of batches of corn DDGS produced with varying levels of solubles added to the wet grains. The DDGS samples produced

contained solubles added at approximately 0, 30, 60, and 100% of the maximum possible addition of solubles to the grains. This corresponds to adding 0, 12, 25, and 42 gallons of syrup to the grains fraction per minute. Dryer temperatures decreased as the rate of solubles addition to the grains decreased. Particle size increased, and was more variable as increasing additions of solubles were added to the grains fraction. Adding increasing amounts of solubles resulted in



darker colored DDGS (reduced L*) and less yellow color (reduced b*). Increased addition of solubles resulted in increased crude fat, ash, TME_n (poultry), magnesium, sodium, phosphorus, potassium, chloride, and sulfur, but had minimal effects on crude protein and amino acid content and digestibility.

Table 2. Factors influencing nutrient composition of distiller's co-products.¹

<u>Raw Materials</u>	<u>Processing Factors</u>
<ul style="list-style-type: none"> • Types of grains • Grain variety • Grain quality <ul style="list-style-type: none"> • Soil conditions • Fertilizer • Weather • Production and harvesting methods • Grain formula 	<ul style="list-style-type: none"> • Grind Procedure <ul style="list-style-type: none"> • Fineness • Duration • Cooking <ul style="list-style-type: none"> • Amount of water • Amount of pre-malt • Temperature and time • Continuous or batch fermentation • Cooling time • Conversion <ul style="list-style-type: none"> • Type, quantity, and quality of malt • Fungal amylase • Time and temperature • Dilution of converted grains <ul style="list-style-type: none"> • Volume and gallon per bushel or grain bill • Quality and quantity of grain products • Fermentation <ul style="list-style-type: none"> • Yeast quality and quantity • Temperature • Time • Cooling • Agitation • Acidity and production control • Distillation <ul style="list-style-type: none"> • Type: vacuum or atmospheric, continuous or batch • Direct or indirect heating • Change in volume during distillation • Processing <ul style="list-style-type: none"> • Type of screen: stationary, rotating, or vibratory • Use of centrifuges • Type of presses • Evaporators <ul style="list-style-type: none"> • Temperature • Number • Dryers <ul style="list-style-type: none"> • Time • Temperature • Type <ul style="list-style-type: none"> • Amount of syrup mixed with grain

¹ Olentine, 1986.

DDGS Nutrient Value and Digestibility for Dairy Cattle

Corn DDGS is a very good source of protein for dairy cows. The protein content in corn DDGS is typically more than 30% on a dry matter (DM) basis. Corn DDGS is also a good source of ruminally undegradable protein (RUP), or by-pass protein, for cattle (**Table 3**). Most of the readily degradable protein in corn is 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 by-products, lysine is the first limiting amino acid. As a result, milk production can sometimes be increased when dairy cows are fed rations containing supplemental ruminally protected lysine and methionine, or when DDGS is blended with other high protein ingredients that contain more lysine. However, in most situations feeding rations containing DDGS results in milk production being as high, or higher, than when dairy cows are fed rations containing soybean meal as the protein source. It also 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 fed diets containing dark colored DDGS had lower milk production than cows fed diets containing golden colored DDGS. Therefore, it is important to use high quality sources of golden colored DDGS in dairy cow diets to achieve maximum milk production.

Boucher et al. (2009) concluded that when adequate prediction equations are identified and validated, it may be possible to predict RUP-amino acid digestibility from the digestibility of amino acid in the intact feed because standardized digestibility of amino acids and RUP-amino acids was highly correlated. Furthermore, although ADICP concentration may be a useful indicator of protein quality, much of the variation in amino acid digestibility among DDGS samples is not explained by differences in ADICP concentrations. Mjoun et al. (2010) compared ruminal degradability and intestinal digestibility of protein and amino acids in soybean and corn distillers grains products and found that amino acid availability from distillers grains co-products was comparable to that of soybean co-products.



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). Corn DDGS contains more energy 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 3-fold 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.

Nuez-Ortin and Yu (2011) compared the NRC 2001 chemical summary approach to an *in situ* assay approach for estimating energy content of wheat, corn and wheat-corn blends of DDGS and found that the predicted energy values were not different, but refinements of the NRC 2001

formula are needed for better prediction of digestible NDF and crude protein of these co-products.

Table 3. Nutrient composition of corn DDGS for dairy cattle.¹

Nutrient	Corn DDGS (% of Dry Matter)
Crude protein	30.1
RUP ^a % of crude protein	55.0
NE _{maintenance} , Mcal/kg	2.07
NE _{gain} , Mcal/kg	1.41
NE _{lactation} , 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

^a RUP = ruminally undegradable protein.

¹ Schingoethe, 2004.

DDGS Nutrient Value and Digestibility for Beef Cattle

A range of commonly reported nutrient values for dried distillers grains (DDG) and dried distillers grains with solubles (DDGS) are shown in **Table 4** (Tjardes and Wright, 2002). Distiller's grains with or without solubles is an excellent energy source for beef cattle. In the U.S., finishing beef cattle have successfully been fed as much as 40% DDGS of ration DM 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_{gain} 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 DM. In many studies, feeding corn DDGS at levels of 15 to 20% of the diet DM 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.

Table 4. Range of concentrations of selected nutrients in corn DDG and DDGS (100% dry matter basis).

Nutrient	DDG ¹	DDGS ²
Dry matter, %	88-90	88-90
Crude protein, %	25-35	25-32
Degradable intake protein, % of CP	40-50	43-53
Fat, %	8-10	8-10
NDF, %	40-44	39-45
TDN, %	77-88	85-90
NE _m , Mcal/kg	1.96-2.21	2.16-2.21
NE _g , Mcal/kg	1.48-1.54	1.50-1.54
Calcium, %	0.11-0.20	0.17-0.26
Phosphorus, %	0.41-0.80	0.78-1.08

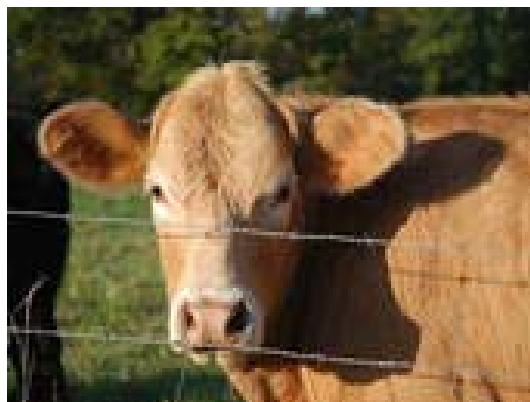
¹ Dried distiller's grains.

² Dried distiller's grains with solubles.

Adapted from Tjardes and Wright (2002).

Distiller's grains with or without solubles is a very good protein source in beef cattle rations, and are high in RUP. 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. The proportion of bypass protein (RUP) in DDGS is approximately 60 to 70% compared to 30% for soybean meal. However, Erickson et al. (2005) indicated that the high bypass protein value of DDGS is due to the innate characteristics of the protein rather than drying or moisture content, and does not appear to be influenced by ADIN since protein efficiency (kg gain/kg supplemental protein) appears to stay the same, or increase as the amount of ADIN in DDGS increases.

Distiller's grains, with or without solubles, are low in calcium but high in phosphorus and sulfur. Depending upon the feeding level, adding distiller's grains to the diet may allow complete removal of other supplemental phosphorus sources from the mineral mixture previously fed. Due to the high levels of wet or dried DGS fed, beef cattle feedlot diets contain excess phosphorus relative to their requirement. This results in excess phosphorus being excreted in manure and must be considered when developing manure management plans. Due to the low



calcium level of DDGS, supplemental calcium sources (e.g. ground limestone or alfalfa) must be added to the diet to maintain a calcium to phosphorus ratio between 1.2:1 to no more than 7:1 to avoid reductions in animal performance and urinary calculi (Tjardes and Wright, 2002). Distiller's grains with and without solubles can sometimes be high in sulfur and contribute significant amounts of sulfur to the diet. If more than 0.4% sulfur from feed (DM basis) and water is consumed, polioencephalomalacia in cattle can occur. Furthermore, sulfur interferes with copper absorption and metabolism, which is worsened in the presence of molybdenum. Therefore, in geographic regions where high sulfur levels are found in forages and water, the level of DDGS that can be added may need to be reduced (Tjardes and Wright, 2002).

DDGS Nutrient Value and Digestibility for Swine

Gross energy (GE) in DDGS averages 5,434 kcal/kg DM (**Table 5**), and is greater than the concentration of GE in corn (Stein and Shurson, 2009). However, the digestibility of energy, measured as a percentage of GE, is lower in DDGS than in corn (Stein and Shurson, 2009). The DE and ME content of DDGS is 4,140 and 3,897 kcal/kg DM, respectively (Pedersen et al., 2007). These values are similar to the DE and ME content in corn (**Table 5**). The net energy value of DDGS has not been determined, but research is currently being conducted to measure these values.

Table 5. Concentration of energy in corn and 10 sources of corn distillers dried grains with solubles (DDGS) fed to growing pigs¹ (Stein and Shurson, 2009).

Item Ingredient:	Corn		DDGS		
	Average	SD	Lowest value	Highest value	
GE, kcal/kg DM	4,496	5,434	108	5,272	5,592
ATTD ² of energy, %	90.4	76.8	2.73	73.9	82.8
DE, kcal/kg DM	4,088	4,140	205	3,947	4,593
ME, kcal/kg DM	3,989	3,897	210	3,674	4,336

¹Data from Pedersen et al. (2007). N = 11.

²ATTD = apparent total tract digestibility.

Since most of the starch in corn is converted to ethanol, DDGS contains approximately 35% insoluble and 6% soluble dietary fiber (Stein and Shurson, 2009; **Table 6**). The average apparent ileal digestibility, ATTD, and hindgut fermentation of total dietary fiber in 24 sources of corn DDGS were 23.0, 47.3, and 24.4%, respectively (Urriola et al., 2010). However, the concentration of volatile fatty acids in cecal digesta and feces increase with the length of time pigs are fed DDGS diets, suggesting that DE value of DDGS improves when present in the diet over time (Urriola and Stein, 2010). This relatively low fiber digestibility results in a low DM digestibility, and explains why the digestibility of gross energy in DDGS is low relative to its DE

and ME content. Accurate ME prediction equations have been developed for estimating the ME content of DDGS, reduced-oil DDGS, and other co-products for swine and are discussed in **Chapter 22**.

Table 6. Concentration of carbohydrates and apparent total tract digestibility (ATTD) of dietary fiber in corn distillers dried grains with solubles^{1,2}

Item	Average	Lowest value	Highest value	SD
Starch, total, %	7.3	3.8	11.4	1.4
Starch, soluble, %	2.6	0.5	5.0	1.2
Starch, insoluble, %	4.7	2.0	7.6	1.5
ADF, %	9.9	7.2	17.3	1.2
NDF, %	25.3	20.1	32.9	4.8
Insoluble total dietary fiber, %	35.3	26.4	38.8	4.0
Soluble total dietary fiber, %	6.0	2.36	8.54	2.1
Total dietary fiber, %	42.1	31.2	46.3	4.9
ATTD, total dietary fiber, %	43.7	23.4	55.0	10.2

¹ Unpublished data from the University of Illinois and the University of Minnesota. N = 46 for data on starch, ADF, and NDF; n = 8 for data on insoluble, soluble, and total dietary fiber.

² Stein and Shurson, 2009.

The standardized ileal digestibility of amino acids has been measured in 34 sources of corn DDGS, one source of sorghum DDGS, and 2 sources of wheat DDGS (**Table 7**). These results show that amino acid digestibility can vary significantly among sources even when the DDGS is produced from the same type of grain (Stein et al., 2005, 2006; Urriola et al., 2009; Pahn et al., 2008a).



Table 7. Concentration and standardized ileal digestibility (SID) of crude protein (CP) and amino acids (AA) in distillers dried grains with solubles (DDGS) fed to growing pigs¹ (Stein and Shurson, 2009).

Item	Concentration of CP and AA (%)			SID of CP and AA (%)		
	Corn DDGS	Sorghum DDGS	Wheat DDGS	Corn DDGS	Sorghum DDGS	Wheat DDGS
CP	27.27	31.50	40.67	72.8	71.4	72.2
Indispensable AA						
Arg	1.16	1.06	1.53	81.2	78.2	85.5
His	0.72	0.68	0.92	77.5	70.6	77.4
Ile	1.00	1.31	1.35	75.2	72.7	79.6
Leu	3.12	4.02	2.66	83.7	76.3	82.9
Lys	0.78	0.66	0.65	62.0	62.0	56.6
Met	0.55	0.51	0.53	82.0	75.4	81.1
Phe	1.32	1.62	1.92	81.0	75.8	86.3
Thr	1.06	1.03	1.21	70.8	68.6	74.9
Trp	0.21	0.34	0.40	70.2	70.4	85.7
Val	1.34	1.59	1.70	74.5	72.3	81.9
Dispensable AA						
Ala	1.90	2.79	1.48	78.0	73.4	68.0
Asp	1.82	2.09	1.92	68.6	68.0	56.7
Cys	0.53	0.47	0.73	73.3	65.6	75.2
Glu	4.28	6.08	9.81	80.4	75.5	86.3
Gly	1.02	0.99	1.62	63.4	66.9	67.8
Pro	2.06	2.41	4.11	74.3	83.1	81.0
Ser	1.16	1.35	1.88	75.6	72.5	77.0
Tyr	1.01	-	-	80.9	-	-

¹Corn DDGS data (34 sources) Stein et al. (2005, 2006), Urriola et al. (2007c), Pahm et al. (2008). Sorghum DDGS data (1 source) Urriola et al. (2007c). Wheat DDGS data (2 sources) Widyaratne and Zijlstra (2007) Lan et al. (2008).

Lysine digestibility is the most variable compared with all other essential amino acids (Fastinger and Mahan, 2006; Stein et al., 2006; Pahm et al., 2008a). The greater variation in lysine digestibility compared with the digestibility of other amino acids is because lysine is the most sensitive amino acid to heat damage and the extent of heat-damage varies among DDGS sources (Cromwell et al., 1993; Stein et al., 2006). Most amino acids in DDGS have a digestibility that is approximately 10 percentage units less compared to corn, which may be a result of the greater concentration of dietary fiber in DDGS compared to corn. However, except for lysine, variability in amino acid digestibility among DDGS sources is within the normal range of variation observed in other feed ingredients. Sources of DDGS that have a low lysine digestibility often have low lysine content. As a result, the ratio of lysine to crude protein provides an estimate of the relative lysine digestibility among DDGS sources (Stein, 2007). Amino acid digestibility in sorghum DDGS and in wheat DDGS is similar to the values measured in corn DDGS (Urriola et al., 2009; Widyaratne and Zijlstra, 2007; Lan et al., 2008).

Color measurement with Minolta or Hunter lab spectrophotometers has been used to predict the digestibility of lysine in DDGS. In extreme situations, when there is a wide color range in DDGS samples, color measurement with Minolta or Hunter lab spectrophotometers may useful to predict lysine digestibility among DDGS sources (Cromwell et al., 1993; Fastinger and Mahan, 2006). In general, dark colored DDGS (L^* less than 50) has lower amino acid digestibility, which may lead to reduced growth performance when fed to swine compared with light colored DDGS

(Cromwell et al., 1993; Fastinger and Mahan, 2006). However, due to the improvements in drying conditions used by ethanol plants, prediction of lysine and amino acid digestibility by using color measurements may not be very accurate as shown in **Figure 1**. For more information related to the use of DDGS color as an indicator of amino acid digestibility, refer to **Chapter 8**.

Use of optical density and front face fluorescence appears to more accurately predict the digestibility of lysine and other amino acids in DDGS than color measured by Hunter and Minolta scores (Urriola et al., 2007a,b), but these methods have not been validated or commercialized. The color of DDGS and relative amino acid digestibility has also been predicted by measuring ADIN (Cromwell et al., 1993). Enzyme assays such as IDEA™ and pepsin/pancreatin (Pedersen et al., 2005; Schasteen et al. 2005) have been evaluated as potential *in vitro* techniques for predicting digestible crude protein and amino acid concentrations in DDGS, but the accuracy of these procedures is less than desirable.

Digestible lysine prediction equations for DDGS in swine have been developed. Pahm et al. (2008b) developed an accurate prediction equation for standardized ileal digestible lysine in DDGS using a measurement of reactive lysine as follows:

$$\text{Standardized ileal digestible lysine (\%)} = 0.023 + 0.637 \times \text{reactive lysine (\%)}$$

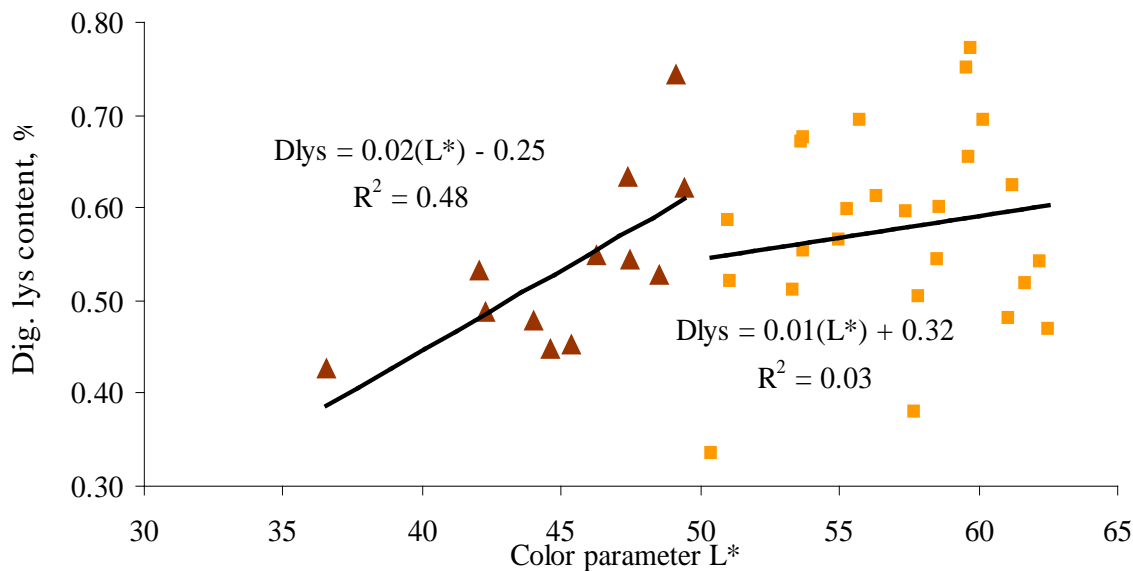
Reactive lysine can be estimated from the concentration of furosine in a DDGS sample after acid hydrolysis (Pahm et al., 2008b). Furosine is measured using HPLC and the concentration of reactive lysine is estimated as follows:

$$\text{Reactive lysine (\%)} = \text{analyzed lysine (\%)} - \text{furosine (\%)} / 0.32 \times 0.40$$

The accuracy of this equation was confirmed in a study conducted by (Kim et al., 2010). However, measurement of furosine is not commonly done by commercial laboratories. Therefore, Stein (2011) developed an equation for estimating digestible lysine which does not require measuring furosine in a DDGS sample as follows:

$$\text{Standardized ileal digestible lysine (\%)} = -0.636 + [0.858 \times \text{lysine (\%)}] \times [0.12 \times (100 \times \text{lysine (\%)} / \text{crude protein (\%)})]$$

This equation can be used to accurately estimate digestible lysine in DDGS for use in swine diets.

Figure 1. Relationship Between Lightness of Color (L*) and Digestible Lysine Content of Corn DDGS (Urriola 2007a, b).

The apparent total tract digestibility (ATTD) of phosphorus in DDGS is approximately 59% for swine (**Table 8**), which is much greater than in corn (Pedersen et al., 2007). The ATTD of phosphorus in DDGS corresponds to bioavailability values between 70 and 90% relative to P bioavailability in dicalcium phosphate (Burnell et al., 1989; Whitney and Shurson, 2001). Therefore, if DDGS is included in diets fed to swine, the utilization of phosphorus in DDGS will increase, and the need for supplemental inorganic phosphate in the diet is reduced. The standardized total tract digestibility (STTD) of P in corn and corn germ resulting from the addition of microbial phytase to the diet can be predicted by regression equations, but microbial phytase has much less of an effect on the STTD of P in DDGS and HP-DDG and responses to addition of increasing dietary levels of phytase are not accurately predicted by regression equations (Almeida and Stein, 2012).

Table 8. Concentration and digestibility of phosphorus (P) in 10 sources of corn distillers dried grains with solubles fed to growing pigs¹ (Stein and Shurson, 2009).

Item	Average	Low	High	SD
Total P, %	0.61	0.51	0.74	0.09
Total P, % DM	0.70	0.57	0.85	0.10
Apparent total tract digestibility, %	59.1	50.1	68.3	5.18
Digestible P, %	0.36	0.28	0.47	0.06

¹ Data from Pedersen et al. (2007). N = 11.

DDGS Nutrient Value and Digestibility for Poultry

Waldroup et al. (2007) published an excellent review of published data and developed a standardized nutrient matrix for corn DDGS for poultry. First, they determined a weighted average of proximate analysis and amino acid values (**Table 9**) from 5 published sources (Spiehs et al., 2002; Fiene et al., 2006; Parsons et al., 2006; Fastinger et al., 2006; and Batal and Dale, 2006).



Table 9. Average composition (% as-fed basis) of selected nutrients among DDGS sources.¹

Nutrient	Weighted Average
Dry matter	89.36
Crude protein	26.45
Fat	10.08
Fiber	6.99
Ash	4.67
Arginine	1.09
Histidine	0.68
Isoleucine	0.96
Leucine	3.00
Lysine	0.73
Methionine	0.50
Cystine	0.54
Phenylalanine	1.31
Threonine	0.96
Tryptophan	0.21
Valine	1.30
Serine	1.07

¹ Waldroup et al., 2007.

Estimates have been determined for true metabolizable energy content (TME_n) in DDGS, and these estimates vary among sources (**Table 10**). From these estimates, Waldroup et al. (2007) calculated the weighted average TME_n content of DDGS to be 2,851 kcal/kg. Several other researchers have estimated the apparent metabolizable energy (AME_n) of DDGS to average approximately 2,728 kcal/kg (**Table 11**). Adeola and Ileleji (2009) obtained ME and ME_n values (kcal/kg) of the corn DDGS samples of 3,013 and 2,963, respectively, when a semi-purified nitrogen-free diet was used as the basal diet; and 2,904 and 2,787, respectively, when a practical corn-soybean meal diet was used as the basal diet. These different results indicate that nutritionists should exercise due caution regarding the source of data for ME values of corn DDGS when formulating diets containing DDGS. Batal and Dale (2006) developed prediction equations for estimated TME_n in DDGS from crude protein, fat and fiber (**Table 12**), but the R^2 values are low and not reliable for estimating energy content of DDGS for poultry diet

formulation. However, Rochelle et al. (2011) developed AME_n prediction equations for DDGS with a relatively high R² as follows:

$$\text{AME}_n, \text{ kcal/kg DM} = 3,517 - (33.27 \times \% \text{ hemicellulose, DM basis}) + (46.02 \times \% \text{ crude fat, DM basis}) - (82.47 \times \% \text{ ash, DM basis}) \quad R^2 = 0.89$$

Hemicellulose is calculated by subtracting ADF from NDF content. Alternatively, the following equation can also be used:

$$\text{AME}_n, \text{ kcal/kg DM} = (-30.19 \times \% \text{ NDF, DM basis}) + (0.81 \times \text{gross energy, kcal/kg DM basis}) - (12.26 \times \% \text{ crude protein, DM basis}) \quad R^2 = 0.87$$

The preceding two equations also provide accurate AME_n estimates not only of DDGS, but also reduced-oil DDGS, and other co-products for poultry and are discussed in **Chapter 20**. Adeola and Zhai (2012) showed that ileal digestible energy, ME, and ME_n were 20, 23, and 24% greater for DDGS than DDG (distillers dried grains without solubles), respectively.

Table 10. True metabolizable energy content (TME_n kcal/kg) estimates among DDGS sources.¹

Reference	N	High	Low	Average	Species
NRC (1994)	1	-	-	2,864	All
Roberson et al. (2003)	1	-	-	2,800	Turkeys
Lumpkins et al. (2004)	1	-	-	2,906	Broilers
Batal and Dale (2004)		2,380	3,079	2,831	Layers
Noll (2005)	1	-	-	2,980	Turkeys
Roberson et al. (2005)	1	-	-	2,884	Layers
Parsons et al. (2006)	20	2,606	3,054	2,864	Layers
Batal and Dale (2006)	17	2,496	3,197	2,827	Layers
Fastinger et al. (2006)	5	2,485	3,047	2,871	Layers
Waldroup et al. (2007)	1	-	-	2,851	Broilers
Hong et al. (2008)		2,863	2,976	2,904	Broilers

¹ Adapted from Waldroup et al. (2007) and Salim et al. (2010).

Table 11. Apparent metabolizable energy content (TME_n kcal/kg) estimates among DDGS sources.¹

Reference	N	Average	Species
NRC (1994)	1	2,840	All
Roberson et al. (2003)	1	2,756	Turkeys
Noll (2005)	1	2,760	Turkeys
Roberson et al. (2005)	1	2,770	Layers
Waldroup et al. (2007)	1	2,770	Broilers
Applegate et al. (2009)	1	2,526	Broilers
Rochelle et al. (2011)	6	2,148 - 3,098	Broilers

¹ Adapted from Salim et al. (2010).

Table 12. Equations to predict true metabolizable energy (kcal/kg) of DDGS from crude protein (CP), fat, fiber, and ash content.¹

Equation	R ²
$TME_n = 2439.4 + 43.2 \times \text{fat}$	0.29
$TME_n = 2957.1 + 43.8 \times \text{fat} - 79.1 \times \text{fiber}$	0.43
$TME_n = 2582.3 + 36.7 \times \text{fat} - 72.4 \times \text{fiber} + 14.6 \times \text{CP}$	0.44
$TME_n = 2732.7 + 36.4 \times \text{fat} - 76.3 \times \text{fiber} + 14.5 \times \text{CP} - 26.2 \times \text{ash}$	0.45

¹ Batal and Dale, 2006.

Fiene et al. (2006) used stepwise regression analysis of 150 DDGS samples to develop prediction equations to estimate amino acid content from crude protein, fat and fiber (**Table 13**). However, the R² values of several prediction equations are low (arginine, cystine, lysine, and tryptophan) and indicate that using these equations will not provide accurate estimation of amino acids from key proximate components.

Table 13. Equations to predict amino acid content of DDGS from crude protein (CP), fat, and fiber.¹

Amino acid	Equation	R ²
Arginine	$Y = 0.07926 + 0.0398 \times \text{CP}$	0.48
Isoleucine	$Y = -0.23961 + 0.04084 \times \text{CP} + 0.01227 \times \text{fat}$	0.86
Leucine	$Y = -1.15573 + 0.13082 \times \text{CP} + 0.06983 \times \text{fat}$	0.86
Lysine	$Y = -0.41534 + 0.04177 \times \text{CP} + 0.00913 \times \text{fiber}$	0.45
Methionine	$Y = -0.17997 + 0.02167 \times \text{CP} + 0.01299 \times \text{fat}$	0.78
Cystine	$Y = 0.11159 + 0.01610 \times \text{CP} + 9.00244 \times \text{fat}$	0.52
TSAA	$Y = -0.12987 + 0.03499 \times \text{CP} + 0.05344 \times \text{fat} - 0.00229 \times \text{fat}^2$	0.76
Threonine	$Y = -0.05630 + 0.03343 \times \text{CP} + 0.02989 \times \text{fat} - 0.00141 \times \text{fat}^2$	0.87
Tryptophan	$Y = 0.01676 + 0.0073 \times \text{CP}$	0.31
Valine	$Y = 0.01237 + 0.04731 \times \text{CP} + 0.00054185 \times \text{fat}^2$	0.81

¹ Fiene et al, 2006.

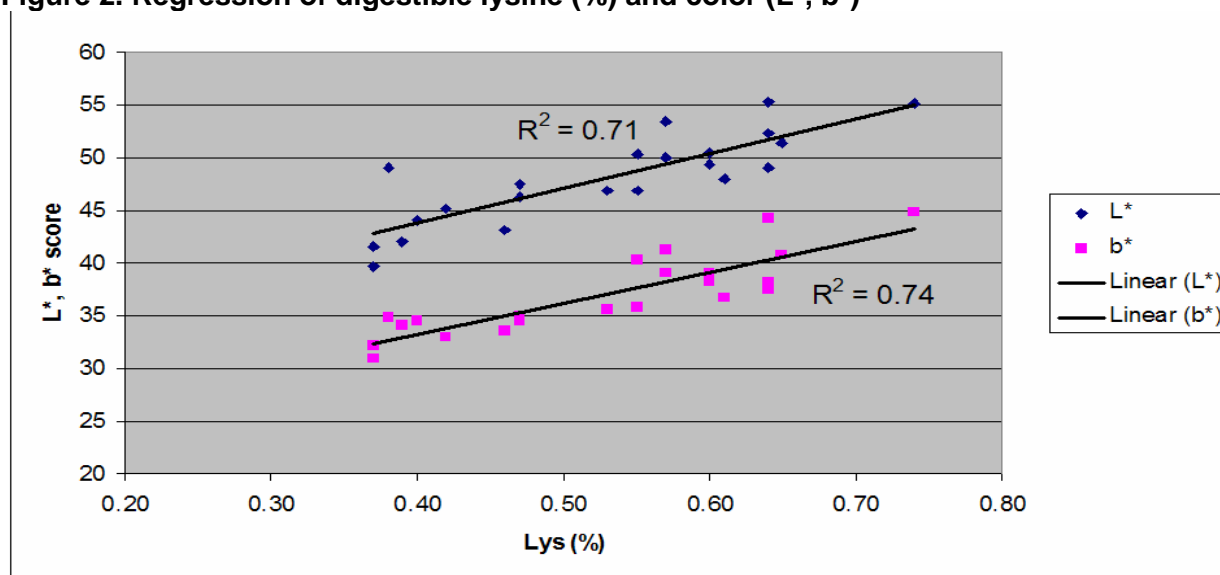
In order to obtain the most value when using DDGS in poultry diets, it is important to determine and use accurate estimates of digestible amino acids in DDGS. Waldroup summarized results of studies by Fiene et al. (2006), Parsons et al. (2006), Fastinger et al. (2006), and Batal and Dale (2006) on amino acid digestibility of DDGS. Average amino acid digestibility coefficients are shown in **Table 14**. One *in vitro* method that is being used to estimate amino acid digestibility in DDGS for poultry is the IDEA™ assay by NOVUS International (St. Louis, MO). Results from Schasteen et al. (2005) and Fiene et al. (2006) showed that IDEA™ reasonably predicts lysine digestibility in DDGS for poultry, but the correlations between *in vivo* determined and *in vitro* estimated digestibility of other amino acids was low.

Table 14. Digestible amino acid coefficients (%) of DDGS for poultry.¹

Nutrient	Weighted Average
Arginine	85.3
Histidine	84.5
Isoleucine	82.2
Leucine	89.3
Lysine	68.5
Methionine	86.8
Cystine	77.3
Phenylalanine	87.7
Threonine	75.1
Tryptophan	84.1
Valine	81.4
Serine	82.8

¹ Waldroup et al., 2007.

Determining color of DDGS samples has been another method used to estimate amino acid, especially lysine, digestibility among DDGS sources for poultry (Cromwell et al., 1993; Ergul et al., 2003; Batal and Dale, 2006; Fasting et al., 2006). Lightness and yellowness of color of DDGS appear to be reasonable predictors of digestible lysine content among corn DDGS sources for poultry (**Figure 2**; Ergul et al., 2003). True lysine digestibility among DDGS sources ranged from 59 to 83% for poultry Ergul et al. (2003). Batal and Dale (2006) showed that DDGS sources with more lightness ($L^* = 60.3$) and yellowness ($b^* = 25.9$) represented DDGS sources with an average lysine digestibility of 0.66% and DDGS sources that were darker ($L^* = 50.4$) and less yellow ($b^* = 7.41$) in color had low (0.18%) lysine digestibility. These results suggest that color measurements can be used to differentiate above and below average lysine digestibility among DDGS sources, but may not be accurate enough to estimate lysine digestibility values for accurate diet formulation. For more information related to the use of DDGS color as an indicator of amino acid digestibility, refer to **Chapter 8**.

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

Source: Ergul et al. (2003).

There is a significant amount of total and available phosphorus in DDGS, but it varies among sources (Singsen et al., 1972; Martinez-Amezcuca et al., 2004; Lumpkins and Batal, 2005). Singsen et al., 1972 showed that DDGS from beverage alcohol production had the same phosphorus bioavailability as found in dicalcium phosphate. Martinez-Amezcuca et al. (2004) showed that phosphorus bioavailability can range from 69 to 102% relative to KH_2PO_4 and that increased temperatures during DDGS production increases the bioavailability of phosphorus, but decreases lysine digestibility. Lumpkins and Batal, (2005) reported estimates of relative phosphorus availability to be 68 and 54% in two different experiments. Based on these results, Waldroup (2007) suggested that the average relative phosphorus bioavailability in DDGS is 62% for poultry. Tahir et al. (2012) developed a prediction equation to estimate the phytate P content in DDGS as follows:

$$\text{Phytate P in DDGS (\%)} = 0.4447 + (0.9696 \times \% \text{ Ca}) - (0.0149 \times \% \text{ ADF}) + (0.0064 \times \% \text{NDF}) - (0.025 \times \% \text{ crude fat})$$

The sodium content of corn DDGS can range from 0.01 to 0.48% averaging 0.11%. 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 can contain as much as 40 ppm of xanthophyll. The xanthophyll content of corn DDGS has been shown in commercial field and university 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.

Conclusions

The variability in nutrient content and digestibility among DDGS sources can be a challenge when determining economic and feeding value for livestock and poultry. However, new nutritional “tools” are being developed and many are commercially available to rapidly, accurately and inexpensively estimate total and digestible nutrient content of specific DDGS sources. The nutrient composition and digestibility in this factsheet can be useful when evaluating DDGS sources and determining reasonable nutrient loading values to use when formulating livestock and poultry diets.

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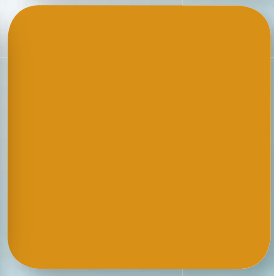
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CHAPTER 5

Recommended Laboratory Analytical Procedures for DDGS



Chapter 5

Recommended Laboratory Analytical Procedures for DDGS

Introduction

Laboratory analysis of feed ingredients is a common practice in the feed industry in order to verify that the ingredient meets guaranteed specifications, determine nutrient composition for use in animal feed formulation, and determine the presence and concentration of potential contaminants. Therefore, the accuracy of measurement of various chemical compounds in feed ingredients including DDGS is essential.

Analytical procedures can be categorized based on the level of validation of a specific laboratory method (Thiex, 2012). A single laboratory validation applies to a specific laboratory, technician, and equipment, whereas, a multi-laboratory validation involves validating a procedure in 2 to 7 laboratories to provide information on how well the results of a method are reproduced outside of the original laboratory. A full harmonized protocol collaborative study validation occurs when at least 8 laboratories provide acceptable data using the same procedure. An excellent summary of recommended analytical procedures for DDGS has been published by Thiex (2012) and key points are summarized in this chapter.

Recommended Procedures for Meeting DDGS Trading Standards (AFIA, 2007)

Moisture	NFTA 2.2.2.5 Lab Dry Matter (105°C/3hr)
Crude protein	AOAC 990.03 Protein (Crude) in Animal Feed AOAC 2001.11 Protein (Crude) in Animal Feed and Pet Food Copper Catalyst
Crude fat	AOAC 945.16 Oil in Cereal Adjuncts (Petroleum Ether)
Crude fiber	AOAC 978.10 Fiber (Crude) in Animal Feed and Pet Food (F.G. Crucible)

Recommended Procedures for Nutrient Analysis of DDGS for Diet Formulation

Acid detergent fiber – **AOAC 973.18** Fiber, Acid Detergent, and Lignin, H₂SO₄ in Animal Feed and **ISO, 2008** are equivalent

Acid detergent lignin – **AOAC 973.18** Fiber, Acid Detergent, and Lignin, H₂SO₄ in Animal Feed and **ISO 13906:2008** are equivalent

Amylase-treated neutral detergent fiber – **AOAC 2002.04** Amylase Treated Neutral Detergent Fiber in Feeds and **ISO 16472:2006** are equivalent

Ash – **AOAC 942.05** and **ISO 5984:2002** are equivalent

Note: if the ash contains unoxidized carbon, the sample should be re-ashed

Trace minerals - Solubilization involves either dry ash followed by dissolving in acid, or wet ash using various acids depending on the elements being measured. Detection includes gravimetric techniques, visible spectrophotometry, flame and graphite furnace atomic absorption spectrophotometry (**AOAC 968.08**; **ISO 6869:2000**), or atomic mass spectroscopic detection (ICP-MS; **ISO 27085:2009**).

Sulfur – **AOAC 923.01** Sulfur in Plants and **ISO 27085:2009** are comparable

Phosphorus – **AOAC 965.17** Phosphorus in Animal Feed, Photometric Method, **ISO 6491:1998**

Determination of Total Phosphorus Content – Spectrophotometric Method, and **ISO 27085:2009** can be used

Selenium – **AOAC 996.16** Selenium in Feeds and Premixes, Fluorometric Method and **AOAC 996.17** Selenium in Feeds and Premixes, Continuous Hydride Generation Atomic Absorption Method are acceptable

Chlorine – **AOAC 969.10** Potentiometric Method, **AOAC 943.01** Volhard Method, and **ISO 6495:1999**

Chromium – No official methods. No methods have been validated

Fluorine – Microdiffusion technique (Mineral Tolerances of Animals, 2005). No methods have been validated.

Iodine – ICP-MS technique (Mineral Tolerances of Animals, 2005). No methods have been validated.

Amino acids – **AOAC 994.12** for all amino acids except tyrosine and tryptophan, **ISO 13903:2005**

Tryptophan – **AOAC 988.15**

Starch – No official method. AOAC 920.40 is no longer valid because of discontinued production of the enzyme needed for the assay, **AOAC 996.11** is most commonly used but has defects.

Recommended Procedures for Measuring Possible Contaminants in DDGS (Caupert et al., 2012)

Mycotoxins

See **Chapter 10** for recommended and GIPSA approved rapid mycotoxin testing kits.

Recommended instrumental methods for mycotoxin testing

Aflatoxins – AOAC 994.08

Deoxynivalenol – MacDonald et al. (2005a)

Fumonisin – AOAC 2001.04 and Rottinghaus et al. (1992)

T-2 – Romer Labs (2010)

Zearalenone – AOAC 994.01 and McDonald et al. (2005b)

Aflatoxins, Deoxynivalenol, Fumonisin, T-2, and Zearalenone - (Sulyok et al., 2007)

Antibiotic residues

FDA CVM has used a liquid chromatography and ion trap tandem mass spectrometry procedure (Heller, 2009) to determine 13 antibiotics in distillers grains including:

Ampicillin	Monensin
Bacitracin A	Oxytetracycline
Chloramphenicol	Penicillin G
Chlortetracycline	Streptomycin
Clarithromycin	Tylosin
Erythromycin	Virginiamycin M1

Extraction efficiency of this procedure ranged from 65% to 97% with quantitation limits from 0.1 to 1.0 µg/g. Accuracy ranged from 88 to 111% with coefficients of variation from 4 to 30%. The only FDA approved method for detecting virginiamycin residues is a bioassay procedure Phibro (QA@Phibro.com), which is recommended over the LC-MS method of Heller (2009) which only measures one of the two subunits of virginiamycin.

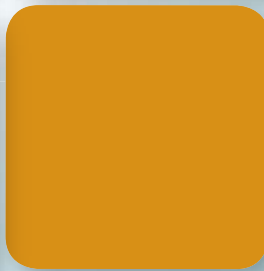
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CHAPTER 6

Comparison of Different Grain DDGS Sources – Nutrient Composition and Animal Performance



Chapter 6

Comparison of Different Grain DDGS Sources – Nutrient Composition and Animal Performance

Introduction

A variety of feedstocks are used to produce ethanol and DDGS around the world. Grains, such as corn, wheat, and barley vary in starch content (**Table 1**), and those with the greatest amount of starch (e.g. corn) are used to a greater extent because they provide the greatest ethanol yield. Since the nutrient composition of grains used to produce ethanol varies, the nutrient composition of the resulting distiller's grains also varies.

Table 1. Starch content and ethanol yield of various feedstocks¹

Feedstock	Moisture, %	Starch, %	Ethanol yield (L/MT)
Starch	-	100.0	720
Sugar cane	-	-	654
Barley	9.7	67.1	399
Corn	13.8	71.8	408
Oats	10.9	44.7	262
Wheat	10.9	63.8	375

¹ Saskatchewan Agriculture and Food. 1993

Sorghum (Milo) DDGS

A comparison of the nutrient composition values for sorghum (milo), a sorghum-corn blend, and corn DDGS (Urriola et al., 2009) is shown in **Table 2**. The amount of sorghum and corn-sorghum blends distiller's grains produced by the U.S. ethanol industry is relatively small compared to the amount of corn DDGS produced. Furthermore, most of the sorghum and corn-sorghum blends of distiller's grains are used locally by beef cattle feedlots, and very little is dried to produce DDGS. Thus, significant quantities of sorghum DDGS are currently not available for export.

Sorghum DDGS is slightly higher in crude protein, significantly higher in ADF and ash, and lower in crude fat, and lysine compared to corn DDGS. Although the levels of methionine and threonine are similar, tryptophan levels are substantially higher, and lysine and arginine are lower, resulting in a significantly lower lysine to crude protein ratio compared to corn DDGS. The sorghum-corn blend of DDGS is intermediate in nutrient composition compared with either sorghum or corn, and is dependent on the proportion of each used.

Table 2. Nutrient composition (as-fed basis) of sorghum, sorghum-corn, and corn DDGS¹

Nutrient, %	Sorghum ²	Sorghum-Corn ³	Corn ⁴
Dry matter	91.2	93.4	91.3
Crude protein	32.7	30.6	28.4
Crude fat	8.0	8.9	10.1
NDF	34.7	36.3	33.3
ADF	25.3	17.2	11.6
Ash	11.9	5.8	2.75
Arginine	1.10	1.31	1.25
Histidine	0.71	0.80	0.75
Isoleucine	1.36	1.14	1.04
Leucine	4.17	3.66	3.22
Lysine	0.68	0.91	0.85
Methionine	0.53	0.58	0.52
Phenylalanine	1.68	1.51	1.35
Threonine	1.07	1.15	1.05
Tryptophan	0.35	0.29	0.24
Valine	1.65	1.49	1.38
Cystine	0.49	0.57	0.49
Total amino acids	30.1	28.3	25.5
Lysine:Crude protein ratio	2.08	2.98	2.98

¹Urriola et al., 2009

²Distillers dried grains with solubles produced from sorghum.

³Distillers dried grains with solubles produced from a blend of corn and sorghum grains.

⁴Distillers dried grains with solubles produced from corn.

These differences in nutrient composition suggest that the energy value and protein quality of sorghum DDGS would be less than for corn DDGS in monogastric animals. Dr. Joe Hancock (Professor, Kansas State University) estimated that the ME_n (kcal/kg) of bronze and yellow sorghum DDGS was 2,677 and 2,866, respectively. These sorghum DDGS values are similar, but slightly lower than the ME_n values reported by Lumpkins and Batal, 2005 (2,827 kcal/kg) and Batal and Dale, 2006 (2,906 kcal/kg) for corn DDGS. High Plains Corporation (Colwich, KS) has estimated that the TDN, NE_{lactation}, NE_{maintenance}, and NE_{gain} for sorghum distillers grains for ruminants to be 82.8%, 0.87, 0.96, and 0.63 Mcal/kg, respectively.

Urriola et al. (2009) showed that the standardized true amino acid digestibility coefficients of sorghum DDGS for swine were 64.0, 76.5, 70.2, and 72.0% for lysine, methionine, threonine, and tryptophan, respectively, which were slightly higher than in corn DDGS for lysine (61.6%) and tryptophan (64.9%), lower than for methionine (82.8%), and the same for threonine (70.2%). Dr. Joe Hancock (Kansas State University) estimated that the lysine bioavailability for poultry to be between 71 to 73%.

Wheat DDGS

Wheat DDGS is becoming more available for use in animal feeds in Canada, Europe and other parts of the world. Wheat DDGS is higher in crude protein (38%) and ash (5.3%), lower in crude fat (4.6%), and similar in ADF and NDF to corn DDGS (**Tables 2 and 3**). The lower fat

content suggests that the energy content in wheat DDGS is lower than corn DDGS. Lysine, methionine, and tryptophan content is also higher in wheat DDGS compared to corn DDGS.

Table 3. Nutrient composition of wheat DDGS.

Nutrient, %	As Fed Basis
Moisture	8.32
Dry matter	91.68
Crude protein	38.48
Crude fiber	6.00
Fat	4.63
Ash	5.28
Calcium	0.10
Phosphorus	0.93
ADF	12.85
NDF	35.50
Starch	1.92
Lysine	0.97
Methionine	0.59
Cysteine	0.83
Threonine	1.09
Tryptophan	0.36
Isoleucine	1.38
Leucine	2.50
Histidine	0.85
Arginine	1.67
Phenylalanine	1.85
Valine	1.74

Nutritional value for swine

Cozannet et al. (2009) conducted a literature review that showed nutrient content of wheat DDGS is highly variable (like that of corn DDGS), where the NDF and starch content averaged 28% and 4.7%, respectively, with minimum and maximum values ranging from 23 to 33% and 2.1 to 10.3% (DM basis), respectively. The average DE content (14.2 MJ/kg DM for swine) and digestible phosphorus (0.60%, dry matter basis) suggest that wheat DDGS is a good source of these nutrients in swine diets. However, the DE content is highly variable (12.8 to 16.0 MJ per kg DM), and is dependent on the NDF level. Lysine content, as a percentage of crude protein ranged from 0.83 to 3.0%, and ileal lysine digestibility ranged from (49 to 72%), which were the most variable nutritional characteristics of wheat DDGS, and likely related to differences in drying processes used among sources.

Nyachoti et al. (2005) conducted a study to determine the nutritional profile and nutrient digestibility in wheat DDGS in growing pigs. Apparent ileal and total tract digestibility of DM, nitrogen and energy were lower in wheat DDGS compared to wheat grain. Furthermore, wheat DDGS samples had lower apparent ileal digestibility of amino acids compared to wheat, with average values for lysine, threonine and isoleucine in wheat DDGS being 43.8, 62.9 and 68.0%, respectively. The average ileal and fecal DE content in wheat DDGS was 9.7 and 13.5 MJ/kg, respectively, whereas respective values for wheat grain were 13.3 and 14.6 MJ/kg.

Thacker (2006) fed increasing levels of wheat DDGS to 72 pigs during the growing period and reported that ADG, ADFI and nutrient digestibility declined as the level of wheat DDGS increased. However, feeding increasing levels of wheat DDGS during the finishing period did not affect growth performance, but dressing percentage and carcass lean declined at harvest.

Widyaratne and Zijlstra (2007) conducted two experiments to evaluate DE, amino acids, and phosphorus, as well as nitrogen and phosphorus excretion, and growth performance of grower-finisher pigs fed corn, wheat, and a wheat/corn blend (4:1) DDGS. Apparent total tract digestibility of energy was highest for wheat grain (85%) and was not different among DDGS sources (77 to 79%). Total tract DE was higher for corn DDGS (4,292 kcal/kg DM) than wheat/corn DDGS, wheat DDGS and wheat grain samples, 4,038, 4,019, and 3,807 kcal/kg, respectively. Apparent ileal digestibility of lysine was highest for wheat (71%) and was not different among DDGS sources (59 to 63%), whereas the apparent ileal digestible lysine content was highest for corn DDGS (0.51% DM), intermediate for wheat/corn DDGS and wheat DDGS (0.45 and 0.42%, respectively), and lowest for wheat (0.37%). Total tract digestibility of phosphorus was lowest for wheat (15%) and did not differ among DDGS samples (53 to 56%). Total nitrogen excretion was highest for wheat/corn DDGS and wheat DDGS (55 and 58 g/day), intermediate for corn DDGS (44 g/day) and lowest for wheat (36 g/day). Total phosphorus excretion was not different among DDGS sources (11 g/day), and was lowest for wheat (8 g/day). Average daily feed intake and ADG were higher for pigs fed the wheat control diet compared with the DDGS diets, but feed efficiency was similar. These results show that the digestible nutrient content of wheat DDGS is lower than corn DDGS, but higher than wheat. Since feeding DDGS reduced growth performance when using the digestible nutrient content previously determined, these researchers indicated that more research is required to improve the feeding value of wheat DDGS.

Emiola et al. (2009) investigated the effect of supplementing a wheat DDGS-based diet with carbohydrase enzyme blends on growth performance and nutrient digestibilities in growing and finishing pigs. Their results showed that supplementing multiple carbohydrase enzymes in a 30% wheat DDGS-based diet improved growth performance and apparent total tract digestibility of DM, nitrogen, gross energy, and crude fiber in growing pigs and apparent ileal digestibility of nutrients in finishing pigs.

Nutritional value for poultry

Thacker and Widyaratne (2007) conducted a feeding trial to determine the effects of feeding 0, 5, 10, 15, and 20% wheat DDGS on nutrient digestibility and performance in broiler chicks. Dry matter, energy, and phosphorus digestibility linearly declined with increasing levels of wheat DDGS in the diet. However, there were no differences in weight gain, feed intake, or feed conversion for chicks fed increasing levels of wheat DDGS in the diet, but weight gain and feed conversion tended to decline when the 20% DDGS diet was fed. These results suggest that wheat DDGS can be successfully added to broiler diets and that the low energy and lysine content can be overcome by proper diet formulation.

Richter et al. (2006) fed diets containing up to 20% wheat DDGS to broiler chicks (0-8 weeks of age) and diets containing up to 15% wheat DDGS to young laying hens (9-18 weeks of age), with the addition of non-starch polysaccharide hydrolyzing enzymes. Broiler growth performance was not affected by dietary wheat DDGS level, and adding non-starch polysaccharide hydrolyzing enzymes improved weight gain by 2.5%. However, finishing performance of broilers decreased with increasing level of wheat DDGS in the diet, suggesting a maximum dietary inclusion rate of 5% for wheat DDGS. Dietary level of wheat DDGS had no effect on laying performance or egg quality.



Leytem et al. (2008) determined the impact of feeding 0, 5, 10, 15, and 20% wheat DDGS to broilers on nutrient excretion and phosphorus solubility. Apparent retention of both nitrogen and phosphorus decreased linearly with increasing levels of wheat DDGS in the diet. Nutrient output per kilogram of dry matter intake increased linearly with increased DDGS inclusion rate for nitrogen, phosphorus, and water soluble phosphorus. Increasing dietary DDGS levels increased phosphorus concentration in excreta, and decreased phytate phosphorus concentrations in excreta, which resulted in an increase in water soluble phosphorus and the fraction of total P that was soluble. These results indicate that high levels of wheat DDGS in the diet increase the amount of nitrogen and phosphorus in the excreta which should be accounted for in manure management plans.

Nutritional value for beef cattle

McKinnon and Walker (2008) showed that replacement of barley grain with wheat-based DDGS at 25 and 50% of the total ration DM increased ADG and gain efficiency of backgrounding steers, with no differences in DM intake or composition of gain.



Beliveau and McKinnon (2008) conducted a trial to evaluate feeding increasing levels of wheat DDGS on feedlot performance and carcass characteristics of growing and finishing cattle. Their results showed wheat DDGS is an effective replacement for barley grain in cattle diets by providing both energy and protein to the diet. For finishing cattle, wheat DDGS has an energy value at least equal to that of barley grain when fed at levels up to 23% of the diet DM.

Hao et al. (2009) evaluated the impact of feeding 0, 20, 40, 60, and > 60% wheat DDGS on manure nutrient and volatile fatty acid excretion in feedlot cattle. Total nitrogen (feces), phosphorus, pH (manure), and water soluble ammonia, increased when cattle were fed the 40 and 60% DDGS diets compared with the 0% DDGS diet. Isobutyric, valeric, and isovaleric VFAs were found in the highest concentrations in feces from cattle fed the 40 and 60% wheat DDGS diets, even though total VFA content did not change with dietary DDGS level. These research results suggest that manure produced from cattle fed wheat DDGS will provide more nitrogen and phosphorus to crop land, and also increase ammonia emissions and odor, suggesting that wheat DDGS be restricted to a maximum of 20% in cattle diets to minimize excess manure nutrients and malodors.

DDGS from Other Feedstock Sources

Although corn and wheat are the predominant grains used to produce ethanol and DDGS worldwide, other grains and high starch feedstocks are also used, but to a much lesser extent. Limited data on crude protein, crude fat, and crude fiber for DDGS produced from various alternative feedstock have been published, but **Table 4** provides a summary of their general composition differences (Moreau et al., 2012). It is important to recognize that corn DDGS has a higher concentration of crude protein, crude fat, and crude fiber than any of these alternative DDGS sources, which makes it the most valuable feed ingredient derived from ethanol production.

Table 4. Nutrient composition (dry matter basis) of DDGS produced from various grains^{1,2}

Nutrient, %	Crude Protein	Crude fat	Crude Fiber
Barley, hulled	17.7	2.5	5.7
Oats	16.0	6.3	2.0
Rye	8.0-10.4	ND	ND
Triticale	10.33	ND	ND
Rice, brown long grain	7.94	2.92	3.5
Rice, short white	6.50	0.52	2.8
Pearl millet	9.73-13.68	6.8	ND
Cassava	1.5-3.0	0.2	3-4

¹ND = not determined

²Adapted from Moreau et al., 2012

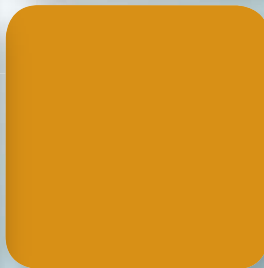
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CHAPTER 7

Physical and Chemical Characteristics of DDGS Related to Handling and Storage of DDGS



Chapter 7

Physical and Chemical Characteristics Related to Handling and Storage of DDGS

Introduction

Physical and chemical properties of DDGS vary among sources and can influence its feeding value, handling, and storage characteristics. These include color, smell, particle size, bulk density, pH, color, thermal properties, flowability, shelf life stability, and hygroscopicity. Distiller's dried grains with solubles is characterized as a heterogeneous granular material consisting of a range of particle types, sizes and shapes. Particles included corn fragments (i.e. tip cap, and pericarp tissues), non-uniformly crystallized soluble protein and lipid coatings on the surface of these fragments, and agglomerates (i.e. "syrup balls") that are formed during the drying process (Rosentrater, 2012). These characteristics affect handling, flowability, and storage behavior of DDGS.

Physical properties of DDGS vary among and within ethanol plants, and much of this variation is caused by several factors (Rosentrater, 2012) including:

- Raw material (corn) characteristics
- Hammermill settings
- Conditions, additives, and chemicals used during processing
- Proportion of condensed distillers soluble added to wet distillers grains before drying
- Type of dryer used
- Drying time and temperature
- Cooling and conditioning of DDGS after drying
 - Flat storage vs. vertical silo
 - Final moisture content
 - Cooling time prior to shipping
 - Loading into transport vehicles and containers when hot
 - Ambient temperature and humidity

Considerable research has been conducted during the past few years to measure various physical properties, particularly focused on flowability of DDGS (Rosentrater, 2006a; Ganesan et al., 2008a,b). Rosentrater (2006a) collected DDGS samples from 6 dry grind ethanol plants in eastern South Dakota in 2004 to determine moisture, water activity, thermal conductivity, thermal resistivity, thermal diffusivity, bulk density, angle of repose, and color measures by Hunter L*, a*, and b*, and the results are shown in **Table 1**.

Table 1. Average and range of physical properties of 144 samples of DDGS from 6 dry grind ethanol plants ¹

Physical Property	Minimum	Maximum	Mean
Moisture content, %	13.4	21.2	14.7
Water activity, -	0.53	0.63	0.55
Thermal conductivity, W/m°C	0.06	0.08	0.07
Thermal resistivity, m°C/W	13.1	15.6	14.0
Thermal diffusivity, mm ² /s	0.13	0.15	0.13
Bulk density, kg/m ³	389.3	501.5	483.3
Angle of repose, °	26.5	34.2	31.5
Color, Hunter L*	40.0	49.8	43.1
Color, Hunter a*	8.0	9.8	8.7
Color, Hunter b*	18.2	23.5	19.4

¹ Rosentrater, 2006.

In general, the variability (standard deviations) among samples within measurement was low except for bulk density. The moisture content averaged 14.7% in these samples which is above the 12% recommended maximum moisture content for feed ingredients to minimize transportation costs and microbiological spoilage (Rosentrater, 2006a). Water activity is a measure of the amount of “free” water available and the susceptibility of the samples for spoilage and deterioration by microorganisms and chemical agents. Thermal conductivity, resistivity, and diffusivity describe the ability of a material to conduct heat, resist heat, or diffuse heat, respectively. Sources of DDGS have thermal conductivity values ranging from 0.06 to 0.08 W/(m°C) and thermal diffusivity values ranging from 0.13 to 0.15 mm²/s (Rosentrater, 2012). Bulk density is an important factor in determining the storage volume of transport vehicles, vessels, containers, totes, and bags. Bulk density affects transport and storage costs. Low bulk density ingredients have higher cost per unit of weight. It also affects the amount of ingredient segregation that may occur during handling of complete feeds. High bulk density particles settle to the bottom of a load during transport, whereas low bulk density particles rise to the top of a load. Angle of repose is a measure of flowability of a substance and color L* is the lightness or darkness of color, a* is the redness or greenness of color, and b* is the yellowness or blueness of color.

Color

Color of corn DDGS can vary from very light, golden yellow in color to very dark brown in color. A detailed summary of the relationship of DDGS color to quality and nutritional value is found in **Chapter 8**. Color is measured in the laboratory using either Hunter Lab or Minolta colorimeters which are used extensively in the human food and animal feed industries to measure the extent of heat damage (browning) in heat processed foods (Ferrer et al., 2005) and feed ingredients (Cromwell et al., 1993). These colorimeters are now commonly used to measure color characteristics of DDGS sources in the U.S. ethanol industry. Lightness or darkness of color is determined by the L* reading (0 = dark, 100 = light), the a* reading measures the redness of color and the b* reading measures the yellowness of DDGS color. Bhadra et al. (2007) reported that L* ranged from 36.6 to 50.2, a* ranged from 5.2 to 10.8, and b* ranged from 12.5 to 23.4 among DDGS sources.

Several factors affect DDGS color including the amount of solubles added to grains before drying, type of dryer and drying temperature used, and the natural color of the feedstock grain being used. The color of corn kernels can vary among varieties and has some influence on final DDGS color. Corn-sorghum blends of DDGS are also somewhat darker in color than corn DDGS because of the bronze color of many sorghum varieties.

When a relatively high proportion of solubles are added to the mash (grains fraction) to make DDGS, the color becomes darker. Noll et al. (2006) conducted a study where they evaluated color in batches of DDGS where approximately 0, 30, 60, and 100% of the maximum possible of syrup was added to the mash before drying. Actual rates of solubles addition to the mash were 0, 12, 25, and 42 gallons/minute. As shown in **Table 2**, increasing solubles addition rate to the mash resulted in a decrease in L* (lightness of color) and b* (yellowness of color), with an increase in a* (redness of color). Similar results were also reported by Ganesan et al. (2005).

Table 2. The Effect of the Rate of Solubles Addition to Mash on Color Characteristics of DDGS.

Color (CIE Scale)	0 gal/min	12 gal/min	25 gal/min	42 gal/min	Pearson Correlation	P Value
L*	59.4	56.8	52.5	46.1	- 0.98	0.0001
a*	8.0	8.4	9.3	8.8	0.62	0.03
b*	43.3	42.1	40.4	35.6	- 0.92	0.0001

Adapted from Noll et al. (2006).

Dryer temperatures in dry-grind ethanol plants can range from 127 to 621°C. The amount of time DDGS spends in the dryer also influences the color. In general, the higher the dryer temperature and the longer DDGS remains in the dryer, the darker the resulting DDGS will be. The amount and length of heating is highly correlated to color and lysine digestibility and due to the wide range in dryer temperatures, there is a wide range in lysine digestibility that exists among DDGS sources.

When heat is applied to feed ingredients, a browning or Maillard reaction occurs resulting in the formation of high molecular weight polymeric compounds known as melanoidins. The degree of browning (measured via absorbance at 420 nm) is used to assess the extent the Maillard reaction has taken place in foods. Digestibility of lysine is affected by the extent of the Maillard reaction. Lightness and yellowness of DDGS color have been shown to be reasonable general predictors of digestible lysine content among corn DDGS sources for poultry (**Figure 1**; Ergul et al., 2003) and swine (Cromwell et al., 1993; Pederson et al., 2005). However, among sources of 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%). In a more robust study, Urriola (2007) evaluated the relationship between L* of DDGS sources and digestible lysine content for swine and found that this relationship was poor for samples with L* greater than 50, and an improved, but still poor relationship for DDGS samples with L* less than 50. Cromwell et al. (1993) evaluated the relationship between Hunter Lab color scores of various sources of DDGS and acid detergent insoluble nitrogen on growth performance of pigs (**Table 3**).

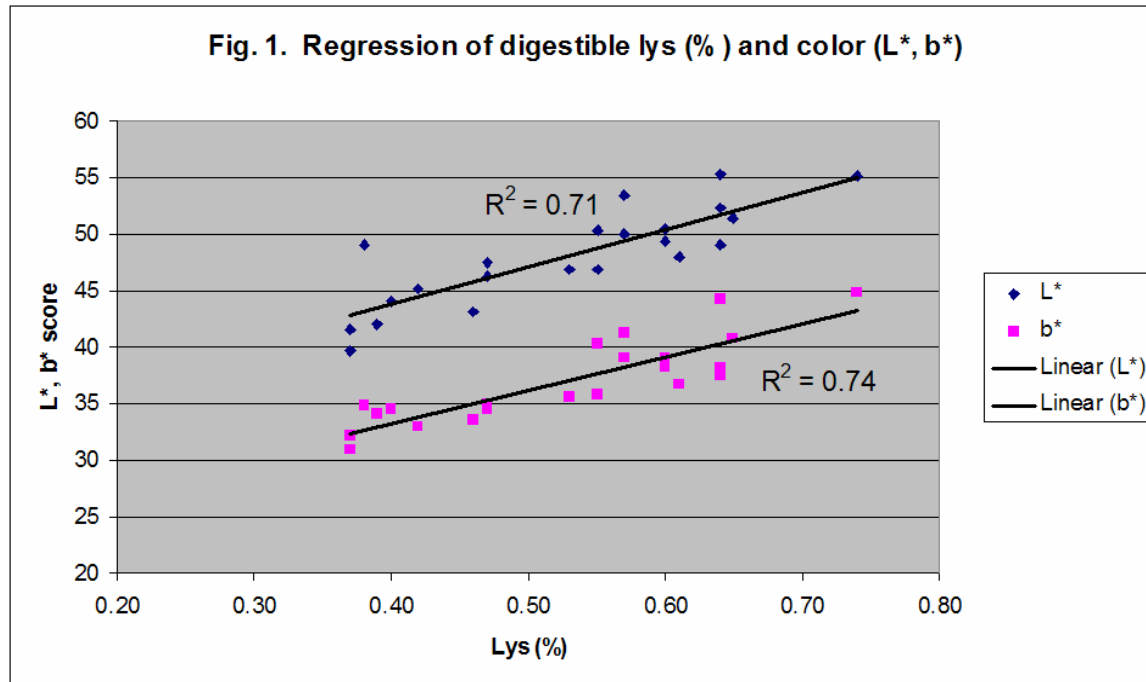


Table 3. Effect of Acid Detergent Insoluble Nitrogen (ADIN) and Color Score on Growth Performance of Pigs Fed Three Blended Sources of DDGS¹

DDGS Source	L* ^b	a* ^b	b* ^b	ADIN, %	ADG, g ^a	ADFI, g ^a	F/G ^a
A	29.0	6.5	12.7	27.1	218	1,103	5.05
E	31.1	6.1	13.1	36.9			
G	38.8	6.8	16.5	16.0	291	1,312	4.52
I	41.8	6.5	18.8	26.4			
B	53.2	4.7	21.8	8.8	390	1,416	3.61
D	51.7	7.1	24.1	12.0			

¹Cromwell et al., 1993.

^aSignificant differences among diets ($P < .01$).

^bL* = lightness of color (0 = black, 100 = white). The higher the a* and b* values, the higher amount of redness and yellowness, respectively.

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 as a result, use less enzymes, while other plants will use more enzymes and do 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.

Smell

High quality, golden DDGS has a sweet, fermented smell. Dark colored DDGS sources that have been overheated have a burned or smoky smell.

Particle Size and pH

Particle size and particle size uniformity of feed ingredients are important considerations for livestock and poultry nutritionists when selecting sources and determining the need for further processing when manufacturing complete feeds or feed supplements. Particle size affects nutrient digestibility, mixing efficiency, amount of ingredient segregation during transport and handling, pellet quality, bulk density, palatability, sorting of meal or mash diets, and the incidence of gastric ulcers in swine.

Bulk density is an important factor to consider when determining the storage volume of transport vehicles, vessels, containers, totes, and bags. Bulk density affects transport and storage costs. Low bulk density ingredients have higher cost per unit of weight. It also affects the amount of ingredient segregation that may occur during handling of complete feeds. High bulk density particles settle to the bottom of a load during transport, whereas low bulk density particles rise to the top of a load.

Several unpublished studies conducted at the University of Minnesota have shown that particle size among DDGS sources is highly variable. In a 2001 study, the average particle size among 16 ethanol plants was 1282 microns (SD = 305, CV= 24%), and ranged from 612 microns to 2125 microns. Two additional DDGS nutrient analysis and physical characteristics surveys were conducted by researchers at the University of Minnesota in 2004 (34 samples from ethanol plants in 11 different states) and 2005 (35 samples). As shown in **Tables 4 and 5**, average particle size ranges between 665 to 737 μm , but the range in particle size is extremely large 73 to 1217 μm . The pH of DDGS sources averages 4.1 but can range from 3.6 to 5.0.

Table 4. Particle Size, Bulk Density, and pH of 34 DDGS Sources Analyzed in 2004.

	Average	Range	SD	CV, %
Particle size, μm	665	256 - 1087	257.48	38.7
Bulk density, lbs/ft^3	31.2	24.9 – 35.0	2.43	7.78
pH	4.14	3.7 – 4.6	0.28	6.81

Table 5. Particle Size, Bulk Density, and pH of 35 DDGS Sources Analyzed in 2005.

	Average	Range	SD	CV, %
Particle size, μm	737	73 – 1217	283	38.0
Bulk density, lbs/ft^3	25.2	22.8 – 31.5	8.6	34.2
pH	4.13	3.6 – 5.0	0.33	7.91

Recent studies have been conducted to evaluate particle size variation and characteristics in DDGS. Liu (2009) conducted a study to evaluate the effect of particle size distribution of ground corn and its effects on the particle size distribution in DDGS. To do this, he analyzed 6 ground corn samples and their corresponding DDGS for particle size distribution, using a series of 6 US standard sieves: Numbers 8, 12, 18, 35, 60, and 100, and a pan. Individual corn and DDGS samples had variable geometric mean diameter of particles, and the average diameter of DDGS particles was greater than that of corn (0.696 vs. 0.479 mm), indicating that during conversion of

corn to DDGS, certain particles become larger. The relationship between diameter and mass frequency of individual particle size categories varied, but the particle size distribution of the whole sample was correlated between them ($r = 0.81$). When comparing the nutrient composition of corn to DDGS, crude protein, oil, ash, total non-starch carbohydrates were concentrated 3.59, 3.40, 3.32, 2.89 times more than found in corn. Although there were positive correlations between protein and non-starch carbohydrate content L^* color values between corn and DDGS, the variation in nutrients and color attributes were greater in DDGS than in corn. The variation was larger in the separated fractions than in the whole fraction for both corn and DDGS. Liu (2009) concluded that the physical and chemical characteristics of the raw material (corn), processing method, and addition of yeasts are among the major factors that cause large variations in particle size among DDGS sources.

Liu (2008) obtained 11 corn DDGS samples from different ethanol plants in the U.S. Midwest, and determined particle size distribution of each sample using a series of six selected US standard sieves: Nos. 8, 12, 18, 35, 50, and 100, and a pan. Particle size among and within DDGS samples was highly variable, averaging 0.660 mm for the geometric mean diameter of particles, and a geometric mean standard deviation average of 0.440 mm of particle diameters by mass. The majority had a unimodal particle size distribution, with a mode in the size class between 0.5 and 1.0 mm. Particle size distribution and color were poorly correlated with nutrient composition of DDGS samples, but the distribution of nutrients and color values were highly correlated with particle size distribution. In various separated fractions of DDGS, the protein content, L^* and a^* color values were negatively correlated, while oil and total CHO content were positively correlated with particle size. These results suggest that it is possible to fractionate DDGS to concentrate certain nutrients based on particle size, and the particle size distribution can be used as an index for potential of DDGS fractionation.

Clementson et al. (2009) investigated the occurrence of particle segregation within piles of DDGS formed by gravity discharge and its effects on subsequent spatial nutrient variability. Particle segregation tests were conducted using piles of DDGS that were formed in a laboratory using DDGS samples from an "old" and a "new" generation fuel ethanol plant. Tests were also performed in a plant study creating piles of DDGS formed from the same two fuel ethanol plants. In both studies, the DDGS piles were formed by gravity-driven discharge and sampled at various locations from the center of the pile to the periphery. Their results showed that particle segregation does result in significant differences in particle size at the sampled locations of the pile, and that particle size (geometric mean diameter) increased from the core of the pile to the periphery. Crude protein and moisture content were the only nutrients that were correlated with particle size, but the correlation of crude protein with particle size was not consistent, while there was a strong, positive correlation of particle size with moisture. These authors concluded that a standard sampling protocol should be developed to insure accurate nutrient determination in DDGS sources based on variable crude protein and moisture content among different portions of a DDGS pile.



Flowability

Unfortunately, DDGS can have some undesirable handling characteristics related to poor flowability under certain conditions. Reduced flowability, or the potential for reduced flowability in DDGS, has caused rail freight companies to not permit the use of their railcars for transport of DDGS (NCERC, 2005). Therefore, DDGS marketers must use their own rail cars to transport DDGS. Reduced flowability and bridging of DDGS in bulk storage containers and transport vehicles limits the acceptability of some DDGS sources for some customers because feed mills do not want to deal with the inconvenience and expense of handling a feedstuff that does not flow through their feed milling systems.

Flowability is defined as the ability of granular solids and powders to flow during discharge from transportation or storage containments. Flowability is not an inherent natural material property, but rather a consequence of several interacting properties that simultaneously influence material flow (Rosentrater, 2006b). Flowability problems may arise from a number of synergistically interacting factors including product moisture, particle size distribution, storage temperature, relative humidity, time, compaction pressure distribution within the product mass, vibrations



during transport, and/or variations in the levels of these factors throughout the storage process (Rosentrater, 2006b). In addition, other factors that may affect flowability include chemical constituents, protein, fat, starch, and carbohydrate levels as well as the addition of flow agents.

Since flow behavior of a feed material is multidimensional, there is no single test that completely measures the ability of a material to flow (Rosentrater, 2006b). Shear testing equipment are the primary equipment used to measure the strength and flow properties of bulk materials. They also measure the amount of compaction as well as the bulk strength of materials (Rosentrater, 2006). Another approach for measuring the flowability of granular materials involves measuring four main physical properties: angle of repose, compressibility, angle of spatula, and coefficient of uniformity (e.g. cohesion) (Rosentrater, 2006b).

Several recent studies have been published regarding the causes of DDGS flowability problems and potential solutions to improve flowability. In a review of research data on the flowability and handling characteristics of bulk solids and powders, Ganesan et al. (2008a), suggested that DDGS flowability may be affected by storage moisture, temperature, relative humidity, particle size, time, or temperature variations, and other factors. Bhadra et al. (2008) evaluated surface characteristics and flowability of DDGS using cross sectional staining of DDGS particles and showed that a higher amount of protein thickness compared to carbohydrate thickness in surface layers from DDGS had lower flow function index, and greater cohesiveness, which indicates possible flow problems. They also observed that higher surface fat occurred in samples with worse flow problems.

Ganesan et al. (2007a) used data obtained from previous work using exploratory data analysis techniques to develop a comprehensive model to predict the flowability of DDGS. A simple and robust model ($R^2 = 0.93$, $SE = 0.12$) was developed, but the model was exclusively based on the DDGS from one ethanol plant. Since DDGS flow properties vary among sources, they suggested using this methodology to develop similar models to predict the flowability of DDGS for other plants. In a follow-up study, Bhadra et al. (2009) measured flowability characteristics of DDGS samples from five ethanol plants in the north central region of the U.S. using Carr and Jenike tests, and the resulting data were mathematically compared with a previously developed empirical model. Their assessment of overall flowability suggested that DDGS samples do have the potential for flow problems, although no samples exhibited complete bridging.

Ganesan et al. (2008b) then conducted a study to determine the effect of moisture content and solubles level on the physical, chemical, and flow properties of DDGS. They determined the effect of five moisture levels (10, 15, 20, 25, and 30%) on the resulting physical and chemical properties of DDGS containing 4 levels of solubles (10, 15, 20, and 25%). Results from this study showed that the level of solubles and moisture content had significant effects on physical and flow properties (e.g., aerated bulk density, packed bulk density, and compressibility). The dispersibility, flowability index, and floodability index were used to show that flowability generally declined as moisture content increased for most of the soluble levels evaluated. The color and protein content of the DDGS were also affected as soluble levels increased.

In a subsequent study, Ganesan et al. (2008c) evaluated the flow properties of DDGS with varying soluble and moisture contents using Jenike shear testing. Results from this study showed that depending on the solubles level in DDGS, and moisture content above a certain level, that the moisture actually began acting as a lubricant, easing the flow of the DDGS. They also observed that with the addition of higher levels of solubles and moisture, the compressibility of DDGS increased. They concluded that DDGS is a cohesive material, and it is likely to produce cohesive arching problems.

In attempts to improve DDGS flowability, two studies have been conducted to determine the effects of adding selected flow agents to DDGS on flowability (Ganesan et al., 2008d; Johnston et al., 2009). Ganesan et al. (2008) evaluated the effect of 0, 1, and 2% calcium carbonate addition to DDGS with variable moisture content and soluble levels. Flowability of DDGS was reduced when percentage of solubles and moisture content increased. Adding the flow agent (CaCO_3) did not improve the flow properties of DDGS, which may have been due to the lack of surface affinity between DDGS and the flow agent particles, or too little inclusion of the flow agent. Similarly, Johnston et al. (2009) conducted a study to evaluate the addition of a moisture migration control agent at 2.5 kg/metric ton (DMX-7), calcium carbonate at 2%, or a clinoptilolite zeolite at 1.25%. The experiment was conducted at a commercial, dry-grind ethanol plant using DDGS at two different moisture levels (9 vs. 12%). Flow rate of DDGS at unloading was higher for the 9% compared with 12% moisture level (620 vs. 390 kg/min). Flow rates of DDGS at unloading were: 509 (Control), 441 (DMX-7), 512 (Calcium carbonate), and 558 (Zeolite) kg/min. None of the ACA created flow rates that differed significantly from Control. These researchers concluded that increasing moisture content from 9% to 11.6% decreased flowability of DDGS and that the flow agents tested in this study, at the selected concentrations, did not improve flowability of DDGS.

Storage Stability

Moisture

Preservatives and mold inhibitors are commonly added to wet distiller's grains (~50% moisture) to prevent spoilage and extend shelf life. However, since the moisture content of DDGS is usually between 10 to 12%, there is minimal risk of spoilage during transit and storage unless water leaks into transit vessels or storage facilities. It is well accepted in the grain handling and feed industry that moisture content of grain and grain by-products should be less than 15% to prevent heating and spoilage (i.e. molds and mycotoxins) during transport and storage. Therefore, unless the moisture content of DDGS exceeds 15%, the shelf life of DDGS appears to be many months. No research studies have been conducted to demonstrate that preservatives and mold inhibitors are necessary to prevent spoilage and extend shelf life of DDGS.

“Clumping” or “caking” can occur as a result of loading DDGS into trucks, rail cars, or containers if it has not been cooled and “cured” properly before loading. This often causes flowability problems and difficulty unloading DDGS. The addition of flow agents did not improve flowability of DDGS but low moisture content (9%) improved flowability compared to DDGS containing 12% moisture (Johnston et al., 2009).

Fat oxidation

In the past, most corn DDGS sources contained 11 to 12% fat (corn oil) on a DM basis, but with the widespread implementation of corn oil extraction technologies, crude fat content can now range from 5 to 12%. Regardless of crude fat content, the fatty acid profile and characteristics of corn oil do not change appreciably and are shown in **Tables 7 and 8**.

Vegetable oils, like corn oil are high in unsaturated fatty acids. As a result, vegetable oils have a higher unsaturated to saturated fatty acid ratio (U:S) compared to animal fats. The U:S ratio affects the melting point and energy value of fat, as well as the fatty acid composition in liver, fat, meat, and milk of pigs and poultry. The iodine value is a method of estimating U:S ratio. Each double bond in a fatty acid has the capability of taking up two atoms of iodine. By reacting fatty acids with iodine, it is possible to determine the degree of unsaturation of a fat or oil. The iodine value is defined as grams of iodine absorbed by 100 grams of fat. Because unsaturated fats have more double bonds, they will have higher iodine values than saturated fats. Iodine value can be used to estimate fatty acid profiles of various fat sources.

Fats are susceptible to breakdown by oxidation to form peroxides, which are unstable compounds, and can become rancid. Peroxide value is sometimes also referred to as initial peroxide value because it is determined on a sample as submitted. A peroxide value of 5.0 mEq of peroxide/kg or lower is an indication of little or no rancidity. High free fatty acid content may indicate oxidation or breakdown of the fat and potential rancidity. Free fatty acids are those that are not linked to glycerol by an ester linkage, but are in free form. Oxidation of fat produces free fatty acids as a by-product. Moisture in fats and high fat ingredients may increase rancidity.

However, this is of relatively little concern in DDGS because the moisture content is typically only 10 to 11%.

Table 7. Selected fatty acids (% total fatty acids) in corn oil.¹

	≤C16:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	≥C:20
Corn oil	0.0	10.9	0.0	1.8	24.2	59.0	0.7	---

¹ Swine NRC, 1998.

Table 8. Chemical characteristics and energy value of corn oil.¹

	Total Saturated, %	Total Unsaturated, %	U:S Ratio	Iodine Value	Total ∑ N-6	Total ∑ N-3	DE, kcal/k g	ME, kcal/k g
Corn oil	13.3	86.7	6.53	125	58.0	0.7	8755	8405

¹ Swine NRC, 1998.

In a field study conducted by the U.S. Grains Council, fat stability of U.S. DDGS was evaluated in hot, humid sub-tropical on-farm storage conditions in Taiwan. This study was conducted at a commercial dairy farm in central Taiwan. The DDGS was produced by an ethanol plant in South Dakota and exported to Taiwan in a 40 foot container. Upon arrival in Taiwan, DDGS was re-packaged in 50 kg feed bags with a plastic lining. Bags of DDGS were stored in a covered steel pole barn for ten weeks during the course of the trial. The trial was conducted from September to November 2003, under high temperature and humidity conditions. A random sample of DDGS was obtained weekly from storage and stored in a freezer until analysis for peroxide value and free fatty acid analysis. Analytical results are shown in **Table 9**. Initial and week 10 peroxide values for DDGS were not different and were well below the maximum 5.0 mEq peroxide/kg threshold value for rancidity. Although the level of free fatty acids in oil extracted from DDGS increased slightly from week 1 to week 10, there is no evidence that lipid oxidation (rancidity) occurred in DDGS. This indicates that the fat in DDGS is stable for at least a 10 week storage period in hot and humid climates where the average temperature was 25.4°C (range from 17.1°C to 32.4°C) and the average % relative humidity was 79.9% (range from 41.2% to 99.5%).

Table 9. Peroxide value of DDGS and free fatty acid concentration of oil extracted from DDGS at week 1 and week 10 of storage.

Analysis	Week 1 Sample	Week 10 Sample
Peroxide value, mEq/kg	0.70	0.60
Free fatty acids, % as oleic	11.2	16.2

Another field study was sponsored by the Minnesota Corn Growers Association in 2003 (www.ddgs.umn.edu), to evaluate DDGS samples (obtained weekly) from storage at commercial feed mill in Jalisco, Mexico for moisture (dry matter), mycotoxins (aflatoxin, ochratoxin, T-2 toxin, fumonisin, and zearalenone), and a measure of fat oxidation (rancidity). Average environmental temperature during the 16-week storage period was 17.0°C, and ranged from an average low of 9.3°C to an average high temperature of 24.7°C. There was no detectable change in oxidative rancidity during the 16-week storage period or presence of mycotoxins.

It is presumed that the apparent stability of corn DDGS is due to the presence of high concentrations of natural antioxidants. Corn contains a high concentration of compounds that have natural antioxidant activity. Adom and Liu (2002) found that corn had the highest total antioxidant activity compared to wheat, oats and rice, and had the highest percentage of bound antioxidants. It is possible that the presence of significant amounts of antioxidants naturally found in corn are likely responsible for excellent stability of DDGS for several weeks of storage, even under hot, humid conditions.

Water Adsorption Properties of DDGS

Limited information exists regarding the water adsorption properties (hygroscopicity; ability to attract moisture) of DDGS. However, the U.S. Grains Council sponsored a broiler field trial in Taiwan, where moisture content of DDGS was monitored during storage at a commercial feed mill from March 16 to June 10, 2004. A random sample of DDGS was obtained weekly from storage at the feed mill and analyzed for moisture over a 13-week storage period. Moisture content of DDGS increased from 9.05% at the beginning of the storage period to 12.26% at the end of the 13-week storage period (**Table 6**). As expected, crude protein concentration did not change in DDGS, and no aflatoxin was present initially or at the end of the storage period. Therefore, it appears that under humid climatic conditions, DDGS will increase in moisture content during long-term storage.

Table 6. Laboratory analysis results for moisture, crude protein, aflatoxin, of DDGS during storage at the commercial feed mill in Taiwan.

Sample Date	Sample Number	Moisture, %	Crude protein, %	Aflatoxin, ppb
16-Mar-04		9.05	27.60	0.00
17-Mar-04		10.17	27.61	0.00
24-Mar-04	1	10.65	27.59	0.00
31-Mar-04	2	10.70	27.63	0.00
7-Apr-04	3	10.71	27.62	0.00
14-Apr-04	4	10.76	27.73	0.00
21-Apr-04	5	10.93	27.71	0.00
28-Apr-04	6	11.02	27.62	0.00
5-May-04	7	11.28	27.54	0.00
12-May-04	8	11.16	27.61	0.00
19-May-04	9	11.70	27.63	0.00
27-May-04	10	11.88	27.61	0.00
3-Jun-04	11	12.13	27.50	0.00
10-Jun-04	12	12.26	27.53	0.00

Moisture appears to be a major factor affecting DDGS flowability during storage and transport, in which storage moisture, temperature, relative humidity, particle size, and time variations may interact to determine flow characteristics. Ganesan et al. (2008e) conducted a study to develop sorption isotherms for DDGS with varying soluble levels, in order to provide facility designers and operators with relevant storage and transport information. They determined equilibrium moisture content of DDGS with four different soluble levels (10, 15, 20, and 25% on a dry basis) using a static gravimetric method at 10°C, 20°C, 30°C, and 40°C over four equilibrium relative humidity levels of 60, 70, 80, and 90%. They observed that the sorption capacity of DDGS increased with increasing temperature and solubles level, and followed a type III isotherm, which is commonly observed in high-sugar foods. The equilibrium moisture content for DDGS containing 10, 15, 20, and 25% solubles (dry basis) ranged from 8.61 to 47.07% (dry basis), 11.58 to 83.49% (dry basis), 13.72 to 90.70% (dry basis), and 15.03 to 132.01% (dry basis), respectively. These researchers applied 9 models to fit the isotherm data, but learned that no common model could accurately predict the sorption isotherms of DDGS with various soluble levels. As a result, they developed a new equilibrium moisture content model (Ganesan-Muthu-Rosentrater model) that included solubles level in DDGS as one of the effects along with temperature and moisture content. This model, along with a new modified exponential 2 model, produced the best fits for DDGS with varying soluble levels, and can be used to predict equilibrium moisture sorption behavior of DDGS under a variety of storage conditions (Ganesan et al., 2007b).

Pelleting

Pelleting DDGS and complete feeds has a number of advantages compared to the granular form including improved flowability, increased bulk density, reduces waste, dust, and particle segregation, as well as potentially improving palatability and energy digestibility when fed to livestock.

Rosentrater (2007) conducted two studies involving laboratory scale and commercial scale to determine the feasibility of pelleting DDGS. The positive results obtained in the laboratory scale study were reproduced in the commercial scale study. In the commercial scale study, he used a single source of DDGS and used two processing lines representing two different equipment manufacturers (Manufacturer A and Manufacturer B). Processing conditions are described in **Table 7**. The major differences between the two pelleting processes were pellet die length, die length/diameter ratio, conditioned mash temperature, pellet mill exit temperature, and moisture content of conditioned mash, pellet mill exit moisture, and cooler exit moisture.

As shown in **Tables 8 and 9**, nutrient and amino acid composition were mostly unchanged before and after pelleting, and heat damage to protein was negligible. Researchers did observe some slight performance differences between the manufacturing processes.

Table 7. Processing conditions used to pellet DDGS¹

Parameter	Manufacturer A	Manufacturer B
Pellet die diameter, in.	11/64	11/64
Pellet die length, in.	1 3/4	2 5/8
Length/diameter ratio	10.2	15.3
Ambient temperature, °F	49	49
Conditioned mash temperature, °F	175	155
Pellet mill exit temperature, °F	190	160
Cooler exit temperature, °F	56	55
DDGS moisture, %	11.34	11.34
Conditioned mash moisture, %	17.73	16.08
Pellet mill exit moisture, %	17.57	16.62
Cooler exit moisture, %	13.49	12.80

¹ Rosentrater, 2007.**Table 8. Nutrient content (dry matter basis) of DDGS before and after pelleting.¹**

Nutrient	DDGS	Manufacturer A	Manufacturer B
Moisture, %	10.8	12.1	12.1
Dry matter, %	89.3	87.9	88.0
Crude protein, %	28.8	28.1	28.6
Heat damaged protein, %	2.9	2.8	2.8
Available protein, %	26.0	25.3	25.8
ADF, %	14.3	13.0	15.4
NDF, %	31.4	30.3	28.9
Crude fiber, %	7.1	5.9	6.6
Crude fat, %	11.0	11.1	11.5
Ash, %	3.84	3.98	4.00
Total starch, %	11.7	13.9	12.5

¹ Rosentrater, 2007**Table 9. Amino acid content (dry matter basis) of DDGS before and after pelleting.¹**

Amino acid	DDGS	Manufacturer A	Manufacturer B
Alanine, %	2.50	2.15	2.24
Arginine, %	1.08	1.08	1.29
Aspartic acid, %	1.66	1.68	1.71
Cystine, %	0.80	0.83	0.82
Glutamic acid, %	4.61	4.63	4.69
Glycine, %	1.05	1.01	1.01
Histidine, %	0.76	0.74	0.74
Isoleucine, %	1.00	0.83	0.84
Leucine, %	3.18	3.00	3.10
Lysine, %	0.80	0.81	0.81
Methionine, %	0.59	0.58	0.54
Phenylalanine, %	1.34	1.33	1.37
Proline, %	2.12	2.13	2.15
Serine, %	1.24	1.36	1.30
Threonine, %	0.92	1.01	0.99
Tyrosine, %	1.07	1.11	1.07
Tryptophan, %	0.28	0.24	0.28
Valine, %	1.41	1.08	1.18

¹ Rosentrater, 2007

Pelleting DDGS did cause changes in physical properties (**Table 10**). Pelleting DDGS resulted in darker color, regardless of manufacturer equipment used, but bulk density increased (9 to 20%) and angle of repose (a measure of flowability) decreased 18 to 19% indicating substantially improved flowability for pelleted DDGS. Pellet durability was high (89 to 94%) regardless of the manufacturing equipment used. These results suggest that high quality DDGS pellets can be manufactured without the use of pellet binders. However, pelleting conditions may need to be modified (e.g. pellet die length/diameter ratios) depending on the source of DDGS used.

Table 10. Physical properties of DDGS before and after pelleting.¹

Property	DDGS	Manufacturer A	Manufacturer B
Water activity, -	0.474	0.538	0.534
L* color	40.66	33.26	34.19
a* color	9.48	5.15	6.01
b* color	20.00	13.64	15.17
Particle size-GMD, mm	0.93	-	-
Particle size-GSD, mm	1.61	-	-
Thermal conductivity, W/m°C	0.07	-	-
Thermal diffusivity, mm ² /s	0.15	-	-
Bulk density, kg/m ³	476.14	571.93	519.50
Angle of repose, °	20.06	16.36	16.21
Unit density, kg/m ³	-	1035.25	938.44
Durability, %	-	93.93	88.87
Mechanical strength, MPa	-	0.51	0.30
Modulus elasticity, MPa	-	5.24	2.41

¹ Rosentrater, 2007

Xu et al. (2008) conducted a study to evaluate pelleting corn DDGS (3.5 cm in length, 1.5 cm in diameter) utilizing a closed-end die under axial stress from a vertical piston applied by an Instron universal testing machine. The pelleting conditions included DDGS moisture content of 25-35%, processing temperature of 100 to 120°C, pressure of 12.5 to 37.5 MPa, and dwell time of 5 to 15 seconds. They measured pellet density, durability, and stability and observed that moisture content, temperature, and pressure significantly affected the properties of DDGS pellets, but the impact of dwell time was negligible. They also observed that increasing temperature initially increased and then decreased unit density, but high moisture and pressure had positive effects on unit density and pellet durability. As pressure and moisture content increased, the density ratio also increased. The results of this study support the conclusions from the Rosentrater (2007) study that suggest that DDGS can be effectively pelleted over the range of variables evaluated. In this study, the optimum pelleting conditions were 34.6% moisture content (much higher than found in DDGS), 107°C press temperature, and 36.8 MPa pressure, which resulted in maximum durability, density, and acceptable dimensional stability.

Conclusions

The physical characteristics of DDGS are similar to other dry, granular feed ingredients such as soybean meal and corn gluten meal, but moisture content, particle size, and stickiness affect thermal properties, bulk density, and flowability. Particle size and temperature and time of heating during the drying process vary among ethanol plants and affect nutrient digestibility of DDGS. Use of conventional pellet dies and processes in commercial feed mills may result in reduced pellet durability and throughput of pellet mills when manufacturing diets containing DDGS. However, modifying the pelleting conditions according to the guidelines summarized in this chapter can result in acceptable pellet quality when DDGS is included in animal feeds.

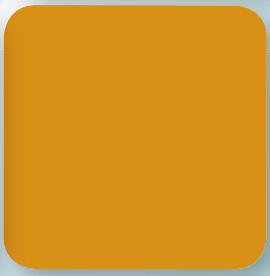
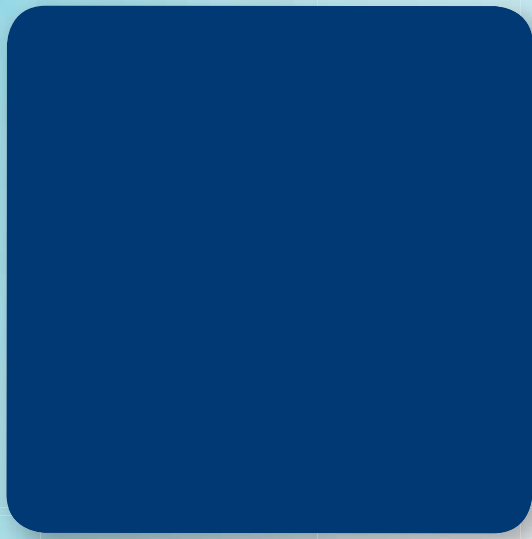
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CHAPTER 8

Is Color the Only or Best Indicator of DDGS Quality?



Chapter 8

Is Color the Only or Best Indicator of DDGS Quality?

Why is DDGS color a quality issue?

There are no grading systems, or defined and regulated quality standards for DDGS like there are for corn (e.g. U.S. #2) and other U.S. grain commodities. As a result, misunderstandings can occur between buyers and sellers of U.S. DDGS worldwide. Establishing prices, writing contracts, and meeting expectations are problematic in the absence of quality standards. While professionals in industry, government, and academia have discussed, and attempted to develop quality standards for DDGS during the past decade, attempts failed due to disagreements on the need for defined quality standards and perhaps the fear of increased transparency and ability to distinguish quality and value differences among DDGS sources. Most U.S. DDGS marketers prefer to focus only on maximum guarantees for moisture and fiber, and minimum guarantees for fat and protein. However, because of variability in nutrient content and quality among U.S. DDGS sources, many international DDGS buyers often demand more guarantees for specific quality attributes to minimize their risk of obtaining co-products that don't meet their expectations.

The color of DDGS has become a quality factor of great importance for some buyers in the export market, and it is being used to differentiate real or perceived quality and value among DDGS sources. Several years ago, some DDGS marketers and buyers developed a subjective color evaluation system using a 5-color scoring card (**Figure 1**) to differentiate color among DDGS sources. Although this DDGS color score card is still used in the market today, many marketers have stopped using it because it is too subjective and resulted in frequent arguments with buyers because of different interpretations of the actual color score of DDGS. As a result, many marketing contracts that are now being negotiated between U.S. suppliers and foreign buyers (especially in Asian countries) contain a minimum guarantee for a quantitative measure of color (e.g. L^* - lightness or darkness of color). The minimum guarantee currently being used to differentiate lightness of DDGS color is a Hunter $L^* >50$ to meet some buyer's expectations. Increasing amounts of U.S. DDGS continue to be exported to various countries regardless of color, but for some markets demanding a guarantee of light colored DDGS (i.e. $L^* >50$), there is a significant price premium obtained for those who can guarantee an $L^* >50$ in the DDGS sources they market.

As a result, some U.S. suppliers have become frustrated and question the value of using DDGS color as an indicator of quality, especially if they are unable to supply DDGS that meets the buyer's color expectations. Therefore, the purpose of this paper is to define DDGS quality and the role of using color as a quality indicator in the marketplace, and provide a description of a variety of other quality characteristics and measurements that can be used to assess DDGS value.

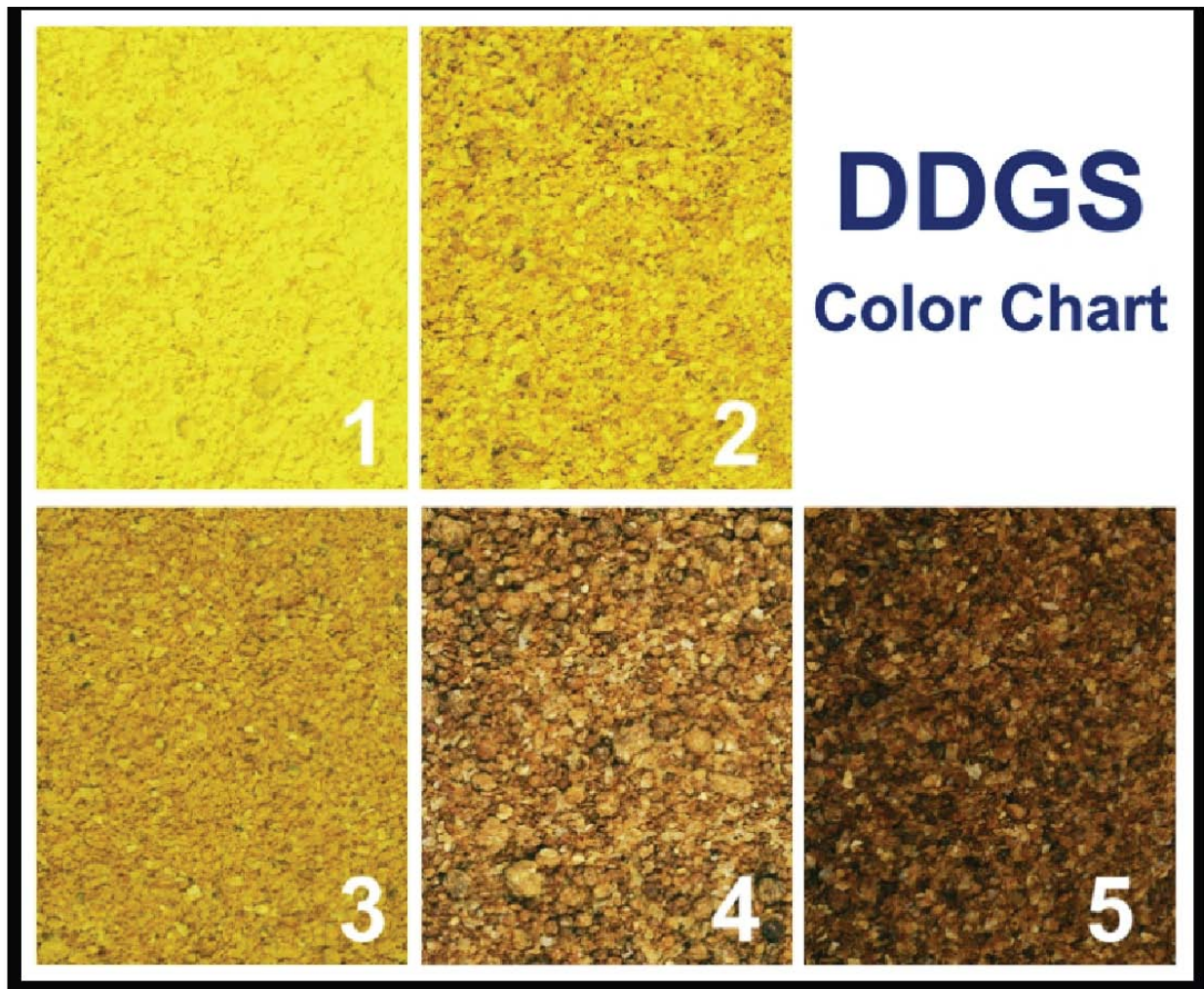


Figure 1. Example of a DDGS color score card.

What is quality?

There are many definitions of quality. Quality is defined as an essential character or inherent feature that represents a degree of excellence, superiority, or a distinguishing attribute (<http://www.merriam-webster.com/dictionary/quality>).

In the context of business (<http://www.businessdictionary.com/definition/quality.html>), quality has been defined as a general measure of excellence or state of being free from defects, deficiencies, and significant variations. The ISO 8402-1986 standard defines quality as "the totality of features and characteristics of a product or service that bears its ability to satisfy stated or implied needs." In the context of manufacturing, quality is defined as strict and consistent adherence to measurable and verifiable standards to achieve uniformity of output that satisfies specific customer or user requirements. Quality can be determined objectively using criteria that are measurable, and subjectively which may be characteristics that can be observed and may be approximated, but cannot be measured. As a result, quality is a general term that refers to the desirable characteristics of material things and can mean different things to different people.

How is quality of feed ingredients and feeds determined?

Feed manufacturers and animal producers use a variety of qualitative and quantitative methods to assess the quality of feed ingredients and feeds including physical, chemical, and biological tests. Physical evaluation of feeds is qualitative but used to identify changes in the nature of the raw materials and feeds. The physical characteristics commonly evaluated include color, particle size, bulk density, homogeneity, smell, taste, touch, and sound. The presence of other grains, weed seeds, husks, and sand are the most common physical contaminants that can be identified by physical evaluation.

Chemical tests are quantitative and allow precise estimation of nutrient content and possible contaminants. Using a commercial laboratory to determine the proximate analysis of feed ingredients is a common practice to evaluate quality. These measurements typically include moisture, crude protein, crude fiber, crude fat, and ash. Ingredient specifications (nutrient content) are essential for feed manufacturing quality assurance programs and serve as the basis for writing purchasing agreements, assessing quality, and to some extent, formulating diets. These nutrient specifications are the standards to which the delivered ingredient must conform to expectations and sometimes include measuring some potential contaminants of concern (e.g. mycotoxins, dioxin).

Feed microscopy is also sometimes used in determining if feeds or feed ingredients have been adulterated or contain contaminants. It involves examining samples of feed ingredients with a microscope under low (8x to 50x) and high (100x to 500x) magnification to evaluate shape, color, particle size, softness, hardness, and texture of feeds.

Biological evaluation of feed ingredients is also done, but is generally confined to universities or large feed companies with animal and laboratory research facilities. It involves the use of animals, and personnel with specialized training to conduct digestion and metabolism trials on various animal species. These methods are time consuming, expensive and, as a result, cannot be routine procedures used as part of a feed manufacturing quality control program. However, they provide the best assessment of feed ingredient quality and feeding value compared to all other methods.

Thus, quality is a general term that refers to the desirable characteristics of material things and can mean different things to different people. For some, DDGS quality may refer to the absence of mycotoxins, and other undesirable anti-nutritional factors that may be detrimental to animal health and performance. To others, it may refer to consistency of nutrient content and digestibility. By these definitions, color can be, and is, used in some markets to define DDGS quality.

Why is color measured?

Color has been used as a subjective indicator of the nutritional quality of feed ingredients for decades. Free amino acids (especially lysine) can undergo Maillard reactions by combining with reducing sugars, rendering them undigestible by the animal. Louis Camille Maillard discovered and described the first evidence of these chemical reactions between sugars and amino acids in 1912. Maillard reactions are a group of chemical reactions that occur when heating sugars and amino acids, as well as complex carbohydrates and amides. These

reactions commonly occur when mid- to high-protein feed ingredients are overheated during the production and drying process, and can be characterized by darkening of color (browning), burned flavor, and burned smell. Drying temperatures used in dry-grind ethanol plants can range from 127 to 621° C. The nutritional significance of the Maillard reactions in DDGS has been shown in ruminants (Klopfenstein and Britton, 1987), as well as in pigs and chickens (Cromwell *et al.*, 1993), and is responsible for losses in protein quality in DDGS (Cromwell *et al.*, 1993; Fastinger and Mahan 2006; Stein *et al.*, 2006). The Maillard reactions also occur in other common ingredients such as dried whey, blood meal, and soybean meal. A darkening of color of these ingredients also indicates overheating and reduced protein quality. Therefore, feed ingredient purchasers and feed manufacturers have been trained to use color as a general indicator for differentiating protein quality and digestibility among feed ingredient sources.

In addition, color can give an indication of the maturity of the grain, storage conditions, presence of toxins, contamination due to sand, and possible use of insecticides/fungicides, which give a dull and dusty appearance. Sorghum with an orange to red color may indicate high tannin content. Browning or blackening of grain or grain co-products can indicate excessive heat treatment or spoilage due to improper storage, thus reducing nutritive value. Black colored fish meal may indicate rancidity of fish oil.

How is color measured?

Hunter and Minolta colorimeters have been used for many years in human food industry as indicators of nutritional and physical characteristics of heat processed products such as candy bars, cookies, and bread. In these food products, color is often an important quality attribute that determines the attractiveness of the product to consumers. Color is measured by reading three color characteristics specifically defined by the *Commission Internationale d'Eclairage*, in Vienna, Austria. [Lightness or L^* (0 dark, 100 lighter), a^* (redness-greenness), and b^* (yellowness-blueness);

Figure 2]. Colorimetric measurements of feed ingredients,

especially for DDGS, have become common in the feed industry to assess the extent of heat damage of mid- to high- protein ingredients. It is important to realize that color scores using Minolta colorimeters are lower than for Hunter Lab colorimeters. Urriola (2007) showed that L^* readings are generally 2.9 units lower, and b^* readings are 1.7 units lower for Minolta compared to Hunter readings of the same sample. However, the ranking of samples by color scores using both methods is the same. Therefore, if color measures are used as criteria for marketing DDGS sources, it is essential that the method used (e.g. Hunter or Minolta) is defined in the contract to avoid misinterpretation of results.

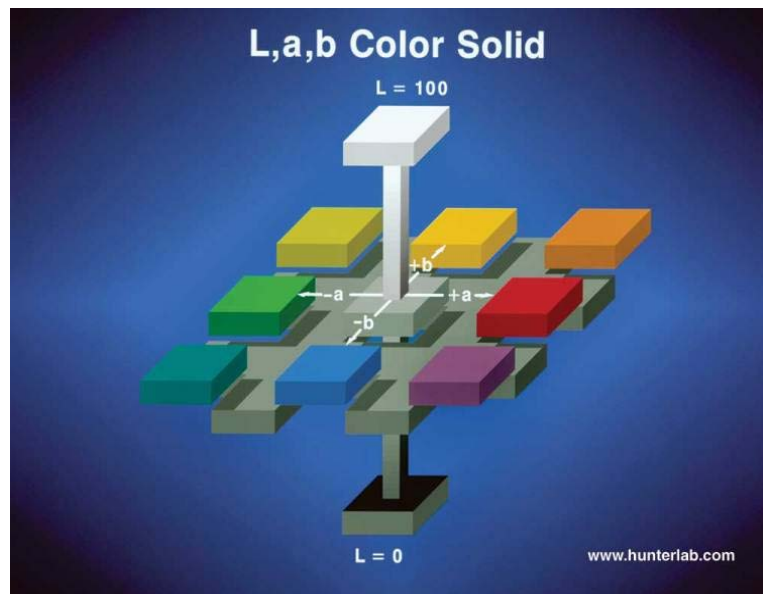


Figure 2. Hunterlab color measurement scales.

Why is color important in some exports markets but not in others?

When living and working in a global economy, it is essential to understand how different cultures around the world perceive things, the symbolic nature of how they may think, and the basis for the actions they choose to take. As an example, the web site (http://webdesign.about.com/od/colorcharts/l/bl_colorculture.htm) describes what different colors mean in different cultures. For example, the color yellow in Chinese culture is considered the most beautiful and corresponds with earth and the center of everything (http://en.wikipedia.org/wiki/Color_in_Chinese_culture). Yellow is ranked above brown and also signifies neutrality and good luck. Yellow was the color of Imperial China, is the symbolic color of the five legendary emperors of ancient China, often decorates royal palaces, altars and temples, and was used in the robes and attire of the emperors. Yellow also represents freedom from worldly cares and is highly regarded in Buddhism.

Furthermore, consumers in many Asian countries prefer dark yellow colored egg yolks and yellow colored chicken skin over pale colored egg yolks and chicken skin typical of that found in the U.S. The color yellow or golden is held in higher esteem than brown and is likely one of the contributing factors to why “golden” DDGS is the preferred color of DDGS in many parts of Asia.

Is there a relationship between DDGS color and nutritional value?

Variation in color among DDGS sources

There are significant differences in color among U.S. corn DDGS sources (**Figure 3**). Fifteen studies have been conducted to evaluate the range of color (L^* , a^* , and b^*), or degree of heating, among DDGS sources and its relationship to differences in nutritional quality and physical characteristics. A summary of the key findings of these studies is show in **Table 1**. All but two studies (Urriola, 2007; Song et al. 2011) evaluated DDGS samples from a limited number of sources (2 to 9 sources). However, despite the limited number of sources evaluated in most of these studies, there was a significant range in L^* color scores among the samples analyzed except for the studies reported by Rosentrater (2006), Pahn et al. (2009), and Kingsly et al. (2010). Samples of DDGS from beverage ethanol plants were included in the Cromwell et al. (1993) and Urriola (2007) studies, which may be the reason for the extremely low L^* values (dark samples) in those studies, but does not explain the low L^* values obtained in the studies by Fastinger and Mahan (2006) and Bhadra et al. (2007), when only DDGS from fuel ethanol plants was evaluated.



Figure 3. Color differences among U.S. corn DDGS sources.

Table 1. Summary of research results involving DDGS color (or degree of heating) on nutritional and physical characteristics.

Reference	# DDGS sources	L* range	a* range	b* range	Key findings
Cromwell et al. (1993)	9	28.9-53.2	ND	12.4-24.1	Significant correlation between DDGS L* and lysine level, and L* and b* with weight gain and feed/gain in broiler chicks. Effects were similar in pigs. ADIN of DDGS sources was also highly correlated with chick weight gain and feed/gain.
Whitney et al. (2001)	2	ND; Light and Dark	ND	ND	Lighter colored DDGS had an AID for lysine of 47.4% but darker colored DDGS had an AID for lysine of 0% for pigs.
Ergul et al. (2003)	4	41.8-53.8	ND	32.9-42.8	Significant correlations between L* and b* and digestible lysine in poultry.
Roberson et al. (2005)	2	ND; Light and Dark	ND	ND	Light colored source had 29.8 mg/kg xanthophyll, dark colored source had 3.5 mg/kg xanthophylls
Rosentrater (2006)	6	40.0-49.8	8.0-9.8	18.2-23.5	L*, a*, and b* were correlated with several physical properties
Batal and Dale (2006)	6	47.9-62.9	4.1-7.6	8.8-28.4	Significant correlations were found between digestible Lys, Thr, Arg, His, and Trp and L* values and b* values, but not with a* values.
Fastinger and Mahan (2006)	5	28.0-55.1	6.7-9.0	15.8-41.9	DDGS sources with higher L* and b* color had greater apparent and standardized digestibility of AA in pigs than DDGS sources of a darker color.
Urriola (2007)	34	36.5-62.5	8.0-12.0	21.3-47.0	Digestible crude protein and amino acids were poorly predicted ($R^2 < 0.30$) from Minolta or Hunter color scores in pigs. Correlation ($R^2 = 0.48$) between L* and SID lysine was higher among samples with $L^* < 50$ than samples with $L^* > 50$ ($R^2 = 0.03$).
Bhadra et al. (2007)	3	36.6-50.2	5.2-10.8	12.5-23.4	Color parameters a* and b* had high correlations with water activity and moderate correlations with thermal properties which may be important for feed storage and further processing
Martinez Amezcua and Parsons (2007)	ND	ND; heat processed light colored DDGS sample	ND	ND	Increased heating of DDGS significantly increased relative P bioavailability in DDGS in poultry, but amino acid digestibility, especially lysine, was greatly reduced.
Ganesan et al. (2008)	ND	40.8-54.1	12.4-18.7	57.6-73.3	Amount of solubles added to grains to make DDGS reduced L* and increased a* and interacts with moisture content to affect DDGS color.
Liu (2008)	6	44.9-59.6	8.3-11.4	31.0-46.4	Most DDGS samples showed a decrease in L* and b*, and a slight increase in a* as particle size increased.
Pahm (2009)	7	49.3-56.4	10.4-14.5	36.7-43.9	Correlation between L* and SID lysine in chicks was poor (0.29), but very high (0.90) for relative bioavailability of lysine.
Kingsly et al. (2010)	1	49.0-53.4	8.8-11.3	24.7-26.5	As the CDS level was reduced, L* value increased and a* decreased.
Song et al. (2011)	31	45.2-58.1	9.3-12.4	26.6-42.4	Significant correlations between measures of fat oxidation (TBARS and PV) and L* and b*. DDGS TBARS were 5 to 25x > corn.

ND = not measured

Relationship between DDGS color and lysine digestibility for pigs and poultry

Research by Evans and Butts (1948) was the first to show that excessive heating of feed ingredients can result in binding of amino acids and protein to other compounds, such as fiber, and reduce amino acid digestibility (especially lysine) in monogastric animals (i.e. swine, poultry, fish). As a result, the use of color as an indicator of excessive heating and reduced amino acid digestibility in DDGS, has been a primary objective in 7 of the 15 research studies conducted (**Table 1**). The first evidence of the relationship between DDGS color, lysine content, and animal performance was published by Cromwell et al. (1993). They showed that lysine concentrations tended to be highest in the lightest colored DDGS sources, intermediate in the medium colored, and lowest in the darkest colored DDGS sources. In addition, there was a significant correlation between Hunter L* and weight gain and feed/gain in broiler chicks. When DDGS sources of similar color scores were blended and fed to pigs, performance results were similar to those observed in the chick studies. Additional poultry studies by Ergul et al. (2003) and Batal and Dale (2006) evaluated DDGS sources representing a wide range of L* and b* values and confirmed the results by Cromwell et al. (1993) by showing that L* and b* were significantly correlated with digestibility of lysine and other amino acids. However, results from a recent study by Pahm et al. (2009), which evaluated 7 DDGS sources that could be classified as “golden” in color, and had a narrow range in L* values (49 to 56), showed no effect of L* on lysine digestibility in poultry, but there were significant differences in the relative bioavailability of lysine among these sources.

Similarly, results from additional pig studies (Whitney et al., 2001; Fastinger and Mahan, 2006) showed lower amino acid digestibility in DDGS sources that had lower L* values (darker in color) compared with sources with higher L* values. However, Urriola (2007) was the first to demonstrate using a large number of DDGS samples (n = 34) over a wide range of L* values (37 to 63) that digestible crude protein and amino acids were poorly predicted ($R^2 < 0.30$) from Minolta or Hunter color scores in pigs. The association between L* and digestible lysine was greater for samples with an L* less than 50 compared to samples with L* greater than 50 (**Figure 4**). However, even for DDGS samples with L* less than 50, the correlation between L* and digestible lysine content in pigs was relatively low ($R^2 = 0.48$), indicating that color cannot be used to accurately predict digestible lysine content among DDGS sources. The results from these studies indicate that L* and b*, but not a* may be useful general indicators of relative lysine digestibility if L* values are < 50, but not if L* values are > 50.

Relationship between drying temperature and relative phosphorus bioavailability in DDGS

Although, there is consistent evidence that excessive heating (lower L* and dark color) during the DDGS drying reduces digestibility of lysine and other amino acids, it may increase the relative bioavailability of phosphorus for poultry. Martinez-Amezcuca and Parsons (2007) applied increasing heating temperatures to light colored DDGS samples and observed that the relative bioavailability of phosphorus was improved, but amino acid digestibility was greatly reduced. This is the first evidence demonstrating that excessive heating of DDGS may enhance its nutritional value for poultry by improving the utilization of phosphorus.

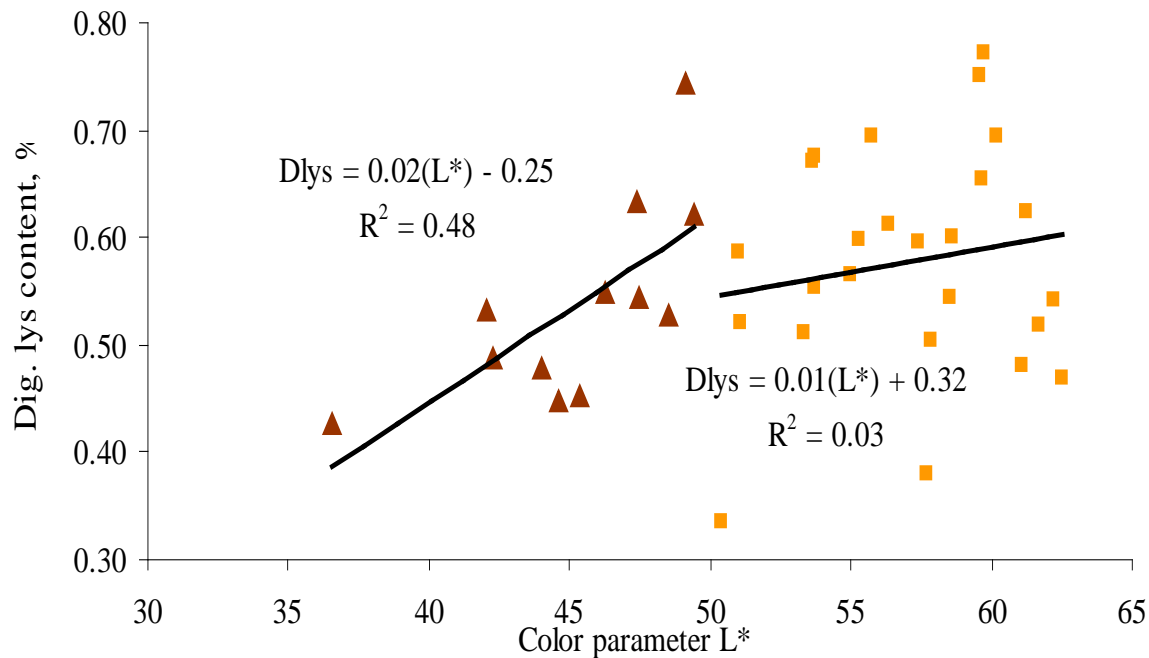


Figure 4. Relationship between lightness of color (L^*) and digestible lysine content of corn DDGS for swine. (Urriola, 2007)

Relationship between DDGS color and xanthophyll content

Limited studies have been conducted to determine xanthophyll content in DDGS. Xanthophylls are yellow/orange pigments naturally occurring in corn and corn co-products, and are valuable components in poultry diets in many countries, especially Asia, in order to produce a desired golden color in egg yolks and broiler skin. Synthetic xanthophyll pigments (often derived from marigold petals) are very expensive, but are commonly added to poultry diets in Asian countries as the primary source of pigment. Therefore, adding corn co-products such as corn gluten meal, and to a lesser extent, DDGS, to poultry diets reduces the need for using expensive synthetic pigments and consequently, reduces diet cost while meeting desired egg yolk and skin color quality standards preferred by consumers.

Xanthophyll values in DDGS have been reported to be between 10.6 mg/kg (NRC, 1981) and 34.0 mg/kg (Sauvant and Tran, 2004). Roberson et al. (2005) did not use Minolta or Hunter colorimeters to measure color, but showed that dark colored DDGS contained 3.5 mg/kg xanthophyll compared to light golden colored DDGS which contained 29.8 mg/kg xanthophyll. They indicated that overheating of DDGS may cause oxidation of xanthophyll resulting in lower concentrations. Therefore, it appears that lighter colored DDGS is more likely to contain higher amounts of xanthophylls than darker colored DDGS.

Relationship between DDGS color and level of lipid oxidation

Very little research has been conducted to evaluate the amount of oxidized oil in DDGS. Dried distillers grains with solubles contains approximately 10% corn oil. Corn oil contains high levels of polyunsaturated fatty acids (particularly linoleic acid) that are vulnerable to lipid peroxidation. Drying temperatures used by ethanol plants can vary substantially (185 to 1100° F), and increased drying time and temperature used during the drying process accelerates lipid peroxidation. Lipid peroxidation in animal feed has been shown to negatively affect pig health and growth performance (L'Estrange et al., 1967; Dibner et al., 1996; DeRouchey et al., 2004). Harrell et al. (2010) showed that nursery pigs fed 20 to 30% DDGS diets had similar growth performance compared to pigs fed highly oxidized corn oil, and feeding oxidized corn oil or DDGS resulted in reduced growth performance compared with pigs fed fresh (non-oxidized) corn oil. Song et al. (2011) recently completed a study to measure thiobarbituric acid reactive substances (TBARS) and peroxide value (PV), which are common analytical methods to measure lipid peroxidation, in DDGS samples obtained from 31 ethanol plants in the U.S. The range in TBARS among DDGS samples was from 1.0 to 5.2 ng MDA equivalents/mg oil, and PV ranged from 4.2 to 84.1 meq/kg oil. The DDGS sample with the highest TBARS and PV values was 25 and 27 times greater, respectively, than the level found in corn. There was a significant negative correlation between L* and b* and the level of lipid peroxidation among DDGS sources indicating darker samples may have higher levels of oxidized lipid than lighter colored DDGS sources.

Is there a relationship between DDGS color and physical characteristics?

Five experiments (**Table 1**) have been conducted to understand the relationship between DDGS color and its physical characteristics, which may affect storage and further feed processing. Rosentrater (2006) was the first to report that L*, a*, and b* were correlated with several physical properties (moisture, water activity, conductivity, resistivity, bulk density, and flowability) of DDGS. Bhadra et al. (2007) confirmed these findings and showed that a* and b* had high correlations with water activity and moderate correlations with thermal properties of DDGS indicating that color may be an indicator for assessing feed storage and further processing characteristics.

Variable amounts of condensed distiller's solubles are added to the coarse grains fraction to produce DDGS among ethanol plants. The proportion of solubles and coarse grains used to produce DDGS affects the nutrient composition of DDGS because the nutrient content of each of these fractions is substantially different. The coarse grains fraction is higher in dry matter (33.8 vs. 19.5%), crude protein (33.8 vs. 19.5%), and crude fiber (9.1 vs. 1.4%), but lower in crude fat (7.7 vs. 17.4%), ash (3.0 vs. 8.4%), and phosphorus (0.6 vs. 1.3%) than the condensed solubles fraction. Therefore, increasing proportions of condensed solubles added to the coarse grains fraction will increase crude fat, ash, and phosphorus but reduce crude protein and crude fiber content of DDGS.

Noll et al. (2006) evaluated the nutrient composition and digestibility of batches of corn DDGS produced with varying levels of solubles added to the wet grains. The DDGS samples produced contained solubles added at approximately 0, 30, 60, and 100% of the maximum possible addition of solubles to the grains. This corresponds to adding 0, 12, 25, and 42 gallons of syrup

to the grains fraction per minute. Dryer temperatures decreased as the rate of solubles addition to the grains decreased. Particle size increased, and was more variable as increasing additions of solubles were added to the grains fraction. Adding increasing amounts of solubles resulted in darker colored DDGS (reduced L*) and less yellow color (reduced b*) (**Table 2**). Increased addition of solubles resulted in increased crude fat, ash, TME_n (poultry), magnesium, sodium, phosphorus, potassium, chloride, and sulfur, but had minimal effects on crude protein and amino acid content and digestibility. Ganesan et al. (2008) and Kingsly et al. (2010) demonstrated that as the amount of condensed distillers solubles added to the coarse grains fraction is increased, L* is reduced and a* increases. Therefore, DDGS L* and a* can be general indicators of nutrient composition changes among DDGS samples.

Table 2. The Effect of the Rate of Solubles Addition to Mash on Color Characteristics of DDGS.

Color (CIE Scale)	0 gal/min	12 gal/min	25 gal/min	42 gal/min	Pearson Correlation	P Value
L*	59.4	56.8	52.5	46.1	- 0.98	0.0001
a*	8.0	8.4	9.3	8.8	0.62	0.03
b*	43.3	42.1	40.4	35.6	- 0.92	0.0001

Adapted from Noll et al. (2006).

University of Minnesota research has shown that there is considerable variation (256 to 1,217 μ m) in particle size among DDGS sources, and DDGS particle size can affect digestible energy (DE) and metabolizable energy (ME) content for swine (Liu et al., 2011). Liu (2008) reported that most DDGS samples showed a decrease in L* value and b*, and a slight increase in a* value as DDGS particle size increased.

Is color the best indicator of DDGS quality?

Not necessarily. It is important to remember that there are many criteria that can be used to describe DDGS “quality”. Results from the research studies summarized in this paper have shown that DDGS color is correlated with several nutritional components and physical characteristics of DDGS. In some cases, a DDGS source with a high L* may infer higher lysine digestibility, xanthophyll content, and minimal lipid oxidation. On the other hand, darker colored DDGS sources may have higher values for some nutrients compared to lighter colored sources. For example, adding increasing levels of solubles to the coarse grains fraction when producing DDGS sources results in higher energy, crude fat and mineral content, with minimal effects on crude protein and amino acid content and digestibility, compared to lighter colored sources containing less solubles. Furthermore, darker colored samples appear to have higher relative phosphorus bioavailability for poultry. Particle size, moisture content, and other physical properties of DDGS are also correlated with color, but the value of these relationships is more difficult to assess from a feed manufacturing and nutritional perspective. **Therefore, using color as the only or best indicator of DDGS quality is not recommended.**

What are more precise methods for assessing DDGS quality and value?

For most DDGS users, a high quality DDGS source is one that is high in nutrient content and digestibility and free of anti-nutritional factors such as mycotoxins. Nutritional quality represents the concentration of digestible nutrients and value or cost savings obtained when adding DDGS to partially replace other ingredients in animal feed. This “value” is substantially different than the “price” paid for DDGS. Market price is established by usually guaranteeing a certain “ProFat” level (e.g. 36%). “Profat” refers to the sum of the concentration of crude protein and crude fat in DDGS, which must equal or exceed the guarantee (e.g. 36%) to avoid a discount for suppliers. However, animal diets (particularly for swine and poultry) are not formulated on a crude protein and crude fat basis, but rather on a ME (metabolizable energy) and digestible amino acid basis. Therefore, sources with higher ME and digestible amino acid content are more “valuable” from a diet cost perspective than those with lower levels of these expensive nutrient components. Although many DDGS sources often have the same “ProFat” content, and thus the same price, they can have substantially different “value” based on ME and digestible amino acid content.

As an example, **Table 3** shows actual crude protein and crude fat concentrations from 5 different DDGS sources. Each source met the minimum 36% ProFat guarantee, and some might think that the sources with the highest ProFat levels are the most valuable (e.g. sources A and C). However, this is not the case when the actual nutrient analysis of each source is used to estimate the ME, digestible amino acid, and available phosphorus content of the sources in swine diets using VAST’s Illuminate® service (<http://v-ast.com/services.htm>). The main contributor to value in DDGS is the ME content, and ranged from 2,970 (source C valued at \$165/ton) to 3,540 kcal/kg (source E valued at \$215/ton). This is a \$50/ton difference in value, but it is likely that each of these sources would be purchased at the same price. If we assume that DDGS quality = DDGS value, then the best way to assess quality is to use various “nutritional tools” available to assess value and obtain more accurate nutrient loading values for more precise feed formulation.

Table 3. Comparison of DDGS value among 5 sources with different levels of crude protein and crude fat.

	A	B	C	D	E
Dry matter, %	87.9	90.1	86.5	91.7	90.0
Crude protein, %	28.2	26.7	27.7	26.7	25.1
Crude fat, %	11.4	9.9	11.5	10.6	11.2
ProFat, %	39.6	36.6	39.2	37.3	36.3
ME, Kcal/kg	3070	3460	2970	3410	3540
Dig. Lys, %	0.54	0.52	0.54	0.61	0.54
Avail. P, %	0.67	0.50	0.62	0.56	0.64
Value, \$	175	204	165	208	215

ME prediction equations for swine and poultry

Because of the variability in nutrient content among DDGS sources, and the economic importance of having accurate ME values for swine and poultry diet formulations, researchers have conducted experiments to determine nutrient and ME content of DDGS sources and developed prediction equations to estimate ME content from various sources for swine (Pedersen et al., 2007; Mendoza et al., 2010; Anderson et al., 2012) and poultry (Batal and Dale, 2006; Rochelle et al. 2011). Examples of these equations are as follows:

Swine

$$\text{ME kcal/kg DM} = (0.949 \times \text{kcal GE/kg DM}) - (32.238 \times \% \text{TDF}) - (40.175 \times \% \text{ash})$$

Anderson et al. (2012) $r^2 = 0.95$ SE = 306

$$\text{ME kcal/kg DM} = 2,815 + (94.5 \times \% \text{ crude fat}) + (96.2 \times \% \text{ crude fiber}) - (33.2 \times \% \text{NDF}) - (66.2 \times \% \text{ash}) + (25.9 \times \% \text{starch})$$

Mendoza et al. (2010) $r^2 = 0.90$ SE = 49

$$\text{ME kcal/kg DM} = -10,267 - (175.78 \times \% \text{ash}) + (23.09 \times \% \text{CP}) - (71.22 \times \% \text{EE}) - (137.93 \times \% \text{ADF}) + (3.036 \times \text{GE, kcal/kg})$$

Pedersen et al., (2007) $r^2 = 0.99$

Where GE = gross energy, TDF = total dietary fiber, NDF = neutral detergent fiber, EE = ether extract, and ADF = acid detergent fiber.

Poultry

Based on 13 diverse corn co-products:

$$\text{AME}_n, \text{ kcal/kg DM} = 3,517 + (46.02 \times \% \text{ crude fat}) - (82.47 \times \% \text{ash}) - (33.27 \times \% \text{hemicellulose})$$

Rochelle et al. (2011) $r^2 = 0.89,$ SE = 191

Based on DDGS only:

$$\text{AME}_n = 2138 - (263.5 \times \% \text{ crude fiber}) + (566.3 \times \% \text{ash}) \quad r^2 = .99$$

$$\text{AME}_n = 1278 - (19.7 \times \% \text{TDF}) + (470 \times \% \text{ash}) \quad r^2 = .99$$

Rochelle et al. (2011)

Prediction of Poultry TME of DDGS from Crude Protein, Fat, Fiber and Ash Content (Batal and Dale, 2006)

$$\text{TME}_n, \text{ kcal/lb} = 2439.4 + (43.2 \times \% \text{ crude fat}) \quad r^2 = 0.29$$

$$\text{TME}_n, \text{ kcal/lb} = 2957.1 + (43.8 \times \% \text{ crude fat}) - (79.1 \times \% \text{ crude fiber}) \quad r^2 = 0.43$$

$$\text{TME}_n, \text{ kcal/lb} = 2582.3 + (36.7 \times \% \text{ crude fat}) - (72.4 \times \% \text{ crude fiber}) + (14.6 \times \% \text{ crude protein}) \quad r^2 = 0.44$$

$$\text{TME}_n, \text{ kcal/lb} = 2732.7 + (36.4 \times \% \text{ crude fat}) - (76.3 \times \% \text{ crude fiber}) + (14.5 \times \% \text{ crude protein}) - (26.2 \times \% \text{ash}) \quad r^2 = 0.45$$

Although these equations provide a mechanism for estimating ME content of DDGS for swine and poultry, there are challenges in using them. First of all, none of them have been validated

in animal feeding trials to verify their accuracy. Secondly, some equations were developed using DDGS samples with less variability in nutrient content than others, which will affect their accuracy over a diverse set of DDGS sources. Third, some nutrient measurements required by equations (e.g. GE, TDF) are not routinely measured (e.g. GE) and/or are expensive (e.g. TDF) in feed mill laboratories, and measurement of some nutritional components (e.g. NDF) can vary substantially among laboratories and procedures used. Finally, adjustments for fat and fiber in some equations seem counterintuitive. For example, ether extract should have a positive effect and crude fiber should have a negative effect on ME, but some equations show an opposite effect.

Methods to assess amino acid digestibility

Digestible amino acids are the second most expensive nutritional component (after energy) in animal feeds. Several research studies (Ergul et al. (2003); Batal and Dale (2006); Fastinger and Mahan (2006); Urriola (2007), have shown that DDGS sources vary substantially in digestible amino acid content for swine and poultry. Therefore, various methods have been evaluated for their accuracy in predicting amino acid digestibility among DDGS sources.

Swine

Crude protein content is a poor predictor of standardized ileal digestible (SID) lysine, but total lysine and reactive lysine content of DDGS are good predictors (Kim et al., 2010), using the following equations: $SID\ Lys\% = -0.482 + (1.148 \times \text{analyzed Lys, \%})$ or $SID\ Lys\% = -0.016 + (0.716 \times \text{reactive Lys, \%})$. The lysine to crude protein ratio in DDGS can be used as a general predictor of relative lysine digestibility among DDGS sources, but not for precise estimations (Stein, 2007). In other words, if the lysine to crude protein ratio is > 2.80 for a DDGS source, it is considered to be highly digestible and suitable for swine and poultry diets.

Poultry

Fiene et al. (2006) developed equations to estimate total amino acid content in DDGS using crude protein, crude fiber, and crude fat determinations. These equations do a reasonable job predicting methionine, and threonine, but give poor predictions for lysine, arginine, cystine and tryptophan. Cromwell et al. (1993) showed that using ADIN (acid detergent insoluble nitrogen) and a high negative correlation with broiler growth rate and feed conversion in DDGS. Use of the IDEA™ assay by Novus International is a good predictor of digestible lysine in DDGS sources for poultry, but not other amino acids.

Commercially available “nutritional tools” to assess DDGS nutritional value

IDEA® (Immobilized Digestive Enzyme Assay) is an analytical method marketed by NOVUS International and is used to estimate digestible amino acid content of various sources of DDGS, soybean meal, and other high protein ingredients for poultry and swine. The accuracy of using IDEA® as a reliable indicator of amino acid digestibility of DDGS sources for swine is currently being evaluated. It appears to reasonably predict digestible lysine content for poultry, but not other amino acids.

AMINORED® is a tool developed by Evonik to identify and rank heat damage of soybean meal and DDGS using an *in vitro* procedure called a Heat Damage Indicator (HDI). The HDI is used to adjust amino acid digestibility depending on the amount of heat damage using a “tool” called AMINORED®. The accuracy of using AMINORED® as a reliable indicator of amino acid digestibility of DDGS sources for swine and poultry is currently being evaluated.

Adisseo provides a service in Asian countries to estimate nutrient content of several ingredients including corn, soybean meal, and DDGS for swine and poultry using NIRS (Near Infrared Reflectance Spectroscopy). Calibrations have been developed for determining proximate analysis components and predicting total and digestible amino acids, as well as AME in corn, soybean meal and DDGS for poultry.

Illuminate® is a “tool” developed by Value Added Science and Technology (<http://v-ast.com/services.htm>) specifically designed to estimate ME content, SID amino acids, and available phosphorus in DDGS sources, and provide relative value comparisons among sources for swine. It is a subscription service and is based on published ME prediction equations, chemical analysis and NIR calibrations for approximately 100 U.S. ethanol plants.

DDGS value “calculator tools”

Several DDGS value calculator tools have been developed to determine DDGS feeding value for livestock and poultry. These tools are extremely useful for determining the actual economic value of DDGS in specific livestock and poultry diets and should be used when evaluating whether the current price for DDGS is economical relative to its nutrient contributions and price relative to other competing feed ingredients. The most recent and comprehensive DDGS value calculator tool was developed by researchers at Iowa State University (Dahlke and Lawrence, 2008) and is useful for a wide variety of diets and food animal species (<http://www.matric.iastate.edu/DGCalculator>). SESAME, (www.sesamesoft.com) developed by researchers (Drs. Normand St-Pierre, Branislav Cobanov and Dragan Glamocic, 2007) at Ohio State University, is a comprehensive tool to help livestock and poultry producers make better feed purchasing choices. In addition, three DDGS evaluation tools have been developed specifically for swine and are available at www.ddgs.umn.edu:

- University of Illinois DDGS Calculator - developed by Drs. Beob G. Kim and Hans H. Stein (Dec. 2007).
- DDGS Cost Calculator for Swine - developed by Dr. Bob Thaler, South Dakota State University Extension Swine Specialist (Sep. 2002).
- DDGS Value Calculator - developed by Dr. Dean Koehler, Vita Plus Corporation, Madison, WI (Sep. 2002).

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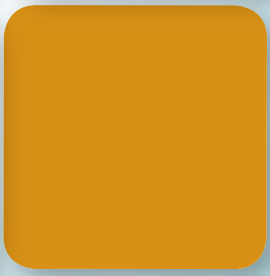
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CHAPTER 9

Antibiotic Use in DDGS Production



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Introduction

One of the ongoing challenges in fuel ethanol production facilities is to control bacterial contamination during fermentation. Lactic acid producing bacteria (*Lactobacillus*, *Pediococcus*, *Leuconostoc*, and *Weissella*) are the most common contaminants (Bischoff et al., 2009; Leja and Broda, 2009; Muthaiyan and Ricke, 2010; Skinner and Leathers, 2004). Other bacterial contaminants including *Bacteroides forsythus*, *Fusobacterium nucleatum*, *Propionicbacterium granulosum*, and *Clostridium aerotolerans* also have detrimental effects on ethanol production (Leja and Broda, 2009; Skinner and Leathers, 2004). Lactic acid bacteria are of concern because they compete with yeast (which produce starch) for essential growth factors, and they produce organic acids, including lactic and acetic acid, which inhibit yeast growth (Skinner and Leathers, 2004). In fact, lactic acid concentrations as low as 1 to 4% inhibit yeast growth, while a 0.3% acetic acid concentration stops fermentation (Hynes et al., 1997; Weigel et al., 1996). Lactic acid bacteria are especially problematic because they can tolerate high temperatures, low pH, and high ethanol concentrations encountered in the fuel ethanol production process. Furthermore, lactic acid bacteria grow rapidly and reach high numbers of viable cells prior to the completion of yeast fermentation (Bischoff et al., 2009; Hynes et al., 1997; Leja and Broda, 2009). Failure to identify and control bacterial contamination can lead to a stalled fermentation, in which all of the starch has not been converted to alcohol. Stalled fermentation results in a shutdown of the fermentors and loss of production time while the system is cleaned of contaminants and re-inoculated (Bischoff et al., 2009; Muthaiyan and Ricke, 2010).

Bacterial contamination reduces ethanol yield by 1 to 5% (Narendranath et al., 1997) and results in the production of lower quality DDGS. Bacteria can thrive during fuel ethanol production because the process is not sterile nor in pure culture conditions (Bischoff et al., 2009). Contaminating bacteria may be introduced to the milling process via raw materials used to make ethanol (heat treatment of raw materials does not kill all contaminants), water used for pump and agitator seals, poorly stored backset, active dry yeasts, and yeast slurry used as inocula (Heist, 2009; Leja and Broda, 2009; Mekanjuola et al., 1992; Muthaiyan and Ricke, 2010; Skinner-Nemec et al., 2007). Improper cleaning, especially of vessels and transfer lines, allows the bacteria to continue to thrive on equipment used in the dry-grind process. The bacteria form biofilms, which are active bacterial colonies that are possibly resistant to antibiotics and cleaning (Rich et al., 2011; Skinner-Nemec et al., 2007). Impediments to process flow can be a source of bacterial colonization as well (Heist, 2009).

Antibiotic Use in Ethanol and DDGS Production

Antibiotics have been used to control bacterial infections during fermentation in ethanol production for many years (Juranek and Duquette, 2007), and virginiamycin and penicillin have been the most commonly used. When antibiotics are used, they are added to fermenters in very small quantities relative to usage rates in animal feeds. For example, when virginiamycin

(Lactrol) is added to fermenters, it is typically added at levels of 0.25 to 2.0 ppm, whereas when virginiamycin (Stafac) is added to swine feeds it is at levels 5.5 to 110 ppm. No data have been published regarding the extent of antibiotic use in fuel ethanol production.

There are two major concerns with the use of antibiotics in fuel ethanol production. First is the potential for bacteria to develop resistance, rendering antibiotics ineffective to control infections (Muthaiyan and Ricke, 2010). Secondly, there is concern regarding the potential for antibiotic residues to remain in animal feeds (i.e. DDGS), and potentially in animal tissues used for human consumption (Benz, 2007). Antibiotic resistance is thought to develop as a result of misuse of antibiotics. This includes antibiotic overdosing when no effect is observed and underdosing when efficient control is observed. Therefore, concerns that the consumption of DDGS containing antibiotic residues by animals could potentially result in animals, and humans consuming food products from those animals, developing resistance to antibiotics used in fuel ethanol production have been raised.

Regulatory Authority of Antibiotic Use in Ethanol Production

The U.S. Food and Drug Administration (FDA) has regulatory authority for all drugs, additives and ingredients used in animal feeds, as well as establish limits for feed contaminants (Benjamin, 2009; de Alwis and Heller, 2012) related to animal food products eventually consumed by humans. This regulatory authority also includes additives used in the production of DDGS (Benjamin, 2009).

In November, 1993, the FDA's Center for Veterinary Medicine issued a "letter of no objection" for the use of virginiamycin at dosage concentrations between 2 to 6 ppm in the fermentation phase of ethanol and DDGS production, and had no objection to potential virginiamycin residues of 0.2 to 0.5 ppm in DDGS. This statement was based calculating virginiamycin residues resulting from inclusion concentrations in ethanol production, estimated residues in DDGS, and in an animal diet containing no more than 20% DDGS. In addition, it was stated that the CVM was unlikely to take regulatory action against DDGS-containing feed with residual virginiamycin concentrations below 0.5 ppm. Virginiamycin concentrations below 0.5 ppm pose no concern to broiler, turkeys, swine, or cattle consuming the feed, nor to the humans consuming food derived from those animals (Benz, 2007). No other antibiotics were included in this letter of no objection. Currently, there are minimal guidelines and no FDA regulatory enforcement and monitoring of antimicrobial residues in distillers co-products produced by fuel ethanol plants.

Due to the dramatic increase in DDGS production and use in animal feeds during the past few years, the FDA has expressed three primary concerns related to antibiotic residues in distillers grains 1) the potential for transfer of antibiotic residues from distillers grains to animal tissues, 2) the potential harm to humans who eat animal tissues containing antibiotic residues, and 3) the potential harm to animal health if antibiotic residues are present in distillers grains. The prevalence of antibiotic use in the ethanol industry, the level of residue detection, and the presence of biological activity in residues in distiller's grains is unknown.

Because of these concerns and limited data on the extent and levels of antibiotic use in ethanol and distillers grains production, the FDA initiated a nationwide survey in December, 2007, and a multi-analyte method calibrated to only detect residues of virginiamycin, erythromycin, and tylosin was used (National Grain and Feed Association 2010; Olmstead, 2009).. Preliminary results from this survey were reported in January, 2009. Antibiotic residues were detected in 24 of 45 samples (obtained from ethanol plants in several states) tested thus far, and 15 of the 45 samples contained residues of virginiamycin, 12 contained residues of erythromycin, and 5 samples contained residues of tylosin. The FDA has not published these results, commented on their health and safety implications, or implemented regulatory action to date.

In 2012, the FDA conducted a second survey using an analytical method described by de Alwis and Heller (2010) to check for 13 antibiotic residues. Of the total of 46 samples analyzed, 3 samples had detectable concentrations of erythromycin, virginiamycin, and penicillin. The first sample contained 0.58 ppm erythromycin, the second sample contained 0.24 ppm penicillin and 0.15 ppm virginiamycin, and the third sample contained 0.16 ppm virginiamycin. Erythromycin had a detection limit of 0.5 ppm, penicillin had a detection limit of 1.0 ppm, and virginiamycin had a detection limit of 0.1 ppm (Luther, 2012).

It is important to note that the FDA used a non-FDA approved multi-analyte residue detection method capable of detecting antibiotic residues as low as 0.1 ppm (dry matter basis) in distiller's co-products (Heller and de Alwis, 2008). The accuracy of this method ranged from 88 to 111% over the quantitative range of 0.1 to 1.0 ppm (Heller and Hemakanthi de Alwis, 2008). The only FDA approved method to quantify antibiotic residues in feeds and feed ingredients is for virginiamycin. This approved method is different than the method used by FDA (Heller and de Alwis, 2008) to quantify antibiotic residues in distiller's grains samples in their recent survey. The approved method is a bioassay developed by SmithKline Beecham (now owned by PhibroChem) that has a limit of detection for virginimycin residues of 0.1 ppm, well below the 0.5 ppm level cited in FDA's 1993 "letter of no objection". It is of great importance to use appropriate analytical methodology when attempting to detect antibiotic residues in distiller's co-products. PhibroChem reported in July, 2009, results from testing 42 samples of wet and dry distiller's grains and DDGS, obtained from 11 ethanol plants by an independent laboratory and Phibro's technical service laboratory. No virginiamycin residues were detected in any samples using the FDA approved bioassay procedure.

In January, 2009, at an International Feed Regulators Meeting in Atlanta, GA, a spokesperson from FDA's Center for Veterinary Medicine announced that "the agency is reviewing the appropriateness of its November 1993 "letter-of-no-objection" under which the agency has exercised enforcement discretion allowing residues of up to 0.5 parts per million (ppm) of virginiamycin in distiller's grain products in the current regulatory environment."

Types of Antibiotics That May Be Used in Ethanol Production

Antibiotics can be bactericidal or bacteriostatic. Antibiotics that kill bacteria in vitro are bactericidal, whereas bacteriostatic antibiotics slow or stop bacterial growth (Merck Sharpe & Dohme, 2004).

Virginiamycin

Virginiamycin is a macro-lide antibiotic and is composed of two components, Factors M and S (Vannuffel and Cocito, 1996). The S and M factors interact synergistically to increase the antimicrobial activity of the product. Virginiamycin is a bacteriostatic when the S and M factors are not associated, and a bactericidal antibiotic when the two components are associated (Merck Sharpe & Dohme, 2004; Hynes et al., 1997; Vannuffel and Cocito, 1996). The two factors are most active in a M to S ratio of 2:1 or 1:1, and the M factor is the first-limiting for antibiotic activity (Cocito, 1979). In combination, the two factors work synergistically to reduce the colony forming capacity of bacteria, but separately, each factor only reduces the viability of most bacteria after an exceedingly long incubation period. In fact, the activity of the two components together is 10 to 100 times greater than the activity of either one individually (Cocito, 1979).

Virginiamycin is a narrow spectrum antibiotic effective at controlling gram positive bacteria including a majority of lactic acid bacteria (Cocito, 1979; Hynes et al., 1997; Islam et al., 1999). The effectiveness of virginiamycin against *Lactobacilli* species is dependent on the strain and growth phase. Currently, some resistance to virginiamycin by several genera of gram positive bacteria, as well as breakdown of virginiamycin by *Lactobacilli* species, has been reported (Hynes et al., 1997). In addition, reports of cross-resistance exist between macrolide antibiotics (e.g. tylosin and erythromycin) and virginiamycin for gram positive bacteria (Cocito, 1979). However, resistance to streptogramins, including virginiamycin, is less common than any other protein synthesis inhibitor (Vannuffel and Cocito, 1996).

In ethanol fermentation, virginiamycin is normally added to fermenters at a level of 0.25 to 2.0 ppm, although the FDA "letter of no objection" allows a maximum use rate of 2 to 6 ppm. Virginiamycin is effective in controlling lactic acid bacteria, preventing ethanol yield reductions as great as 11% in the presence of *Lactobacilli* species (Hynes et al., 1997). The stability of virginiamycin is not greatly affected at temperatures ranging from 25 to 35°C and at pH 3.8 to 4.8 for 72 hours during fermentation (Islam et al., 1999). However, the distillation process (30 minutes at 100°C) has been shown to significantly inactivate virginiamycin where 97.4% of original virginiamycin activity was eliminated under these conditions (Hamdy et al. 1996). PhibroChem, the exclusive producer of virginiamycin for the ethanol industry, indicates that typically drying operations at temperatures as high as 800° F (426.6°C) will result in rapid breakdown of virginiamycin residues in DDGS dryers. From the above references, it can be concluded that virginiamycin residues are easily destroyed if they experience sufficiently high temperatures during the DDGS distillation and drying operations.

Virginiamycin is approved by the FDA for use in animal feed. Consumption of DDGS containing virginiamycin residues by food-producing animals poses little or no harm to animal or human health (Juraneck and Duquette, 2007). Several factors prevent virginiamycin in co-products of fuel ethanol production from being harmful to animals and humans. First, virginiamycin is inactivated during the ethanol distillation process (Hynes et al., 1997). Second, virginiamycin is not absorbed in the gut and was not found in the kidneys, liver, or muscle of chickens fed virginiamycin (Butaye et al., 2003; Juraneck and Duquette, 2007). Third, virginiamycin has been fed to animals at much higher concentrations than FDA approved with no ill effects on the health

of the animals. Finally, virginiamycin concentrations in DDGS (0.2 to 0.5 ppm) are much lower than those currently approved by the FDA for use in animal feeds (FDA, 2010; Juranek and Duquette, 2007). Results from a SmithKline Beecham study, which were provided to the FDA and foreign regulatory agencies as part of the approval process for virginiamycin to be legally and safely used in animal feeds, are shown in **Table 1**. These results show that even when virginiamycin is fed to animals at levels higher than the legally approved levels, residues were not detected in animal tissues (Juranek and Duquette, 2007).

The FDA also conducted a quantitative risk assessment on virginiamycin and human health in 2004 and concluded that virginiamycin poses no threat to human health. Some of the data to support this conclusion are shown in **Table 2**. Therefore, virginiamycin is a safe and effective antibiotic choice for use in the fuel ethanol industry.

Table 1. Effect of feeding high levels of virginiamycin on tissue residues in various animal species.¹

Species	Dosage, ppm	Withdrawal period, days*	Muscle ppm	Liver ppm	Kidney ppm	Fat ppm
Swine	170.5 ppm feed (18 wks)	0	< 0.1	< 0.1	< 0.1	< 0.1
Veal calves	50 mg/kg BW oral dose	3	< 0.1	< 0.1	< 0.2	< 0.2
Trout**	40 ppm feed (12 wks)	0	< 0.1	< 0.1	< 0.1	< 0.1
Rabbits**	80 ppm feed (4 wks)	0	< 0.1	< 0.1	< 0.1	< 0.1
Broilers	110 ppm feed (4 wks)	0	< 0.02	< 0.02	< 0.02	< 0.02
Layers –eggs**	80 ppm feed (6 mo)	0	White < 0.02	Yolk < 0.05		

* Withdrawal period refers to the number of days virginiamycin was removed from the feed before harvest.

**Virginiamycin is not approved for use in trout, rabbits, or layers.

¹ Juranek and Duquette, 2007.

Table 2. Effects of increasing feeding levels of virginiamycin, and exceeding approved usage levels, on health and toxicity of various animal species¹

Species	Dose	Effects
Cattle	25, 75, 125, or 625 g/ton feed, 500 ppm (23 wks)	No adverse health effects or evidence of toxicity
Calves	80 ppm in feed (4 mo)	No adverse effects
Chickens	2,000 ppm feed (24 hrs), 22, 66, or 110 ppm in feed (7 wks)	No evidence of toxicity
Pigs	1,600 mg/kg BW (2 wks), 500 mg/kg BW (3 mo)	No adverse effects

¹ Juranek and Duquette, 2007

Penicillin

Penicillin is not approved by the FDA for use in ethanol and DDGS production. However, penicillin is often added at concentrations above 1.5 mg/L in fuel ethanol production due to the possibility of induced enzymatic degradation of the antibiotic (Hynes et al., 1997). This

concentration is much lower than concentrations approved for use in food animals, and has both bacteriostatic and bactericidal activities on gram positive bacteria and a few gram negative cocci, as well as *actinomycetes* and *spirochaetes*. The stability of penicillin is directly affected by temperature and pH. High temperatures (>35°C) and pH values greater than 8.0 and less than 4.0 cause penicillin to become unstable (Kheirloom et al., 1999). Islam et al. (1999) reported that within 48 hours, penicillin G (0.5 unit/mL) was almost inactivated at 35°C and at pH of 3.8, 4.0, 4.2, and 4.5 during sterile malt glucose yeast extract fermentation. They also found that the biological half-life of penicillin decreased dramatically from 24 hours at 25°C to 4 hours at 35°C. Based on these research results, it is expected that the temperature and pH conditions during ethanol and DDGS production will inactivate penicillin. Fermentation occurs over a 48 to 72 hour time period, when pH declines to less than 4, and at a temperature of approximately 32°C. Distillation at temperatures over 78°C for up to 30 minutes will also inactivate any penicillin remaining in the mash, and drying of DDGS at temperatures between 300 and 600 °C in the rotary drum dryers (Bothast and Schlicher, 2005), should completely inactivate the penicillin residues in DDGS.

Erythromycin

Erythromycin is not approved by the FDA for use in ethanol and DDGS production. It is a 14-membered lactone ring macrolide ring antibiotic that is used in fuel ethanol production (Petropoulos et al., 2008) because it is very effective against most gram negative and gram positive bacteria (Chittum and Champney, 1995). Macrolide antibiotics are bacteriostatic and bind to the 50S subunit of the ribosome in a ratio of one molecule per ribosome (Merck Sharpe & Dohme, 2004; Petropoulos et al., 2008; Vannuffel and Cocito, 1996). The stability of erythromycin is pH and temperature dependent, where it is more stable at the pH range from 7.0 to 8.0 and lower temperatures (Brisaert et al. 1996). It is soluble in alcohol and insoluble in water, but it becomes more unstable with higher alcohol concentrations. Like penicillin, erythromycin is likely inactivated by the low pH and high temperatures encountered during the fermentation and distillation of ethanol. Once consumed, erythromycin is diffused well into body fluids, but food consumption decreases its absorption (Merck Sharpe & Dohme, 2004). It is currently approved for use in food animals. However, it is important to note that erythromycin has an antagonistic effect when combined with virginiamycin or penicillin, and it can cause monensin toxicity due to delayed clearance or altered biotransformation of monensin when fed concurrently (Basaraba et al., 1999; Cocito, 1979; Hof et al., 1997).

Tylosin

Tylosin is not approved by the FDA for use in ethanol and DDGS production. It is an effective, 16-membered ring macrolide antibiotic against gram positive and some gram negative bacteria and inhibits bacterial protein synthesis (Omura et al., 1983; Petropoulos et al., 2008). Tylosin consists of tylosin A, tylosin B, tylosin C, and tylosin D, all of which contribute to its antibiotic potency. Tylosin A is, by far, the major component (usually about 90% and not less than 80%). Tylosin solutions are stable at about pH 7 and temperatures of 60 to 90°C. The decomposition rate of tylosin is largely dependent on pH, buffer type and concentration, temperature, as well as the ionic strength (Paesen et al. 1995). Tylosin is most stable at about pH of 3.5 or about pH of 9.0. Outside of those two pH ranges, there is significant inactivation of the antibiotic. In addition,

increased temperatures and exposure periods can lead to inactivation (Aksenova et al., 1984). Therefore, it is likely, that any residue in DDGS would be inactivated due to its low stability at the pH and high temperatures present in the fuel ethanol production process. Currently, tylosin is approved to be fed in livestock.

Tetracycline

Tetracycline is a bacteriostatic antibiotic that is unstable at low pH ($\text{pH} < 2$) and will form anhydrotetracyclines via the loss of water and proton transfer in strongly acidic conditions (Wang et al., 2008). Furthermore, tetracyclines degrade faster at low pH and high temperatures, its absorption is decreases with metal cations (Al, Ca, Mg, Fe), and it is antagonistic when co-administered with penicillin (Merck Sharpe & Dohme, 2004). Tetracycline is currently approved to be fed to livestock. In the body, it penetrates most body tissues and fluids. Previous studies have looked at the effectiveness of heat sterilization of animal feed ingredients in order to reduce the level of active tetracycline residue, and Hassani et al., (2008) reported that low-temperature, long-time treatments with conventional sterilization ($121\text{ }^{\circ}\text{C}$ for 20 minutes) are most effective in reducing active residues to less than one percent.

Antibiotic Alternatives

Several ethanol plants are evaluating antibiotic alternatives to control bacterial infections. The two most common alternative products are stabilized chlorine chloride and an enzyme derived from hops. Chlorine dioxide is a buffered sodium chlorite with antimicrobial properties, and is activated from sodium chlorite to chlorine dioxide by acid producing bacteria. Sodium chlorite degrades to nontoxic chloride and sodium ions. Hops extract has antimicrobial properties and contains enzymes that control bacteria but also enhances the ability of yeast to convert starch to ethanol. Limited published scientific data is available on these products but results from a few field studies suggest that they may be cost effective alternatives to antibiotics in controlling bacterial infections in fermenters during ethanol production.

Recent Research Results on the Presence and Biological Activity of Antibiotic Residues in DDGS

Paulus-Compart (2012) recently completed a study at the University of Minnesota to determine if antibiotic residues are present in wet and dried distillers grains with solubles, and if so, whether they have biological activity. The objectives of this study were to: 1) collect and evaluate wet and dried distillers co-products samples from multiple geographical locations and dry-grind ethanol plants in the U.S. for the presence of virginiamycin, penicillin, erythromycin, tetracycline, and tylosin residues, and 2) determine the extent of any antimicrobial activity of samples using sentinel bacteria strains of *Escherichia coli* (ATCC 8739) and *Listeria monocytogenes* (ATCC 19115).

Materials and methods

Approximately 20 wet and 20 dried distillers grains samples were collected by independent nutritional consultants from 43 dry-grind ethanol plants located in 9 Midwestern U.S. states every 3 months during a 12-month period. Samples were sent to the University of Minnesota Animal Science Department and immediately frozen (-21° C). Original samples are subsampled and sent to SGS North America (Brookings, SD, U.S.A.) for proximate nutrient analysis and detection of penicillin, erythromycin, tetracycline, and tylosin residues using procedures (de Alwis and Heller, 2010). An additional extraction using phosphate buffer solution (PBS) is utilized to minimize antibiotic residue damage during the extraction process. Residues recovered using PBS extraction were tested against sentinel bacteria strains for *Escherichia coli* (ATCC 8739) and *Listeria monocytogenes* (ATCC 19115) to determine biological activity. Bacterial thresholds were determined for antibiotic residues by adding sentinel bacteria at concentrations of 10^4 , 10^5 , 10^6 , and 10^7 to the antibiotic extract in broth for 18 to 24 hours at 37°C, and then samples were examined for bacterial growth. Bacterial inhibition was also determined by plating 10 mL from each broth on blood agar plates. After 18 to 24 hours of incubation at 37°C, bacterial colonies were counted and recorded as colony forming units (CFU) per mL. Another set of quarterly subsamples were sent to Phibro EPG Laboratory (St. Paul, MN) for detection of virginiamycin residues using a proprietary, FDA-approved bioassay procedure.

Data were analyzed using the Mixed procedure of SAS with sampling period and ethanol plant of origin as random effects, and fixed effects included type of distillers (wet or dry), and the interactions of distillers type × ethanol plant and distillers type × sampling period. Effects were considered significant when P values were ≤ 0.05 and trends were considered when $0.05 > P$ values ≤ 0.10 .

Results

One-hundred and fifty-nine samples (79 wet and 80 dried) were been analyzed for tetracycline, tylosin, erythromycin, and penicillin residues. As shown in **Figure 1**, one sample contained detectable concentrations of tetracycline and one sample contained detectable levels of penicillin, but none of the samples contained tylosin residues. Erythromycin was found in 16 of the samples (10.1%). Only two samples had detectable concentrations of virginiamycin (> 0.3 ppm) using Phibro's FDA-approved bioassay (**Figure 2**). One sample contained 0.6 $\mu\text{g/g}$ and the other contained 0.5 $\mu\text{g/g}$ virginiamycin.

Residue concentrations for all other antibiotics tested were extremely low with mean concentrations (dry matter basis) for dried samples were less than 0.8 $\mu\text{g/g}$ for erythromycin, less than 1.2 $\mu\text{g/g}$ for tetracycline, and less than 0.12 $\mu\text{g/g}$ for penicillin. Residue concentration distribution among samples is shown in **Figures 2, 3, 4, and 5** for virginiamycin, tetracycline, erythromycin, and penicillin, respectively.

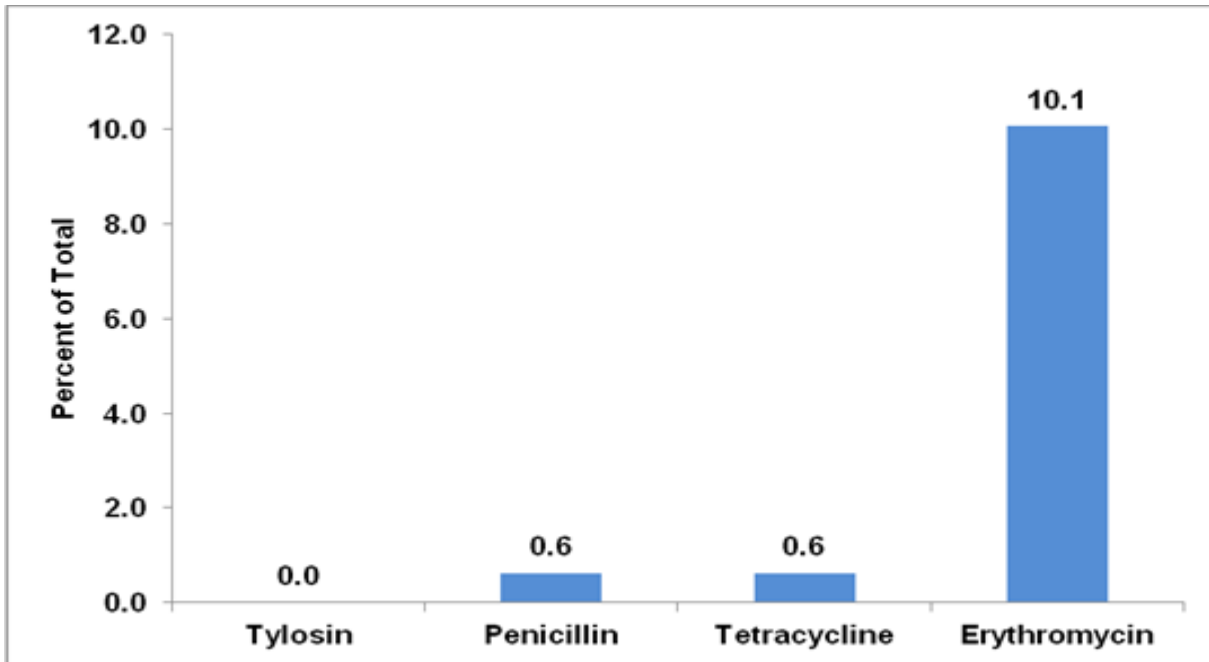


Figure 1. Percentage of samples containing antibiotic residues

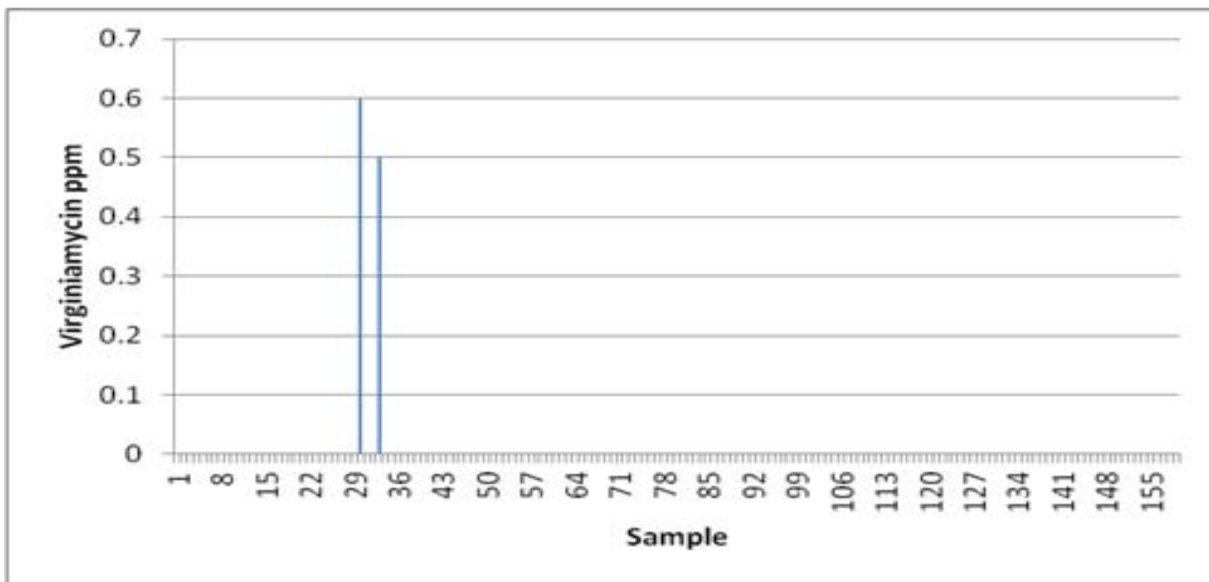


Figure 2. Virginiamycin residue concentrations of wet and dried distillers grains with solubles (DM basis)

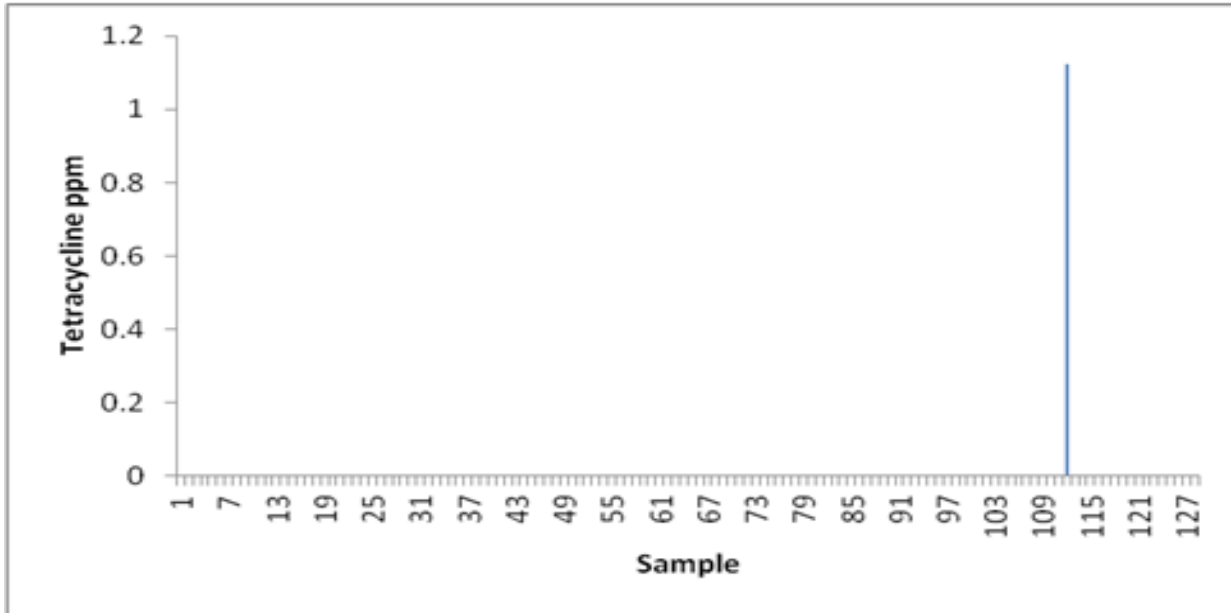


Figure 3. Tetracycline residue concentrations of wet and dried distillers grains with solubles (DM basis).

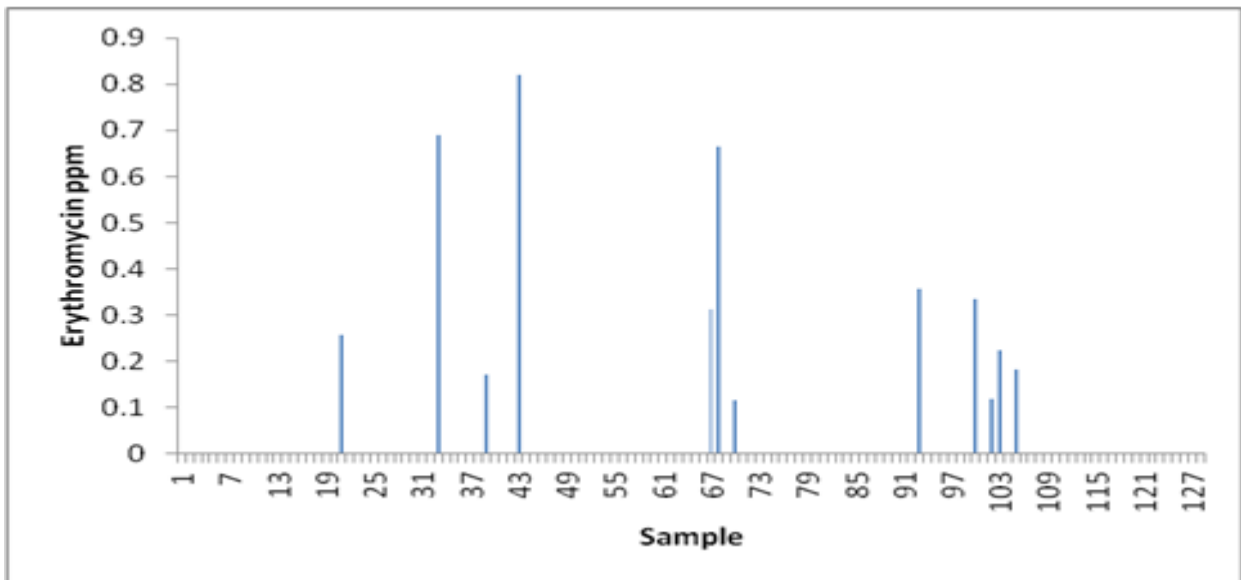


Figure 4. Erythromycin residue concentrations of wet and dried distillers grains with solubles (DM basis).

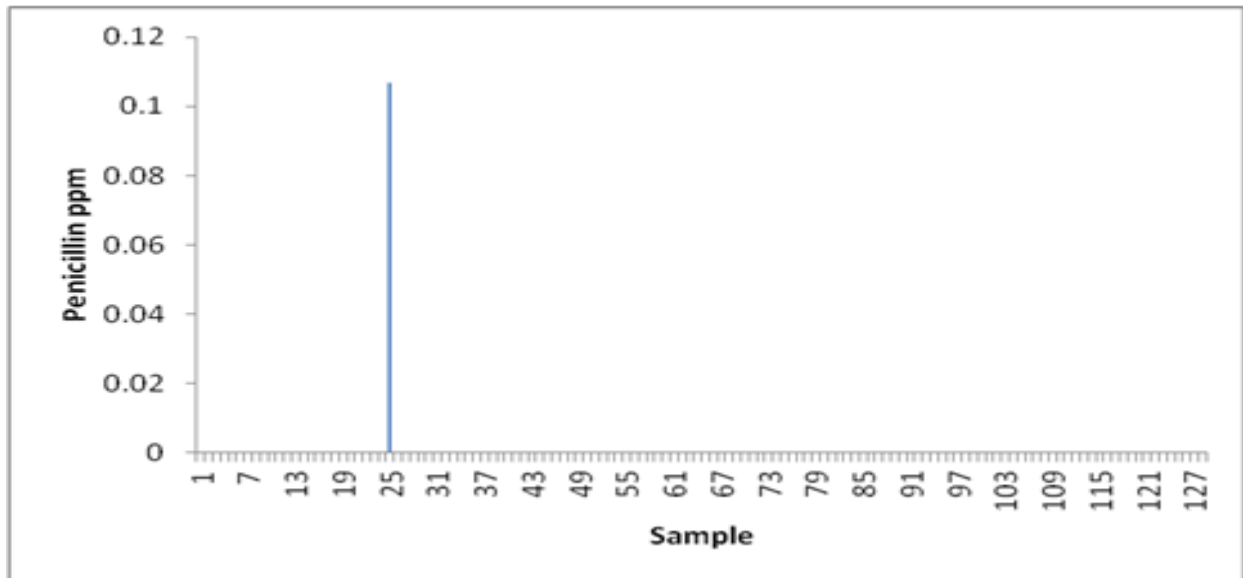


Figure 5. Penicillin residue concentrations of wet and dried distillers grains with solubles (DM basis).

The extract from only one sample was found to have any inhibitory properties for *E. coli*, but not *L. monocytogenes* growth. The extract inhibited *E. coli* (ATCC 8739) at concentrations between 10^4 and 10^5 . However, there were no detectable concentrations of residues from the 5 antibiotics tested in this sample. Therefore, the cause of bacterial inhibition produced by this sample is unclear. All of the other samples tested for antibiotic residue activity showed no bacterial inhibition, and produced plates with too many colonies to count for both *E. coli* and *L. monocytogenes* (ATCC 19115). The results of this study indicate that 20 of the 159 samples (12.6%) tested in this survey contained detectable levels of antibiotic residues. Furthermore, the concentrations of the residues detected in wet and dried distillers co-products were extremely low, and no tylosin residues were detected. Less than 1.3% of the samples tested contained low (0.5 to 0.6 $\mu\text{g/g}$), but detectable concentrations of virginiamycin residues using the FDA-approved bioassay. However, it appears that there is no concern of residues having inhibitory properties when using sensitive strains of *E. coli* and *L. monocytogenes* as sentinel bacteria. These results indicate that antibiotic residues in distillers grains are inactivated during the distillers grains production process, and detectable antibiotic residues had no effect on sentinel bacteria chosen to test their antimicrobial activity.

Conclusions

Antibiotics are often used to control bacterial infections in the dry-grind fuel ethanol production process to enhance ethanol yield and nutritional quality of distillers co-products. Virginiamycin is the most widely used antibiotic in ethanol production, is the best researched and understood. All scientific evidence to date suggests that using virginiamycin in ethanol production poses no concerns for residues or risks for animal and human health. Less than 1.3% of the samples tested contained low (0.5 to 0.6 $\mu\text{g/g}$), but detectable concentrations of virginiamycin residues.

Only 1 sample contained penicillin residues, 1 sample contained tetracycline residues, and no samples contained tylosin residues. Extremely low concentrations of penicillin, erythromycin, and tetracycline residues were detected in wet and dried distillers co-products. However, it appears that there is no concern of residues having inhibitory properties when using *E. coli* (ATCC 8739) and *L. monocytogenes* (ATCC 19115) strains as sentinel bacteria.

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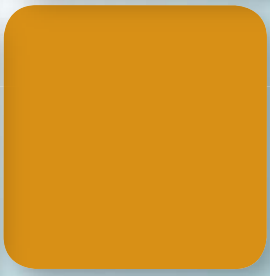
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CHAPTER 10

Mycotoxins in DDGS



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Introduction

Like all feed ingredients, distiller's grains may contain, at times, amounts of mycotoxins that can negatively affect animal performance, or be produced and stored under conditions that cause mold growth and mycotoxin production.

Mycotoxins can be present in DDGS if the grain delivered to an ethanol plant is contaminated with them. Mycotoxins are not destroyed during the ethanol production process, nor are they destroyed during the drying process to produce DDGS. In fact, if mycotoxins are present in corn, their concentration will be increased by a factor of about 3 times in DDGS. However, the risk of mycotoxin contamination in U.S. DDGS is very low because it is uncommon for most of the major corn growing regions in the U.S. to have climatic and weather conditions that lead to mycotoxin production in corn. Furthermore, most ethanol plants monitor grain quality and reject sources that are contaminated with mycotoxins.

Potential Mycotoxins in Corn and DDGS

Mycotoxins are secondary metabolites of fungi that can adversely affect the health, growth, or reproduction of animals, especially humans and domestic animals. Aflatoxins, including aflatoxin B1, B2, G1, and G2, are the most toxic and carcinogenic of the known mycotoxins, and they are produced by several *Aspergillus* species. Corn becomes susceptible to aflatoxin formation during under drought conditions during the growing season, or in high moisture or high humidity storage conditions (Richard, 2000).

Fusarium graminearum is the primary deoxynivalenol-producing fungus in grains in the United States (CAST, 2003). Deoxynivalenol (sometimes referred to as DON or vomitoxin) may coexist with other mycotoxins, such as zearalenone. *Fusarium graminearum* survives in old infested residue remaining in the field from the previous growing season, and cold, moist conditions are favorable for the fungus to grow on corn. Generally, storage is not considered a potential source for deoxynivalenol contamination if the corn was mature and stored at moisture level lower than 14% (Richard, 2000).

Fusarium verticillioides is the primary fungus capable of producing the fumonisins FB1, FB2, and FB3 (Gelderblom et al., 1988). Corn is the major grain commodity affected by this fungus. The specific conditions needed for the production of fumonisins are unknown, but it is suggested that drought stress followed by warm, wet weather during flowering seems to be important. *Fusarium verticillioides* is present in virtually every seed and is also present in the corn plant throughout its growth, and sometimes, there is a considerable amount of fumonisins present in symptomless kernels of corn. Since the discovery of this mycotoxin was fairly recent (1988), there is little information available regarding its production as well as its potential negative effects on animal health and performance (Richard, 2000).

Fusarium sporotrichioides is the principal fungus responsible for the production of T-2 toxin, which is a member of fungal metabolites known as the trichothecenes. The production of T-2 is the greatest under conditions of increased humidity and temperatures of 6–24 °C (CAST, 2003).

Zearalenone is an estrogenic fungal metabolite, and *Fusarium graminearum* is the major fungus responsible for producing this mycotoxin. Moist, cool growing conditions are favorable for this fungus to grow, and are the same conditions ideal for the production of deoxynivalenol. Maintaining moisture content of grain and grain co-products less than 14% is important to avoid zearalenone production.

Mycotoxin Testing

Since the 1960's, many analytical methods have been developed for the testing of mycotoxins in human food and animal feeds due to the concern of toxicity for human health (Trucksess, 2000). Among them, the methods of thin-layer-chromatography (TLC), enzyme-linked immunosorbent assay (ELISA) and immunosensor-based methods have been widely used for rapid screening, while high-performance liquid chromatography (HPLC) with fluorescence detection (FD) and mass spectrometry detection (MS) have been used as confirmatory and reference methods (Krska et al, 2008). However, due to the need for rapid, accurate and more economical on-site methods of mycotoxin determinations, testing kits approved for use on DDGS by the Grain Inspection, Packers and Stockyards Administration (GIPSA) of the United States Department of Agriculture are shown in **Table 1**

(<http://www.gipsa.usda.gov/GIPSA/webapp?area=home&subject=lr&topic=hb>).

Table 1. Mycotoxin Testing Kits for DDGS (Approved by GIPSA).

Brand Name	Manufacturer	Test Range	Test Format	Extraction	Clean-up
Aflatoxin					
Veratox Aflatoxin	Neogen Corporation	5–50 ppb	Microtiter Well Plate Assay	Methanol/water (70 + 30)	ELISA
Ridascreen FAST SC	R-Biopharm	5–100 ppb	Microtiter Well Plate Assay	Methanol/water (70 + 30)	ELISA
Aflatest	Vicam	5–100 ppb	Immunoaffinity Column	Methanol/water (80 + 20)	Affinity column
FluroQuant® Afla IAC	Romer	5–100 ppb	Fluorometry	Methanol/water (80 + 20)	Affinity column
Fumonisin					
AgraQuant Total Fumonisin 0.25/5.0	Romer	0.5–5 ppm	Direct Competitive ELISA	Methanol/water (70 + 30)	ELISA
Zearalenone					
ROSA® Zearalenone	Charm Sciences, Inc.	50–1000 ppb	Lateral Flow Strip	Methanol/water (70 + 30)	

Zhang et al., 2009

These methods are for detection of a single mycotoxin, allow for ease of operation, and are quantitatively sensitive allowing high sample throughput. There are six GIPSA approved methods for testing mycotoxins in DDGS (four methods for aflatoxin, one method for fumonisin, and one method for zearalenone).

When considering testing DDGS for mycotoxin contamination, it is essential to use approved analytical procedures to get accurate results. High performance liquid chromatography (HPLC) is the preferred method to determine the presence and level of mycotoxin in animal feeds. Using HPLC and a variety of detectors, most of the mycotoxins in animal feeds can be separated and detected (Krska et al, 2008). The methods used by major DDGS testing labs in the U.S. are described in **Table 2** and have been validated by individual labs and recently published in peer-reviewed scientific journals.

Table 2. Methods for mycotoxin testing in animal feed.

Target	Testing	Detection Range	Reference
Aflatoxin			
Corn, almonds, Brazil nuts, peanuts and pistachio nuts	HPLC – FD	5 – 30 ppb	AOAC 994.08
Deoxynivalenol			
Cereals and cereal products	HPLC – UV	0.1 ppm (detection limit)	MacDonald et al., 2005a
Fumonisin			
Corn and corn flakes	HPLC – FD	0.5 – 2 ppm	AOAC 2001.04
Corn and corn-based feedstuffs	Thin layer chromatography (TLC)	0.1 ppm (detection limit)	Rottinghaus et al., 1992
T-2			
Food and feed	Thin layer chromatography (TLC)	0.1 ppm (detection limit)	Romer, 1986
Zearalenone			
Corn, wheat and feed	Microtiter Well Plate Assay	0.8 ppm (detection limit)	AOAC 994.01
Barley, maize and wheat flour, polenta, and maize-based baby foods	HPLC – FD	0.05 ppm (detection limit)	MacDonald et al., 2005b
Aflatoxins, Deoxynivalenol, Fumonisin, T-2, Zearalenone			
Food and feed	LC/MS/MS	Aflatoxins (1 – 100 ppb); Deoxynivalenol, (1, 1000 ppb) Fumonisin (16 – 3,200 ppb) T-2, (2 – 1,000 ppb) Zearalenone (20 – 1,000 ppb)	Sulyok et al., 2007

Adapted from Zhang et al. (2009).

Maximum tolerable levels of mycotoxins in animal feed

The U.S. FDA has established maximum tolerable levels for aflatoxins (**Table 3**), deoxynivalenol (**Table 4**), and fumonisin (**Table 5**) in feed ingredients for various types of animal feeds. No action levels, advisory levels or guidance levels have been published by the FDA for T-2 toxin or zearalenone.

Table 3. FDA action levels for aflatoxin in complete feeds and feed ingredients.¹

Animals	Action Levels (ppb)
Finishing beef (i.e., feedlot) cattle	300
Finishing swine (> 100 pounds)	200
Breeding beef cattle, breeding swine or mature poultry	100
Immature animals, dairy cattle or intended use unknown	20

¹ Zhang et al., 2009.

Table 4. FDA action levels for deoxynivalenol in complete feeds and feed ingredients.¹

Animals	Advisory Levels (ppm)
Ruminating beef and feedlot cattle older than 4 months, and chickens with the added recommendation that these ingredients not exceed 50% of the diet	10
All other animals with the added recommendation that these ingredients not exceed 40% of the diet	5
Swine with the added recommendation that these ingredients not exceed 20% of the diet	5

¹ Zhang et al., 2009.

Table 5. FDA Action levels for fumonisin in complete feeds and feed ingredients.¹

Animals	Recommended Guidance Levels (ppm)
Poultry raised for slaughter, no more than 50% of the diet	100
Ruminants older than 3 months raised for slaughter and mink being raised for pelt production, no more than 50% of the diet	60
Breeding ruminants, poultry, and mink, no more than 50% of the diet	30
Swine and catfish, no more than 50% of the diet	20
All other species or classes of livestock and pet animals, no more than 50% of the diet	10
Equids and rabbits, no more than 20% of the diet	5

¹ Zhang et al., 2009.

Presence and Concentrations of Mycotoxins in U.S. DDGS

Zhang et al. (2009) conducted an extensive literature review of published studies and evaluated samples from three large data sets of DDGS samples to determine the extent and level of mycotoxin contamination among U.S. DDGS sources. Concentrations of all mycotoxins in DDGS were generally below the FDA action levels for all mycotoxins. There were only a couple of exceptions where the concentrations of deoxynivalenol or fumonisins were either at, or slightly above, the recommendations for selected sensitive animal species, and in those instances the occurrence rate was less than 10% of all samples tested, and these concentrations were below any harmful concentration when the DDGS would be added with other ingredients to make up the overall animal diet.

Caupert et al. (2011) published additional DDGS mycotoxin concentrations from multiple surveys and concluded that all concentrations of mycotoxins in DDGS were generally below the FDA regulations for the specific mycotoxins. In only a couple of instances where the concentrations of deoxynivalenol or fumonisins either at, or slightly above, the recommendations for sensitive animal species, and in those instances the occurrence was in less than 10% of the samples tested. These concentrations would be well below any harmful concentration when the DDGS is blended with other ingredients to make up the overall animal diet.

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CHAPTER 11

Mycotoxin Situation with the 2011 U.S. Corn Crop and 2012 DDGS Production



Chapter 11

Mycotoxin Situation with the 2011 U.S. Corn Crop and 2012 DDGS Production

Introduction

Mycotoxin prevalence and concentrations in feed ingredients are an ongoing concern in many countries. Historically, mycotoxin prevalence and concentrations in the U.S. corn crop are infrequent and low, respectively, compared the annual occurrence and relatively high concentrations in corn produced in many other countries around the world. Mycotoxins are produced by specific molds (e.g. *Aspergillus* and *Fusarium*), when optimal environmental conditions (e.g. drought stress, wet weather and high moisture, etc.) are present during the corn growing season or during storage. Typically, the incidence of mycotoxin production in U.S. corn is relatively low because of unfavorable mold growth climatic and storage conditions. Recent surveys of mycotoxin contamination and levels from numerous U.S. DDGS sources have been published (Zhang et al., 2009; Caupert et al., 2011; Zhang and Caupert, 2012). In the most recent study, Zhang and Caupert (2012) measured aflatoxins, deoxynivalenol (DON; vomitoxin), fumonisins, T-2 toxin, and zearalenone in 67 DDGS samples from 8 ethanol plants in the Midwestern U.S. from 2009 to early 2011. Among the 5 mycotoxins measured, vomitoxin was of particular interest because the 2009 corn growing season was favorable for vomitoxin production. Results from this survey showed that no more than 12% of the DDGS samples tested contained vomitoxin levels greater than the U.S. FDA minimum advisory concentrations for use in animal feed, and the vomitoxin concentrations were less than 2 ppm for all samples collected in 2011. Almost none of the DDGS samples produced in 2010 contained detectable concentrations of aflatoxins, and the highest concentration detected was 5.7 ppb. Less than 6% of the samples contained fumonisin concentrations higher than the U.S. FDA guidance level for feeding equids and rabbits, while most samples contained zearalenone concentrations between 100 and 300 ppb. No samples contained T-2 toxin above the detection limit.

Challenges of obtaining mycotoxin data

Obtaining current mycotoxin data for the 2011 U.S. corn crop and 2011-2012 DDGS production is difficult for several reasons. First, there is no annual feed industry or governmental monitoring system to report the presence and concentrations of mycotoxins in corn or DDGS. Most of the sampling and testing of mycotoxins is done by various grain, feed, and marketing companies and it is used for proprietary purposes and not published. Secondly, unless initial samples obtained at harvest contain frequent and high levels of one or more mycotoxins of concern, continued monitoring of corn and DDGS samples generally ceases due to low risk of contamination in supply channels of the market and the high cost of analysis. Thirdly, some commercial laboratories (e.g. Dairyland Laboratories) provide mycotoxin data summaries of corn and DDGS samples analyzed, but these results are highly biased and do not reflect the entire corn crop or all of the DDGS being produced because samples submitted were identified as being potentially contaminated and as a result, were submitted for analysis. Therefore, we

must remember that the type of sampling procedures used, and the potential for bias must be considered when evaluating mycotoxin prevalence and concentrations in corn and DDGS.

2011 U.S. Corn and DDGS

Wet weather as well as drought conditions in the Eastern Corn Belt (Michigan, Indiana, and Ohio) during 2011 resulted in some production of mycotoxins, particularly vomitoxin, but the concentrations were lower than those from the 2010 corn crop. In contrast, mycotoxin levels were very low in other major corn producing states of Illinois, Iowa, Minnesota, North Dakota, and South Dakota. Limited data are available (**Table 1**), but initial sampling of DDGS produced from corn harvested in 2011 indicate that the highest levels of vomitoxin (2.8 to 3.8 ppm) was in Indiana and Michigan, but levels at or below 1 ppm in ethanol plants in Illinois, Iowa, Minnesota, North Dakota, and South Dakota. Some areas of Nebraska also had higher than average levels of vomitoxin in corn resulting in 1.5 to 2.0 ppm in DDGS.

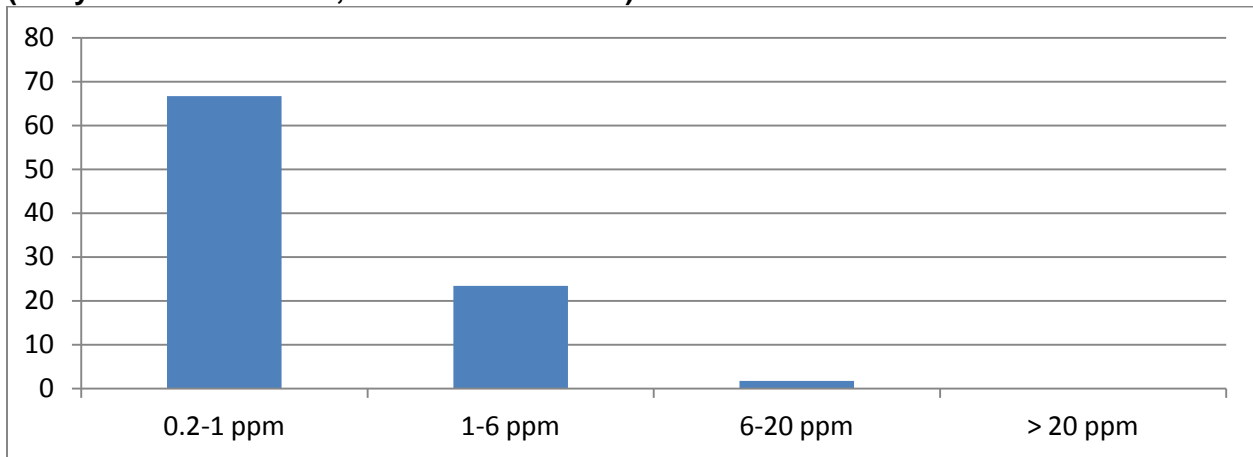
Table 1. Average vomitoxin concentrations in DDGS samples (November , 2011 to January, 2012) produced by state.

State	Average DDGS Vomitoxin Concentration, ppm
Michigan	2.8
Indiana	3.8
Illinois	1.0
Iowa	0.9
Minnesota	0.9
North Dakota	1.2
South Dakota	0.7
Nebraska	1.8

Source: Cenex Harvest States

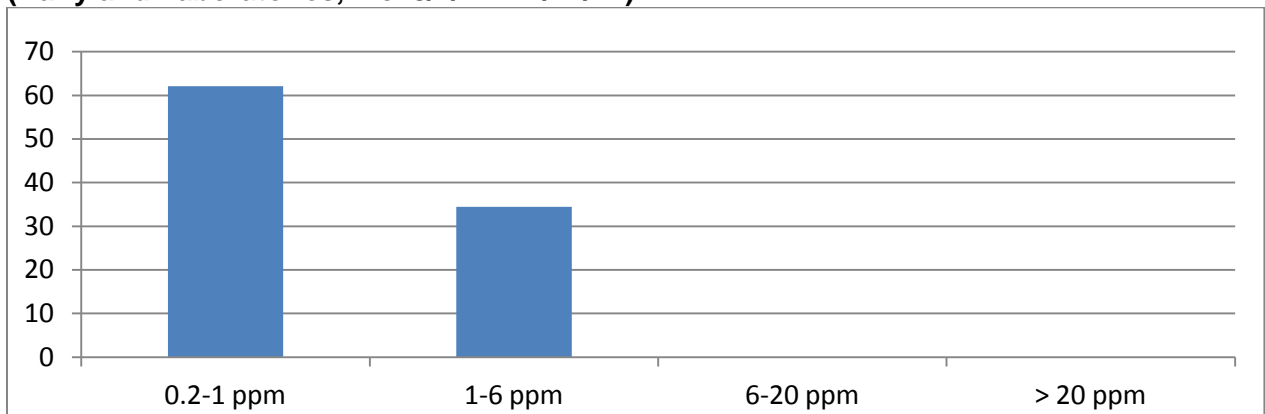
The majority of corn samples submitted to Dairyland Laboratories from August to December, 2011 (www.dairylandlabs.com/documents/moldtoxin10.10.1.pdf), contained relatively low levels of all mycotoxins. As shown in **Figure 1**, approximately 67% of corn samples analyzed contained less than 1 ppm vomitoxin, with about 23% of the samples containing between 1 to 6 ppm vomitoxin. Similar distribution of vomitoxin concentrations were also observed for DDGS samples (**Figure 2**). For zearalenone, about 32% of the corn samples contained concentrations between 10 to 250 ppb, with less than 5% of the samples containing concentrations between 250 to 1,000 ppb (**Figure 3**), but all DDGS samples submitted contained between 10 to 250 ppb zearalenone (**Figure 4**). The majority of corn samples (less than 20%), and about a third of the DDGS samples submitted for analysis had aflatoxins in the range of 2 to 5 ppb, with very few samples exceeding 5 ppb (**Figure 5 and 6**). Finally, T-2 toxin was detected in both corn (**Figure 7**) and DDGS (**Figure 8**) samples submitted to Dairyland Laboratories, but the majority of samples containing T-2 toxin had concentrations less than 100 ppb. These results indicate that corn harvested in 2011 contained primarily vomitoxin, and the majority of samples contained less than 1 ppm. Prevalence and concentrations of zearalenone, aflatoxins, and T-2 toxin were relatively low in corn, with a higher proportion of DDGS samples containing detectable concentrations of these mycotoxins.

Figure 1. Percentage of Corn Samples Containing Various Levels of Vomitoxin (Dairyland Laboratories, Inc. 8/1/11 -12/12/11)



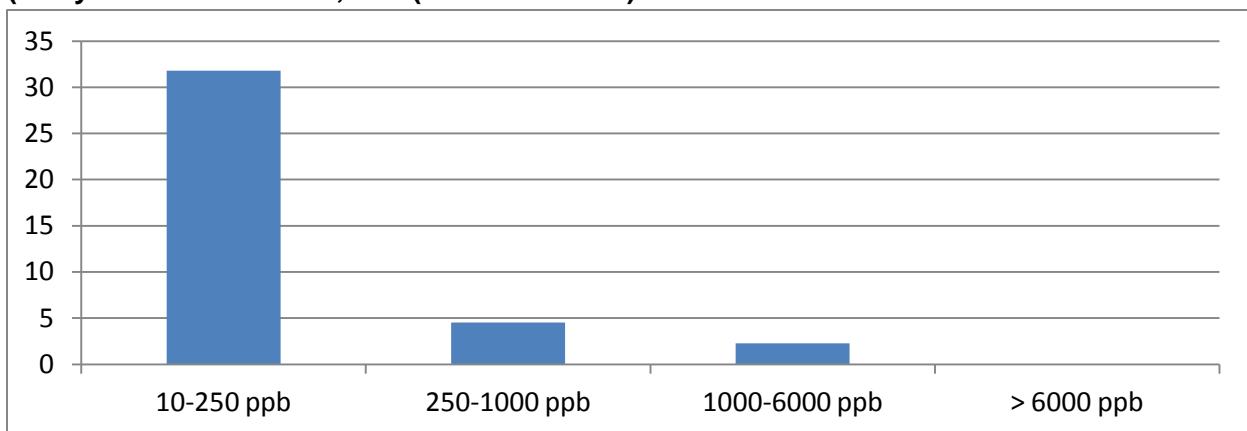
N = 111 samples

Figure 2. Percentage of DDGS Samples Containing Various Levels of Vomitoxin (Dairyland Laboratories, Inc. 8/1/11 -12/12/11)



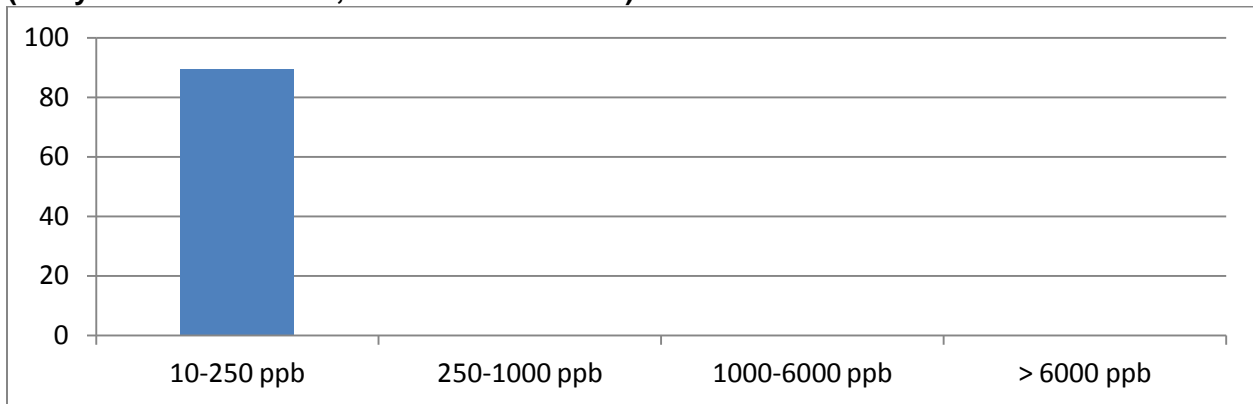
N = 58 samples

Figure 3. Percentage of Corn Samples Containing Various Levels of Zearalenone (Dairyland Laboratories, Inc. (8/1/11-12/12/11)



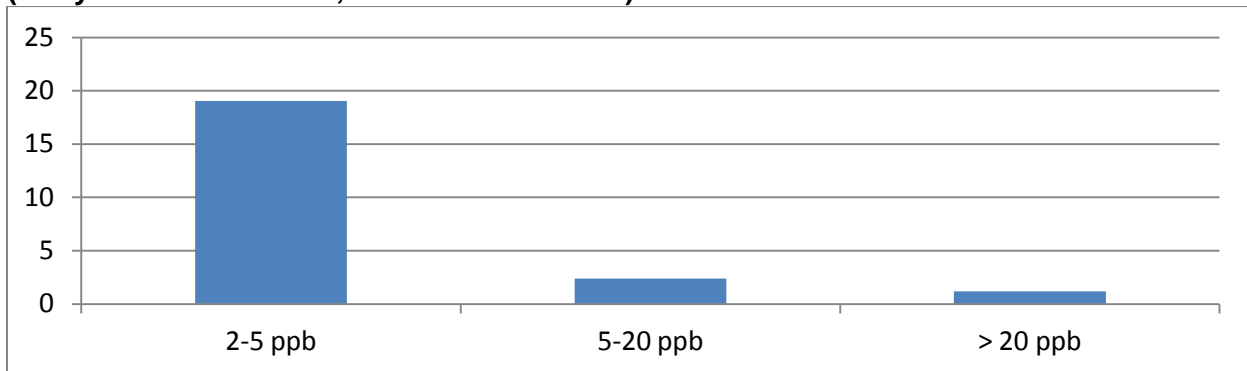
N = 88 samples

Figure 4. Percentage of DDGS Samples Containing Various Levels of Zearalenone (Dairyland Laboratories, Inc. 8/1/11 -12/12/11)



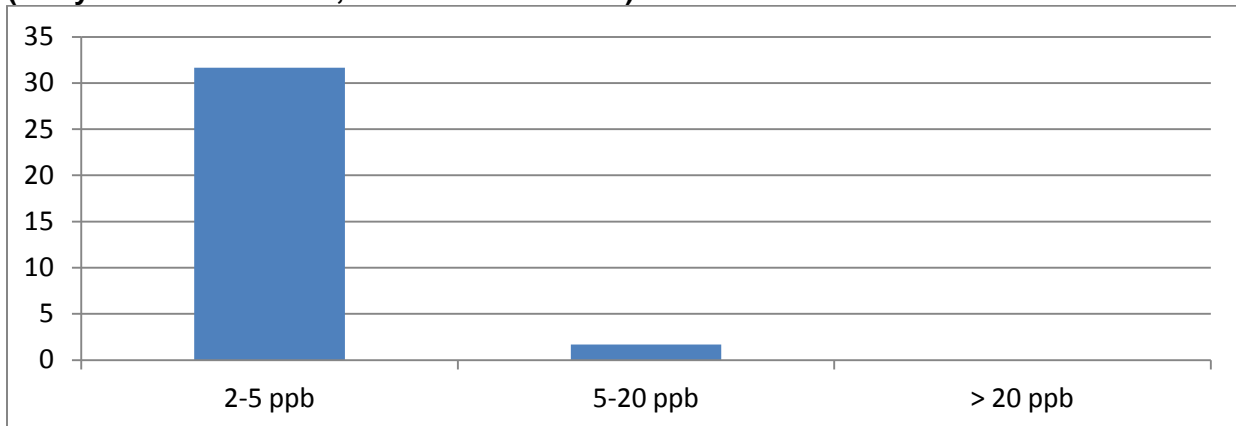
N = 29 samples

Figure 5. Percentage of Corn Samples Containing Various Levels of Aflatoxin (Dairyland Laboratories, Inc. 8/1/11 -12/12/11)



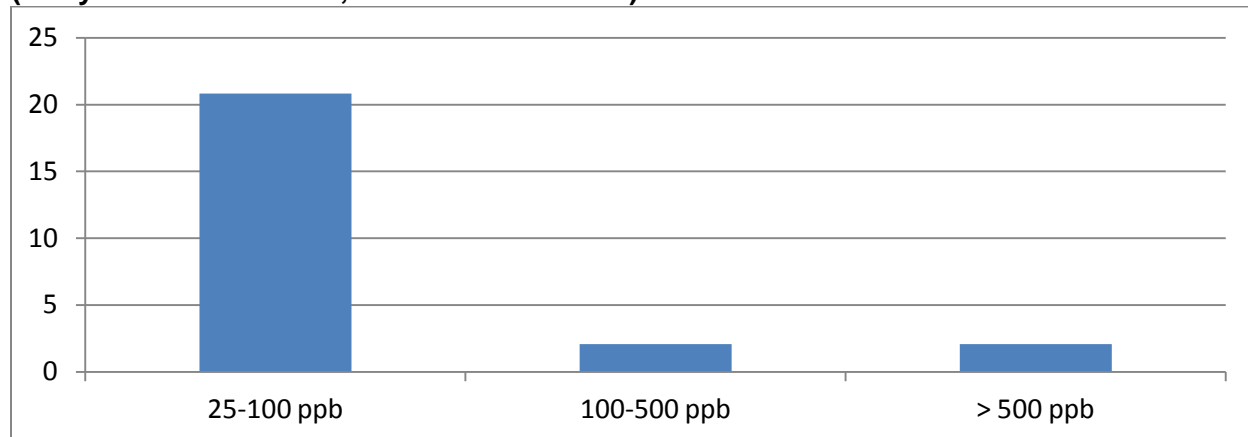
N = 84 samples

Figure 6. Percentage of DDGS Samples Containing Various Levels of Aflatoxin (Dairyland Laboratories, Inc. 8/1/11 -12/12/11)



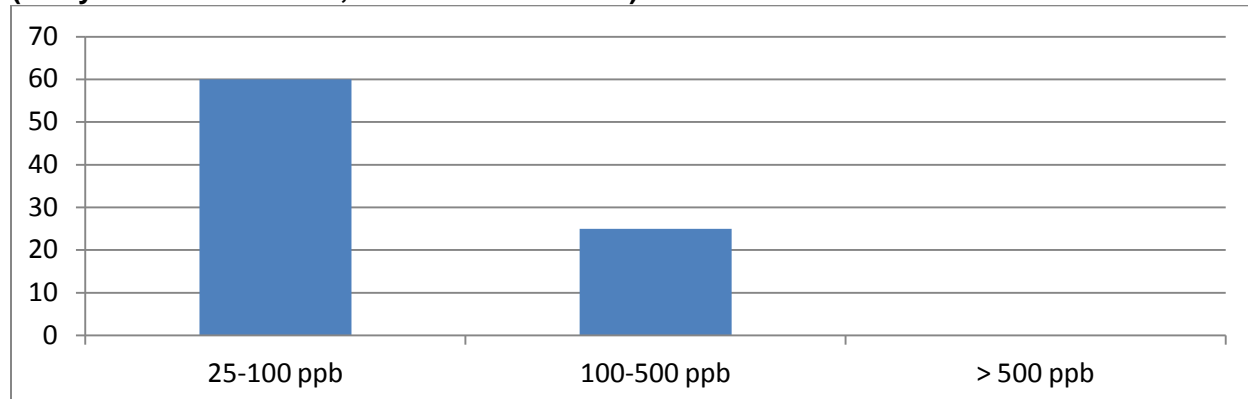
N = 60 samples

Figure 7. Percentage of Corn Samples Containing Various Levels of T-2 Toxin (Dairyland Laboratories, Inc. 8/1/11 -12/12/11)



N = 48 samples

Figure 8. Percentage of DDGS Samples Containing Various Levels of T-2 Toxin (Dairyland Laboratories, Inc. 8/1/11 -12/12/11)



N = 20 sample

In another survey, Nutriquest (Mason City, IA) collected and analyzed 141 DDGS samples from 83 ethanol plants in 12 states from December 2011 and January 2012 (**Figure 9**). No more than two samples from a single ethanol plant were included in the survey. Samples were analyzed for deoxynivalenol (DON) and zearalenone. Their results are consistent with those reported by CHS (**Table 1**) where the concentration of DON was highest in states in the Eastern U.S. Corn Belt (i.e. Ohio, New York, Michigan, and Indiana), except for Nebraska, compared to those in the Western Corn Belt (**Figure 10**). The average, standard deviation, and range of DON concentrations found in DDGS samples in Ohio, New York, Michigan, Indiana, and Nebraska compared to the overall average of 141 samples are shown in **Table 2**. The highest concentration of DON was nearly 17 ppm in Ohio, which exceeds the U.S. FDA advisory level for swine of 5 ppm. Therefore, DDGS coming from ethanol plants in Ohio should be monitored carefully and avoided if possible, if DDGS will be used in swine feeds. Overall, the average concentration of DON was 1.34 ppm which indicates that most U.S. sources have manageable amounts of DON in DDGS to cause minimal effects on animal performance. Concentrations of zearalenone followed a similar pattern to DON, where concentrations were highest in states in the Eastern U.S. Corn Belt (i.e. Ohio, New York, Michigan, and Indiana), except for Nebraska, compared to those in the Western Corn Belt (**Figure 11**).

Figure 9. Number of DDGS samples collected by state December, 2011 to January 2012.

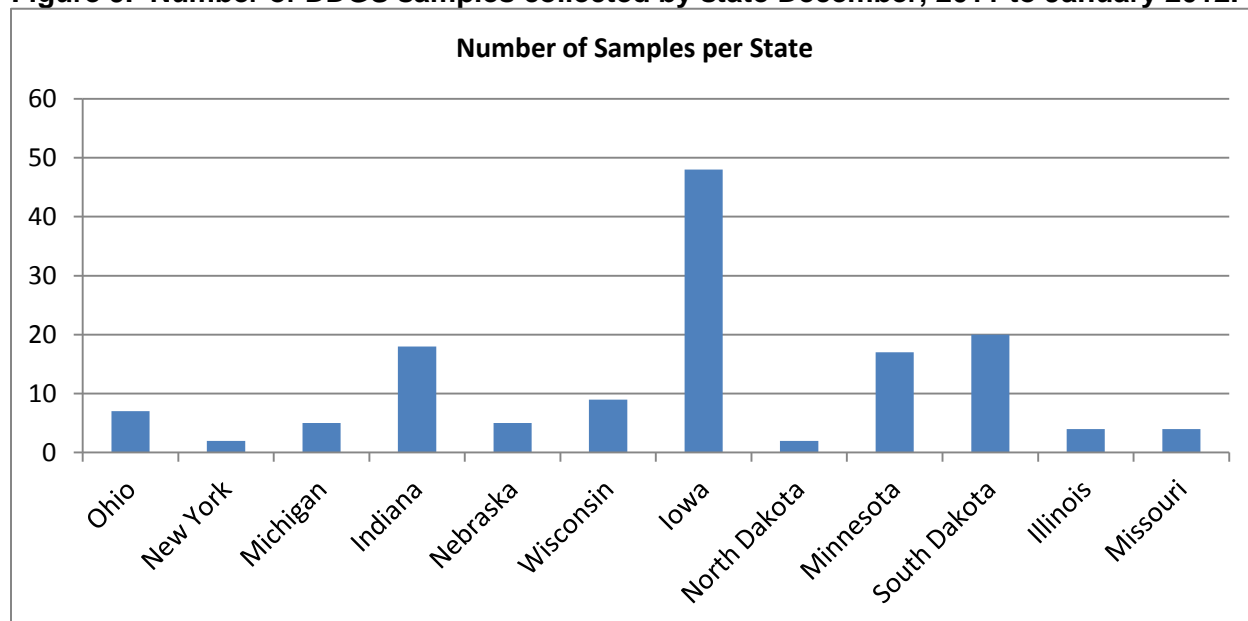


Figure 10. Average concentration of (DON) in DDGS samples collected in 12 states (number in parentheses is the number of samples collected and analyzed per state).

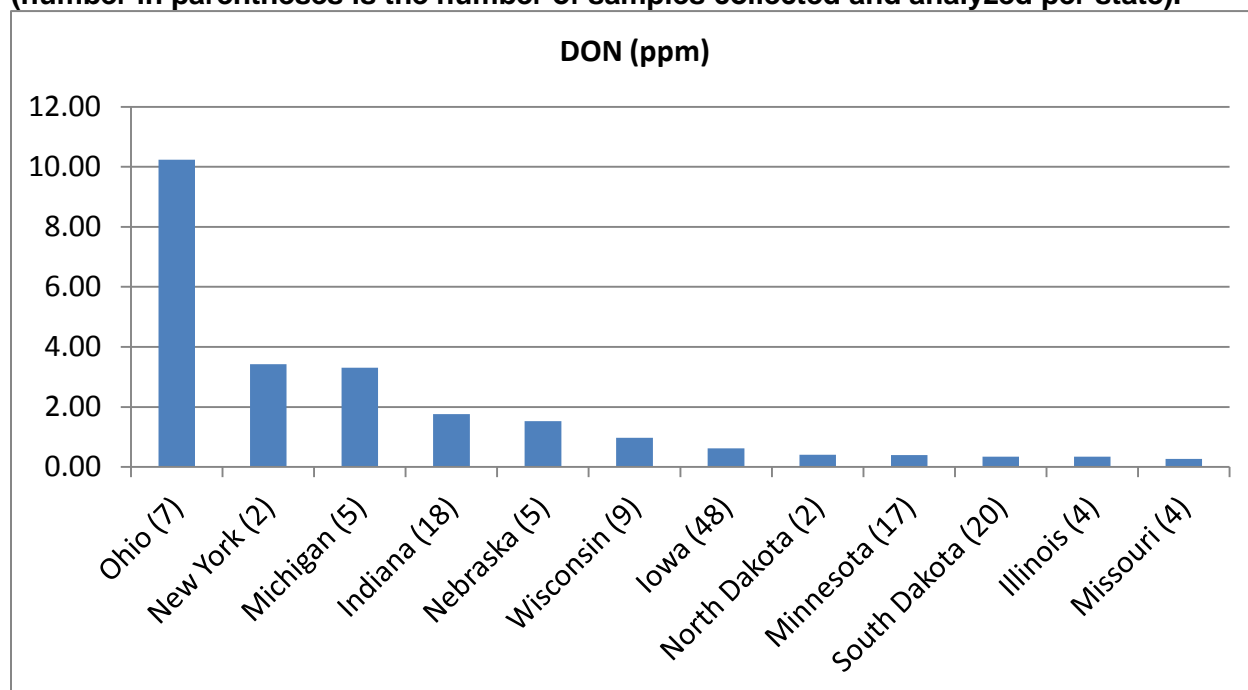
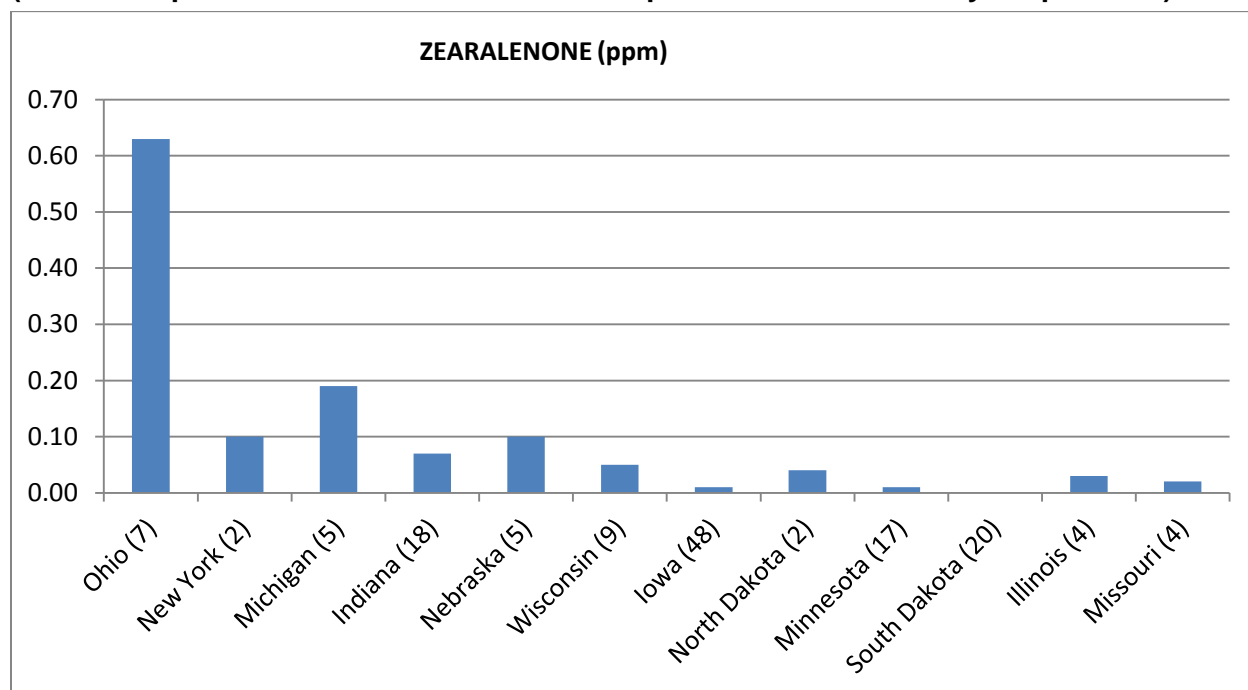


Table 2. Average, standard deviation, and range of DON concentrations found in DDGS samples in Ohio, New York, Michigan, Indiana, and Nebraska compared to the overall average of 141 samples.

Item	All	OH	NY	MI	IN	NE
Number of samples	141	7	2	5	18	5
Mean	1.34	10.24	3.43	3.31	1.76	1.53
Std. Dev.	2.44	4.74	0.19	1.46	1.22	0.90
High	16.99	16.99	3.56	4.96	3.24	2.48
Low	0.04	3.50	3.29	1.81	0.47	0.49

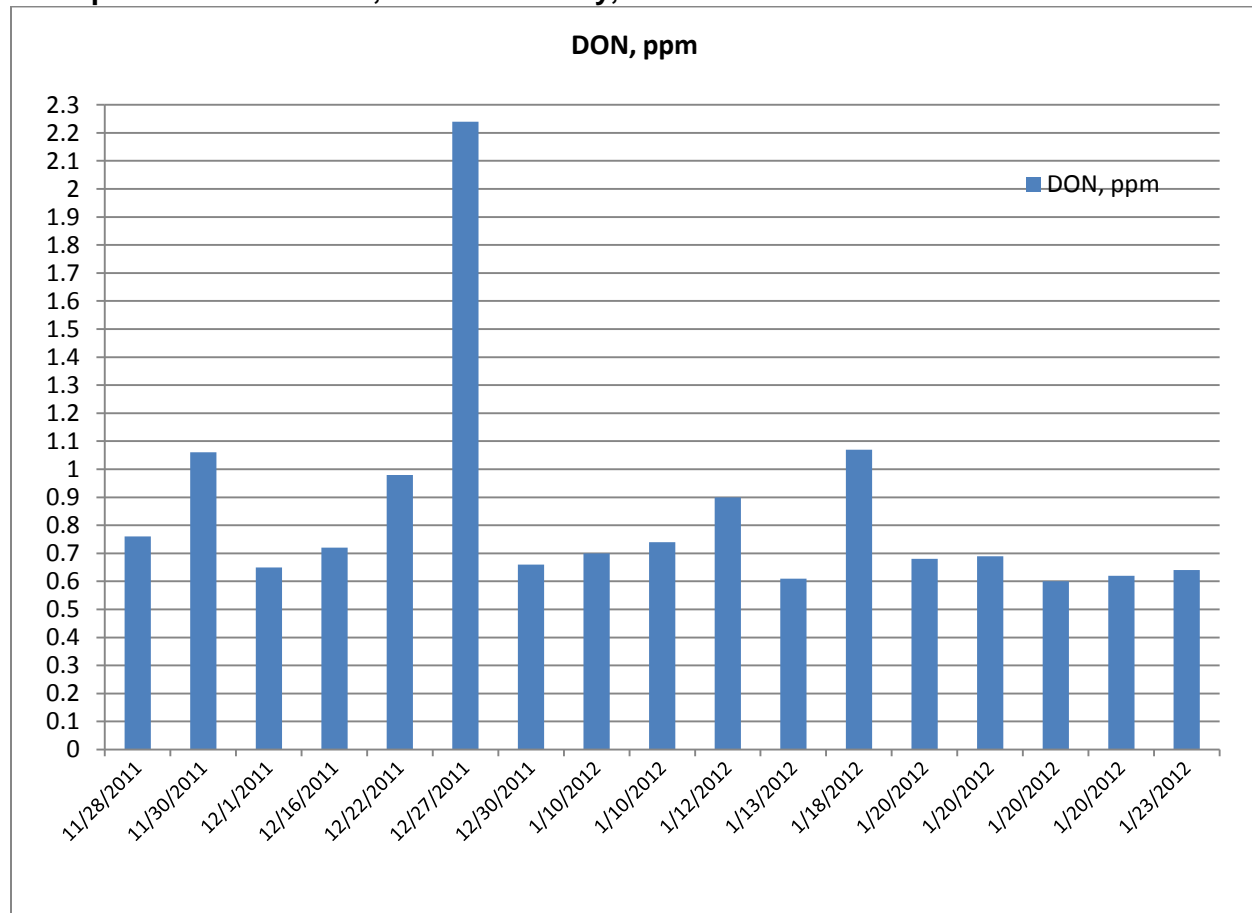
Figure 11. Average concentration of zearalenone in DDGS samples collected in 12 states (number in parentheses is the number of samples collected and analyzed per state).



Vomitoxin Concentrations in DDGS Exports

Limited data are available on mycotoxin presence and concentrations in DDGS being exported. However, data provided by Cenex Harvest States for DDGS samples in containers and barges (**Figure 12**) shows that vomitoxin content was generally less than 1 ppm for the period of November 28, 2011 to January 23, 2012. Only one sample contained slightly more than 2 ppm vomitoxin. No samples had aflatoxin greater than 5 ppb.

Figure 12. Vomitoxin (DON) concentrations of DDGS in barges and containers destined for export from November, 2011 to January, 2012.



Source: Cenex Harvest States

Conclusions

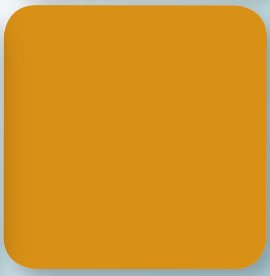
A few states in the U.S. Corn belt had growing and harvesting conditions conducive to vomitoxin production in 2011. However, although DDGS produced in these regions may have higher concentrations of vomitoxin than most regions of the Midwestern U.S., it appears that the majority of DDGS being produced in 2012 will have less than 1 ppm of vomitoxin. Some 2012 DDGS samples may also contain zearalenone, aflatoxins, and T-2 toxin, but the frequency and concentration of these mycotoxins are low.

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CHAPTER 12

Sulfur Concerns and Benefits in DDGS



Chapter 12

Sulfur Concerns and Benefits in DDGS

Introduction

Sulfur (S) is an essential mineral for animals and serves many important biological functions in the animal's body. However, when excess S is present in ruminant diets, neurological problems can occur. When feed and water containing high levels of S (greater than 0.40% of diet DM) are fed to ruminants, a condition called polioencephalomalacia (PEM) can occur. Polioencephalomalacia is caused by necrosis of the cerebrocortical region of the brain of cattle, sheep, and goats. When S is consumed by ruminants, it is reduced to hydrogen sulfide by ruminal bacteria. Hydrogen sulfide is toxic and accumulation in the rumen is thought to be the cause of these toxic effects. Ruminants are more vulnerable to PEM when their diets are abruptly changed from a primarily forage diet to a primarily grain diet. This causes a dramatic shift in rumen microbial populations that produce thiaminase, resulting in a thiamin deficiency. Sulfur also appears to have a significant role and interaction with thiaminase production to cause this condition, but the mechanism is not well understood. In addition, excess dietary S can interfere with copper absorption and metabolism. As a result, when high dietary levels of S are fed for an extended period of time, dietary copper levels should also be increased (Boyles, 2007). This condition does not occur in non-ruminant animals (pigs, poultry, fish).

In contrast, feeding diets containing high sulfur DDGS may be beneficial in avoiding metabolic oxidation imbalance in swine. Recent research conducted at the University of Minnesota (Song et al., 2012) showed that high sulfur content in corn DDGS protects against oxidized lipids in DDGS by increasing sulfur-containing antioxidants in nursery pigs.

Managing Sulfur Content in Ruminant Diets When Feeding DDGS

The Beef Cattle NRC (1996) indicates that the maximum tolerable level for S in feedlot diets is 0.40% (DM basis). Vanness et al. (2009) summarized the incidence of PEM from University of Nebraska corn co-product feeding experiments and showed that the PEM incidence rate increases as total dietary S content increases from 0.40% to more than 0.56% in diets containing 6 to 8% forage (**Table 1**). High S diets (> 0.50%) that are low in effective fiber (< 4%) and high in readily fermentable starch (> 30%) are most likely to cause PEM (Drewnoski et al., 2011). For example, Vanness et al. (2009) reported that cattle consuming a distillers grains diet containing 0.47% S with no forage had a PEM incidence rate of 48%, but cattle consuming a diet containing a similar concentration of S with 6 to 8% forage had a PEM incidence rate of < 1%. Research conducted at the University of Nebraska and Iowa State University has shown that the risk for sulfur toxicity may be less when the forage levels in the diets are greater than 6 to 8% (Drewnoski et al. 2011). If 15% forage (DM basis) is included in the diet, total dietary S concentrations can be increased to 0.5%, which is equivalent to an increase of 10 to 15% distillers grains in the diet, without causing PEM. By increasing the forage content of the diet, rumen pH will not be reduced, and therefore, not favor the formation of hydrogen sulfide and allow the concentration of hydrogen sulfide to increase in the rumen. It appears that feeding

management strategies that minimize the risk of acidosis, such as minimizing feed intake variation, increased feeding frequency, and the use of ionophores, may also reduce the risk of PEM.

Table 1. Incidence of PEM from University of Nebraska corn co-product feeding experiments.

Dietary S	PEM cases/total head	PEM incidence rate
0.40 to 0.46%	3/2147	0.14%
0.47 to 0.56%	3/566	0.35%
>0.56%	6/99	0.56%

Vanness et al. (2009)

Table 2 shows examples of the impact of adding different dietary levels of DDGS, containing different levels of sulfur, to beef cattle diets comprised of corn and corn silage on final diet sulfur levels assuming low sulfate levels in drinking water. These data show that at high dietary inclusion rates (40% of DM intake) and sulfur levels in DDGS greater than 0.80%, total dietary sulfur levels would exceed the 0.40% considered to be the maximum level for causing PEM. If DDGS is going to be fed to cattle, the sulfur content should be determined and considered with the feeding level and sulfur contributions from other dietary ingredients and water to ensure that total dietary sulfur content does not exceed 0.40%.

Table 2. Effect of sulfur content of DDGS and dietary inclusion rate (DM basis) on total dietary sulfur content in corn-corn silage based diets for beef cattle.¹

DDGS inclusion rate, % DM	0.60% S in DDGS	0.80% S in DDGS	1.0% S in DDGS
20	0.21	0.25	0.29
30	0.27	0.33	0.37
40	0.33	0.41	0.49

¹Boyles, 2007.

Sulfur levels can be highly variable among DDGS sources and can range from 0.31 to 1.93% (average 0.69%) on a DM basis (www.ddgs.umn.edu). Sulfuric acid is commonly added during the dry grind ethanol production process to keep pH at desired levels for optimal yeast propagation and fermentation to convert starch to ethanol, and is also used for cleaning because of its lower cost relative to other acids. According to AAFCO Official Publication 2004, p 386, sulfuric acid is generally recognized as safe according to U.S. Code of Federal Regulation (21 CFR 582) and is listed as an approved food additive (21 CFR 573). In addition, corn naturally contains about 0.12% sulfur, and is concentrated by a factor of 3, like all other nutrients when corn is used to produce ethanol and DDGS. Yeast also contain about 3.9 g/kg sulfur and naturally create sulfites during fermentation. Based on the significant variability in S content within and among DDGS sources, it is important to determine the S content of the source being fed and monitor load to load variation. This allows nutritionists and feed formulators the ability to determine an adequate safety margin during feed formulation to manage this variability. The potential range of dietary S content, at various DDGS dietary inclusion rates and S content, assuming within plant variation of 10% is shown in **Table 3**.

In addition to the S content of the feedstuffs, drinking water may also be a significant source of total dietary S intake in certain geographic regions. If the S content of drinking water provided

to cattle is unknown, it should be tested for sulfate content and considered when determining dietary inclusion rates of DDGS and other ingredients. Cattle water consumption also varies by geographic region and is largely influenced by ambient temperature. The additional dietary S intake obtained from drinking water at various ambient temperatures and water sulfate concentrations are shown in **Table 4**.

Table 3. Range of dietary S¹ based on typical within plant variation of S content in DDGS (DM basis).

S content expected in DDGS, %	Diet S with 30% DDGS, %	Diet S with 40% DDGS, %	Diet S with 50% DDGS, %	Diet S with 60% DDGS, %
0.6	0.32-0.34	0.36-0.38	0.40-0.43	0.44-0.48
0.7	0.35-0.37	0.40-0.43	0.45-0.49	0.50-0.54
0.8	0.38-0.40	0.44-0.47	0.50-0.54	0.56-0.61
0.9	0.41-0.44	0.48-0.52	0.55-0.60	0.62-0.67
1.0	0.44-0.47	0.52-0.56	0.60-0.65	0.69-0.74

¹Assumes no sulfur obtained from drinking water and a maximum of 10% variation of DDGS sulfur content. Adapted from Drenowski et al. (2011).

Table 4. Additional dietary S intake (%) from drinking water at various ambient temperatures and water sulfate concentrations¹.

Water sulfate. ppm	5° C	21° C	32° C
200	0.02	0.03	0.05
400	0.04	0.05	0.10
600	0.06	0.08	0.14
800	0.09	0.11	0.19
1000	0.11	0.13	0.24

¹Percentage of S to add to the ration to determine total dietary S intake. Adapted from Drenowski et al. (2011).

Feedlot cattle appear to be most susceptible to S toxicity during the first 30 days on a finishing diet when consuming high S water or high concentrations of S in feed. This increased vulnerability to S toxicity from feeding a high concentrate, high S diet appears to be caused by a dramatic increase in rumen hydrogen sulfide concentrations which results from an increase in sulfate reducing bacteria and a decrease in rumen pH. Since sulfate-reducing bacteria utilize lactate to convert S to sulfide, the increased availability of lactate during this early finishing period may increase their metabolism and produce more hydrogen sulfide. However, hydrogen sulfide concentrations decrease later in the finishing period due to the establishment of bacteria that use lactate and compete with sulfate-reducing bacteria. Therefore, by delaying the feeding of diets with high inclusion rates of DDGS until after the rumen microbes have adapted to a high concentrate diet (approximately 30 days) may also reduce the risk of PEM.

Feeding DDGS with High Sulfur Content to Swine

The maximum tolerable concentration of dietary S in cattle diets is suggested to be 0.40% of DM (NRC, 1996), but the tolerance for S in diets fed to pigs has not been determined. As a result, Kim et al. (2012) conducted 4 experiments to determine if high concentrations of S in DDGS-containing diets negatively affect feed preference and growth performance of weanling

and growing-finishing pigs. Based on the results from these 4 experiments, the authors concluded that dietary S concentration does not negatively affect feed preference, feed intake, or growth performance of weanling or growing-finishing pigs fed corn, soybean meal, and DDGS diets.

Oxidative damage of lipids in feed negatively affect pig health and growth performance (Miller and Brzezinska-Slebodzińska, 1993; Pfalzgraf et al., 1995). Lipid peroxidation occurs during the production of corn DDGS. Corn oil is typically present at a concentration of approximately 10% in DDGS, and contains high levels of polyunsaturated fatty acids (PUFA), particularly linoleic acid, which are vulnerable to lipid peroxidation (NRC, 1998). Increased drying time and temperature used by some ethanol plants can accelerate lipid peroxidation in the production of DDGS. Furthermore, the total S content in corn DDGS can exceed 1% due to the addition of sulfuric acid during the ethanol production process, and S content in DDGS is highly variable (0.3 to 0.9%, as-fed basis; Kim et al., 2012). Although sulfur is an essential component in many physiological functions of animals and is incorporated into amino acids, proteins, enzymes and micronutrients (Atmaca, 2004), very little is known about the impact of feeding DDGS containing a high concentration of S on pig health and performance.

It is possible that feeding DDGS containing oxidized lipids to pigs may require supplementation of higher levels of antioxidants (e.g. vitamin E) than currently being fed. For example, supplementation of additional antioxidants improved growth performance in pigs fed diets containing DDGS or oxidized corn oil (Harrell et al., 2010). However, results from other studies have shown that supplementation of antioxidants had no effect on growth performance in animals under a dietary oxidative stress challenge (Wang et al., 1997b; Anjum et al., 2002; Fernández-Dueñas, 2009).

Recently, Song et al. (2012) conducted a study to evaluate the effects of feeding DDGS with a high content of oxidized lipids on pig growth performance and metabolic oxidation status, and to determine if any of the negative effects could be overcome by increasing the dietary level of vitamin E. Total S content was higher in DDGS diets than corn-soybean meal control diets (0.39 vs. 0.19%, respectively). Dietary inclusion of 30% DDGS improved apparent total tract digestibility of S (86.8 vs. 84.6%) and S retained compared to feeding corn-soybean meal diets. Although pigs were fed highly oxidized DDGS in this study, serum TBARS were similar between DDGS and the control treatments, and there was no interaction between DDGS and dietary vitamin E concentration in serum TBARS. Serum α -tocopherol concentrations were higher in pigs fed DDGS diets compared with those fed control diets when α -tocopheryl acetate (vitamin E) was not provided or provided at NRC level (1.61 vs. 0.69 $\mu\text{g/mL}$, respectively). Pigs fed DDGS diets had higher serum concentrations of S-containing amino acids, particularly methionine and taurine, compared with those fed control diets. Liver glutathione concentration was higher in pigs fed DDGS diets than corn-soybean meal diets (56.3 vs. 41.8 nmol/g, respectively). Dietary inclusion of DDGS and vitamin E increased serum enzyme activity of glutathione peroxidase. The elevated concentrations of S-containing antioxidants (methionine, taurine, and glutathione) *in vivo* may protect pigs against oxidative stress when feeding highly oxidized DDGS. Therefore, increasing levels of vitamin E in diets may not be necessary to protect pigs against metabolic oxidative stress when feeding high S and high oxidized DDGS.

Conclusions

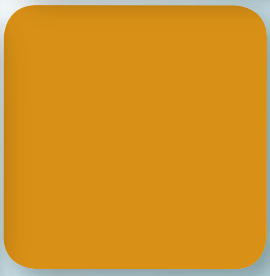
Feeding strategies that increase forage intake, reduce variability in feed intake, and stabilize rumen pH will reduce the risk of S toxicity. Providing 15% roughage in the finishing diet after 30 days on a high concentrate diet will allow feeding diets containing up to 0.50% S without the risk of S toxicity. Determining S content variability in DDGS from load to load will allow establishment of acceptable safety margins for use in formulating diets. Water sulfate content and consumption must also be considered when managing total S intake of feedlot cattle. Feeding 30% DDGS diets containing highly oxidized lipid and high sulfur (0.95%) increases sulfur-containing antioxidants and prevents metabolic oxidative stress in young pigs.

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CHAPTER 13

Feed Safety and Other Possible Contaminants in DDGS



Chapter 13

Feed Safety and Other Possible Contaminants in DDGS

Introduction

Feed safety has a significant impact on our global food safety system. Feed contamination affects the entire food chain and costs millions of dollars in lost revenue and increased costs. Furthermore, it creates fear and panic among consumers, reduces the amount of food available for consumption and consumer trust in the food system. Illness, death and potential future health risks can also occur and because we now live in a global economy, use of contaminated feed can have a global impact. Feed and food safety systems and monitoring are continually improving in many countries. While the risk of hazardous contaminants in U.S. DDGS is extremely low, the U.S. has recently adopted the most rigorous feed safety regulations (including DDGS production) ever in order to further minimize the risk of food safety risks for consumers.

U.S. Food Safety Modernization Act

In January, 2012, the Food Safety Modernization Act was signed into law in the U.S. This was the first significant update and expansion of the U.S. Food and Drug Administration's (FDA) food and feed safety regulatory powers in nearly 70 years (Brew and Toeniskoetter, 2012). Although feed production facilities (including ethanol plants) in the U.S. have been required to be registered with the FDA since 2002, this new law provides the FDA greater authority to revoke a facility's registration due to food or feed safety reasons. This new law also prohibits shipping food or feed by interstate commerce without a current registration. This means that the FDA can force stoppage of sales, and even order a mandatory recall, if it finds significant food or feed safety violations. Enactment of this new law will provide even greater insurance and confidence that U.S. DDGS will meet the most strict feed safety requirements in the world.

While this law has not been implemented, it requires ethanol plants manufacturing corn co-products (i.e. DDGS) to develop and implement a Hazard Analysis and Critical Control Point (HACCP) plan. It is expected that the FDA will release the details of this rule by June 2012. In general, the rule will require feed manufacturers to evaluate known or potential feed safety hazards, identify and implement preventative control procedures, monitor those procedures, take corrective actions when they are not working, and periodically verify that the overall system is working effectively. There will likely be a requirement of written documentation of these feed safety production procedures, and ethanol plants will be inspected by the FDA for compliance. Expected required monitoring in ethanol plants include testing incoming grains and DDGS for mycotoxins, testing DDGS for antibiotic residues and potential microbial contamination such as E coli and Salmonella, use of pest control programs and good manufacturing practices. Antibiotic residues (**Chapter 9**), mycotoxins (**Chapter 10**), sulfur (**Chapter 12**), and the risk of E. coli O157:H7 shedding in cattle fed DDGS (**Chapter 16**) are discussed in detail in other chapters of this Handbook. It is also likely that a product recall plan will be required and

controls to demonstrate that unapproved food or feed additives are not found in the final co-products.

The Food Safety Modernization Act requires the FDA to inspect regulated feed production facilities on a more frequent basis, which has not been commonly performed in ethanol facilities in the past. All ethanol facilities must be inspected by 2018, and at least once every 5 years thereafter. During inspections, records showing HACCP compliance and test results will be reviewed. As a result, higher feed safety standards are being implemented in the production of U.S. DDGS. This chapter briefly discusses a few other feed contaminants and what is currently known about their risk in DDGS.

Salmonella

No data are available nor regulations for DDGS. There has been a long-term scientific debate regarding the feasibility and likely efficacy of enforcing a Salmonella negative standard for animal feeds to reduce the incidence of human salmonellosis (Davies et al., 2004). It is difficult to assess the impact of reducing Salmonella contamination in animal feeds on the risk of human foodborne salmonellosis. Factors that may attenuate or negate the impact of regulatory interventions in commercial feed include:

- Widespread use of on-farm feed mixing
- Incomplete decontamination of feed during processing
- Post-processing feed contamination at the feed mill
- Contamination during feed transport or on-farm storage
- Numerous non-feed sources of Salmonella
- High risk of post-farm infection in lairage
- Post-harvest sources of Salmonella contamination

Dioxins

No data are available nor regulations for DDGS. Dioxins are a group of chemicals representing over 210 different compounds and are ubiquitous to the environment. Only 17 are of toxicological concern and are not produced intentionally. Therefore, they can't be simply prohibited. Dioxins are formed as a by-product of chemical processes and are insoluble in water and soluble in fat. Since dioxins are not biodegradable, they can accumulate in the food chain. Maximum limits have been established for citrus pulp and kaolinitic clay. Fish oil and fish meal are the most heavily contaminated feedstuffs. Animal fat may contain significant but lower levels. However, cereals and seeds, milk by-products, and meat and bone meal are less important sources of dioxin.

Genetically Modified Corn (GM)

Unlike the U.S., several countries have concerns about the safety of genetically modified (GM) crops, and as a result, legally prohibit or restrict production or imports of some, if not all GMO grains and grain co-products. This restriction continues to be controversial, particularly due to record high feed ingredient prices and limited supplies of available feedstuffs for animal

production in many countries around the world. USDA's 2011 Acreage Report shows that biotech corn varieties were planted on 88% of U.S. corn acres in 2011. Stacked genes accounted for 49%, herbicide resistant traits accounted for 23%, and insect resistant traits represented 16% of the 88% of U.S. corn acres. It is not known, but assumed that the same proportion (88%) of corn processed for ethanol and distillers grains production contained biotech traits. There is a substantial amount of scientific evidence that GMO crops are safe. The Council for Biotechnology Information has published a statement indicating that "The Food and Drug Administration (FDA) has determined that biotech foods and crops are as safe as their non-biotech counterparts. The American Medical Association, the American Dietetic Association, and the U.S. National Academy of Sciences have also declared biotech foods safe for human and animal consumption. In addition, since being introduced to U.S. markets in 1996, not a single person or animal has become sick from eating biotech foods. Other international groups that have concluded biotech foods and crops are safe are The United Nations Food and Agriculture Organization, the World Health Organization, the International Council for Science, the French Food Agency, and the British Medical Association. The European Food Safety Authority (EFSA) has also found several biotech varieties to be safe for human and animal consumption. Related links for detailed analysis of the safety of GM crops in the food chain are as follows:

Position of the American Dietetic Association: Agricultural and Food Biotechnology

<http://download.journals.elsevierhealth.com/pdfs/journals/0002-8223/PIIS0002822305021097.pdf>

World Health Organization: Modern food biotechnology, human health and development: an evidence-based study

http://www.who.int/foodsafety/publications/biotech/biotech_en.pdf

United Nations: Effects on human health and the environment

<http://www.fao.org/newsroom/en/news/2004/41714/index.html>

National Academy of Sciences: Safety of Genetically Engineered Foods

http://books.nap.edu/catalog/10977.html?onpi_newsdoc07272004

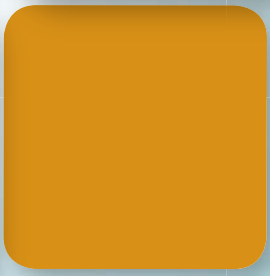
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CHAPTER 14

Use of DDGS in Beef Cattle Diets



Chapter 14

Use of DDGS in Beef Cattle Diets

Introduction

The U.S. beef cattle industry has been a major consumer of wet and dried corn distiller's by-products for decades. As a result, there has been considerable research conducted to evaluate the feeding value of corn distiller's by-products to cattle. Most of the research is related to feeding distiller's grains to finishing beef cattle. Several excellent research summaries and feeding recommendations have been published (Erickson et al., 2005; Tjardes and Wright, 2002; Loy et al., 2005a; Loy et al., 2005b; Schingoethe, 2004). Most recently, Klopfenstein et al. (2008) published an excellent literature review including a meta-analysis of 9 experiments where various levels of wet distiller's grains with solubles were fed to feedlot cattle.

Nutrient Composition of Distiller's By-products for Beef Cattle

For more specific information on the nutrient composition and digestibility of DDGS for beef, refer to **Chapter 4 "Nutrient Composition and Digestibility of DDGS: Variability and *In Vitro* Measurement"**.

Wet and dried distiller's grains with solubles are relatively high in protein (27 to 30%), and historically have been used as a protein supplement in feedlot cattle diets (Klopfenstein et al., 2008). Most of the protein in corn DDGS is zein, which has a high rumen escape value (Little et al., 1968), and about 40% of zein is degraded in the rumen (McDonald, 1954). Although rumen escape protein has been shown to be quite variable among distillers grains sources (Aines et al., 1987), protein in dried distiller's grains has about 2.4 times greater protein value and DDGS has 1.8 times greater protein value than soybean meal.

The primary carbohydrate fraction in DDGS is NDF (neutral detergent fiber). Much of the NDF in DDGS is obtained from the pericarp (bran) portion of the corn kernel which contains about 69% NDF, and is highly (87%) and rapidly (6.2% per hour) digested (DeHaan et al., 1983). Because of the highly digestible and rapidly fermentable fiber in DDGS, it is now being used as a high energy and protein source in diets for feedlot finishing cattle. Farlin (1981) first demonstrated that wet distiller's grains with solubles (WDGS) has more energy per kg of dry matter than corn, which was later confirmed by Firkins et al. (1985) and Trenkle (1996).

The corn oil present in DDGS is also a significant contributor to its energy content. Vander Pol et al. (2007) showed that the digestibility of corn oil was 70% and oil from WDGS was 81% digestible. It appears that some of the oil in WDGS is protected from rumen hydrolysis and hydrogenation. As the level of fatty acid intake increases, fatty acid digestion decreases (Plascencia et al., 2003), which likely explains the decline in feeding value of DDGS when fed at increasing levels of the diet (**Table1**).

Feeding DDGS to Finishing Cattle

In the U.S., much of the distiller's grains with solubles are fed wet to finishing cattle, and as a result, it has higher energy value than DDGS. However, all of the distiller's grains with solubles exported from the U.S. for use in beef cattle rations are dried. Currently, DDGS is considered to be primarily an energy source in diets for finishing cattle. Corn DDGS is very palatable and readily consumed resulting in excellent dry matter intake. Feeding WDGS results in better growth performance compared to feeding DDGS to finishing cattle (Erickson et al., 2005). Replacement of corn grain with WDGS has consistently resulted in a 15 to 25% improvement in feed conversion when 30 to 40% of corn grain is replaced with WDGS in the diet (DeHaan et al., 1982; Farlin, 1981; Firkins et al., 1985; Fanning et al., 1999; Larson et al., 1993; Trenkle, 1997a,b; Vander Pol et al., 2005a). This improvement in feed conversion is primarily due to WDGS having 120 to 150% of the energy value of corn (Erickson et al., 2005). Drying appears to reduce the energy value to 102 to 127% of the energy value of dry rolled corn in high forage diets. It appears the high energy values of WDGS and DDGS are a result of acidosis control (Erickson et al., 2005).



Buckner et al. (2007) conducted a study to evaluate the effects of feeding increasing levels of DDGS to finishing steers on growth performance and carcass characteristics (**Table 1**). The results from this study showed no effect of increasing levels of DDGS on dry matter intake, 12th rib fat depth, loin muscle area, and marbling score, but there was a quadratic effect in ADG and hot carcass weight, and a quadratic trend for gain efficiency. Feeding value increases substantially compared to corn, when DDGS is added to the diet, but declines with increasing dietary inclusion rates (**Table 1**). Klopfenstein et al. (2008) used the Buckner et al. (2007) data, along with results from 4 other experiments in their meta-analysis. Their results also showed a quadratic response to ADG when increasing levels of DDGS were fed, but observed a cubic

response in G:F. Results from this meta-analysis showed that maximum ADG is achieved when including 20 to 30% DDGS in the diet, and maximum G:F is achieved at a DDGS feeding level of 10 to 20% of the diet. Klopfenstein et al. (2008) also showed that the maximum ADG and G:F responses were achieved at higher dietary inclusion rates for WDGS compared to DDGS, and the rate of decline in feeding value with increasing feeding levels was greater for DDGS compared to WDGS.

Table 1. Growth performance and carcass characteristics when finishing steers are fed increasing levels of DDGS in the diet³.

Response criteria	0% DDGS	10% DDGS	20% DDGS	30% DDGS	40% DDGS
DMI, kg/d	9.25	9.47	9.52	9.71	9.47
ADG, kg	1.50	1.61	1.68	1.62	1.59
G:F	0.162	0.171	0.177	0.168	0.168
Feeding value ¹	100	156	146	112	109
Hot carcass wt., kg	351	362	370	364	359
12 th rib fat, cm	1.42	1.37	1.50	1.40	1.47
Loin muscle area, cm ²	80.0	80.6	82.6	81.3	81.3
Marbling score ²	533	537	559	527	525

¹Value relative to corn and calculated by difference in G:F divided by DDGS dietary inclusion rate.

²Marbling score of 400 = slight⁰, 500 = small⁰

³ adapted from Buckner et al., 2007

Leupp et al. (2009) evaluated the effects of feeding increasing levels of corn DDGS on intake, digestion, and rumen fermentation in steers fed 70% concentrate diets and that dry-rolled corn can be replaced with up to 60% DDGS in a 70% concentrate diet with no adverse effects on organic matter digestibility. However, organic matter intake was reduced when 60% DDGS was added to the diet. These researchers concluded that adding 45% DDGS to growing steer diets maximized digestion and rumen fermentation.

DDGS reduces acidosis

Feeding diets containing DDGS reduces acidosis in feedlot cattle fed high grain diets. Subacute acidosis is often a problem when finishing cattle are fed high grain diets containing a significant amount of rapidly fermentable starch. Since the starch content of DDGS is low (2 to 5%), and the fiber, protein, and fat content are high, the forage content of the diet can be reduced when feeding diets containing more than 20% of dry matter intake as DDGS. Lower quality forages can be used effectively in diets that contain greater than 20% DDGS because of its high protein content (Klopfenstein et al., 2008).

High DDGS feeding levels result in excess protein and phosphorus

When DDGS is used as an energy source and added to the diet at levels greater than 15 to 20%, excess protein and phosphorus are fed. The excess protein is used for energy that occurs through deamination of amino acids and results in urea excretion. Vander Pol et al. (2005b) showed that when finishing cattle are fed diets containing 10 or 20% DDGS of diet dry matter, there is no benefit for supplementing diets with urea, suggesting that nitrogen recycling was

occurring. However, Erickson et al. (2005) suggested that to be conservative, it may be best to follow NRC (1996) guidelines for degradable intake protein supplementation when formulating diets containing less than 20% DDGS. Feeding excess phosphorus provided by DDGS in feedlot cattle diets does not appear to have any negative effects on performance or carcass traits if adequate calcium is supplemented to the diets to maintain an acceptable Ca to P ratio.

DDGS may contain high levels of sulfur

High levels of sulfur in DDGS can be a concern for beef feedlot cattle (Lonergan et al. 2001). Ethanol plants use sulfuric acid for cleaning and to control pH during ethanol and DDGS production. As a result, sulfur content of DDGS can be highly variable and range from 0.6 to as high as 1.8%. Adequate dietary sulfur is required by microorganisms in the rumen, but too much sulfur in the diet can cause polioencephalomalacia, reduce dry matter intake, ADG, and liver copper levels. Refer to **Chapter 12 “Sulfur Concerns and Benefits in DDGS”** for a detailed summary of managing sulfur intake in ruminants.

A recent study by Neville et al. (2012) evaluated the effects of feeding an increasing concentration of DDGS (20, 40, and 60%) of the diet and corn processing method (high moisture corn vs. dry-rolled corn) on growth performance, incidence of polioencephalomalacia, and concentrations of hydrogen sulfide gas in feedlot steers. Diets ranged from 0.6 to 0.9% sulfur and were supplemented with thiamine to provide 150 mg/animal/day. Carcass-adjusted final body weight decreased linearly with increasing concentrations of DDGS in the diet but carcass adjusted gain:feed was not affected. Hot carcass weight and backfat were reduced when feeding increasing levels of DDGS resulting in decreased yield grade. Hydrogen sulfide gas increased with increasing concentration of DDGS in the diet but there were no confirmed cases of polioencephalomalacia. Corn processing method did not affect growth performance, incidence of polioencephalomalacia, or hydrogen sulfide gas concentrations in the rumen. These results, as well as those reported by Neville et al. (2010) and Schauer et al. (2008) have consistently demonstrated that S from DDGS can be fed in excess of the maximum tolerable level in both lambs and steers fed high concentrate diets. It is possible the maximum tolerable level of sulfur reported in NRC (2005) needs to be re-evaluated. These authors suggested that the source of dietary (or water soluble) sulfur may play a role in the development of clinical polioencephalomalacia and should be further investigated.

Felix et al. (2012) evaluated the effect of copper supplementation on feedlot performance, carcass characteristics, and rumen sulfur metabolism of growing cattle fed diets containing 60% DDGS. Copper supplementation did not affect rumen pH, but hydrogen sulfide gas concentration was reduced when 60% DDGS diets were supplemented with 100 mg copper/kg diet, but not for cattle fed 0 or 200 mg copper/kg of diet. Copper supplementation improved feed efficiency in cattle fed 60% DDGS diets but had minimal effects on rumen sulfur metabolism when supplemented at twice the maximum tolerable limit for beef cattle.

Feeding DDGS results in excellent beef quality and yield

Feeding diets containing DDGS does not change the quality or yield of beef carcasses, and it has no effect on the sensory and eating characteristics of beef (Erickson et al. 2005). An increasing number of studies have evaluated the quality and sensory characteristics of beef from cattle fed distiller's grains and results consistently show no negative effects on eating characteristics of beef from cattle fed high dietary levels of DDGS.

Roeber et al. (2005) evaluated color, tenderness, and sensory characteristics of beef strip loins from two experiments where wet or dry distiller's grains were fed to Holstein steers at levels up to 50% of the ration. There were no differences in tenderness, flavor, and juiciness. Similarly, Jenschke et al. (2006) showed that finishing beef cattle fed diets containing up to 50% wet distiller's grains (dry matter basis) produced steaks that were similar in tenderness, amount of connective tissue, juiciness, or off-flavor intensity. In fact, steaks from cattle fed the 0 and 10% wet distiller's grains with solubles diets were most likely to have an off-flavor compared to steaks from cattle fed the 30 and 50% wet distiller's grains with solubles diets. Gordon et al. (2002) fed diets containing 0, 15, 30, 45, 60, or 75% DDGS to finishing heifers during a 153 day finishing trial and observed that there was a small, linear improvement in tenderness of steaks from cattle fed increasing amounts of DDGS.

Koger et al. (2010) fed Angus crossbred steers diets containing 20 or 40% wet or dry distillers grains with solubles to replace all of the soybean meal and some of the cracked corn. Carcasses of steers fed distillers grains had greater fat thickness, higher yield grades than steers fed the dry-rolled corn, soybean meal, and alfalfa hay control diet. Loin muscle from steers fed DDGS had higher ultimate pH values than loins from steers fed wet distillers grains. Ground beef from steers fed distillers grains had higher α -tocopherol compared to those fed the control diet, but steers fed 40% distillers grains produced ground beef with higher TBARS (thiobarbituric acid reactive substances) as an indicator of lipid peroxidation, on day 2 of retail display than ground beef from steers fed 20% distillers grains diets. These researchers concluded that steers fed distillers grains may need to be marketed earlier than normal to avoid excess external fat, but there are no adverse or beneficial effects on the incidence of "dark cutters", retail display life of ground beef, or meat tenderness. However, beef from cattle fed distillers grains have increased polyunsaturated fatty acids which may be more susceptible to oxidative rancidity.

No differences were observed for growth performance or carcass characteristics when steers were fed 0 or 30% DDGS in the growing or finishing period (Leupp et al., 2009). Marbling and tenderness were not affected by diet, but steaks from steers fed DDGS during finishing were juicier and had more flavor. These data suggest DDGS can be included at 30% dietary DM in the growing or finishing period to partially replacing dry-rolled corn with no detrimental effects on performance, carcass characteristics, or sensory attributes. However, feeding 30% DDGS may negatively affect steak color.

Similarly, Segers et al. (2011) showed that the composition and tenderness of longissimus lumborum steaks were unaffected by feeding diets containing 25% DDGS or corn gluten feed compared to soybean meal as a protein supplement from weaning to harvest. However, similar to the effects of steak color observed by Leupp et al. (2009), trained panelists in this study also

observed differences in perceived color, but overall color was similar among steaks from differing treatment groups. No differences were found in concentration of TBARS among treatment groups, but steaks from steers fed DDGS became more discolored than steaks after 9 d of retail display and contained greater polyunsaturated fatty acids, suggesting that a numerical increase in lipid oxidation may result in reduced shelf life for meat products from cattle fed DDGS. Results from this study indicate that DDGS and corn gluten feed can be substituted for soybean meal and a portion of corn in beef cattle diets from weaning to slaughter while maintaining meat quality.

Aldai et al. (2010) compared the effects of feeding wheat versus corn DDGS to feedlot cattle on meat quality and showed that wheat DDGS had no negative effects on meat quality but corn DDGS had some positive effects on meat quality such as improved tenderness and palatability compared to beef from cattle fed the barley control diet.

Impact of feeding DDGS on *E. coli* O157:H7 shedding

In 2007, there was a dramatic increase in interest in identifying and understanding the possible reasons for the increases in *E. coli* O157:H7 in ground beef contamination in the U.S. Because of the exponential increase in ethanol and distiller's grains production during this same time period, there were some suspicions that feeding distiller's grains were contributing to this problem. As a result, researchers began conducting studies to determine if there was a relationship between feeding distiller's grains with solubles and the increased incidence of *E. coli* O157:H7 in beef. Refer to **Chapter 16 "Is There a Connection Between Feeding DDGS and *E. Coli* O157:H7 Shedding in Beef Cattle"** of this Handbook for a more detailed, comprehensive summary of research results related to the potential association of DDGS with the prevalence of fecal shedding of *E. coli* O157:H7.

In summary, research results demonstrate that there is no consistent effect of feeding DDGS on *E. coli* O157:H7 shedding in beef cattle. The response to *E. coli* O157:H7 shedding may be affected by DDGS feeding level and other dietary ingredients such as type of corn processing. Currently, there is no scientific evidence suggesting that the levels of DDGS being fed is a cause for *E. coli* O157:H7 contamination in ground beef.

Other DDGS feeding applications

Less research has been conducted related to feeding corn DDGS to other ages of cattle. However, DDGS is an excellent feed ingredient that can be effectively used to supplement energy and protein in the diet when cattle are fed low quality forages. When DDGS is added to diets containing forages low in phosphorus, the phosphorus in DDGS will be of significant value. Other potential uses of DDGS include providing 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.

Feeding DDGS to Beef Cows

Unlike for finishing beef cattle, less research has been conducted on feeding DDGS to beef cows. Loy et al. (2005a) published an excellent summary of results from including DDGS in beef cow diets. The best applications for using DDGS in beef cow diets are in situations where 1) supplemental protein is needed (especially when feeding low quality forages) to replace corn gluten feed or soybean meal, 2) a low starch, high fiber energy source is needed to replace corn gluten feed or soy hulls, and 3) when a source of supplemental fat is needed.

DDGS as a supplemental protein source

Researchers have shown that when DDGS was supplemented to provide 0.18 kg of protein/day to beef cows grazing native winter range in Colorado, it compared favorably to alfalfa hay or cull navy beans (Smith et al., 1999). Shike et al. (2004) compared performance effects of feeding corn gluten feed or DDGS as a supplement to ground alfalfa hay to lactating Simmental cows and observed that cows fed



DDGS gained more weight, but produced less milk compared to cows fed corn gluten feed. However, there were no differences between cows fed DDGS and those fed corn gluten feed on calf weights and rebreeding performance. In a subsequent study, Loy et al. (2005a) reported that researchers at the University of Illinois, compared supplementing diets for lactating Angus and Simmental cows consisting of ground corn stalks with either DDGS or corn gluten feed. Cows nursing calves were limit fed total mixed rations and there were no differences in milk production and calf weight gains between cows supplemented with DDGS or corn gluten feed.

DDGS as a supplemental energy source

Dried distiller's grains with solubles is an effective energy supplement when fed with low quality forages. Summer and Trenkle (1998) showed that DDGS and corn gluten feed were superior supplements to corn in corn stover diets, but not in the higher quality alfalfa diets. Corn stover

(stalks) are low in protein, energy, and minerals, but are low in cost and readily available in major corn producing states in the U.S. When low quality forages (e.g. corn stover) are fed to gestating beef cows in good condition, feeding 1.4 to 2.3 kg of DDGS per day, during the last 1/3 of gestation will meet their protein and energy requirements (Loy et al., 2002). For beef cows fed low quality forage (e.g. corn stalks) in early lactation, supplementing with 2.7 to 3.6 kg of DDGS will meet their protein and energy requirements (Loy et al., 2002).

Radunz et al. (2010) evaluated the effects of late gestation dietary energy source (grass hay, corn, and DDGS) on pre- and post-partum cow performance pre-partum dietary energy source. When these energy sources were fed at or above daily requirements, there were no detrimental effects on pre- or post-partum cow performance, and feeding DDGS as a pre-partum dietary energy source reduced daily feed costs during gestation. Dietary energy source affected the partitioning of energy and caused changes in plasma metabolites resulting in heavier birth weights of calves from cows fed DDGS or corn during late gestation compared to those fed grass hay.

DDGS as a supplemental fat source

Supplemental fat may improve reproduction in cow herds experiencing suboptimal pregnancy rates (<90%). Loy et al. (2002) indicated that feeding supplements with similar fatty acid profiles to corn oil (found in DDGS), pregnancy rates improved. They also indicated that fat supplementation works best in feeding situations where protein and/or energy supplementation is already necessary.

Engle et al. (2008) evaluated the effects of feeding DDGS compared to soybean hulls, in late gestation heifer diets, on animal and reproductive performance. Their results showed that pre-partum diets containing DDGS, as a source of fat and undegradable intake protein, improved pregnancy rates in well-maintained, primiparous beef heifers.

Shike et al. (2009) evaluated the influence of corn co-products, in limit-fed rations on cow performance, lactation, nutrient output, and subsequent reproduction. Cows fed DDGS lost 16 kg less body weight and had 0.9 kg/d less milk production, which resulted in calves tending to have lower ADG than for cows fed corn gluten feed. In a second experiment, cows were fed 2.3 kg/d of ground cornstalks and isocaloric amounts of corn gluten feed (7.7 kg/d) or DDGS (7.2 kg/d) to meet nutrient requirements. In contrast to the first experiment, cows fed DDGS tended to lose more weight than those fed corn gluten feed, but there were no differences in milk production or calf ADG. There were no differences in reproductive performance in both experiments, suggesting that DDGS and corn gluten meal can be included up to 75% of a limit-fed diet, but the higher fat content of DDGS compared with corn gluten feed did not improve reproduction.

Replacement Heifers

Very little research has been conducted on feeding DDGS to replacement heifers. However, based upon numerous studies for finishing cattle, DDGS would be an excellent source of by-

pass protein and energy for developing replacement heifers. In a study by MacDonald and Klopfenstein (2004), replacement heifers grazing brome grass were supplemented with 0, 0.45, 0.90, 1.36, or 1.81 kg DDGS per day. These researchers observed that for each 0.45 kg of DDGS supplemented, forage consumption decreased by 0.78 kg per day and average daily gain increased by 27 g per day.

Loy et al. (2003) evaluated the value of supplementing the ration, daily or three times per week, with DDGS in high forage diets for growing crossbred heifers. These heifers were provided *ad libitum* access to grass hay (8.7% crude protein) and were supplemented with DDGS or dry rolled corn. The supplements were fed at two levels and offered either daily or three times per week in equal proportions. Heifers that were supplemented daily ate more hay, gained faster, but had lower feed conversion than heifers supplemented three times per week. At both the low and high supplementation levels, heifers fed DDGS had better ADG and feed conversion than heifers fed the dry rolled corn (**Table 2**). These authors calculated that the net energy value of DDGS was 27% higher than for corn grain.

Table 2. Growth performance of growing heifers fed native grass hay and supplemented with either corn or DDGS for at two supplementation levels.

		Low ^a	High ^b
ADG, kg/d	Corn	0.37	0.71
	DDGS	0.45	0.86
DM Intake/ADG	Corn	15.9	9.8
	DDGS	12.8	8.0

^aLow = supplement fed at 0.21% of body weight

^bHigh = supplement fed at 0.81% of body weight

Source: Loy et al. (2003).

In a subsequent study, Loy et al. (2004) fed cannulated heifers either no supplement, DDGS supplemented daily, DDGS supplemented alternating days, dry rolled corn daily, or dry rolled corn supplemented on alternating days. As expected, hay intake was higher for heifers that received no supplementation compared to those that did, but there were no differences in feed intake between heifers supplemented with DDGS or corn. Heifers that were supplemented with DDGS had higher rates of rumen fiber disappearance than heifers supplemented with corn.

Loy et al. (2008) determined the effect of supplement type, concentration, and frequency of feeding on feed intake and growth performance to estimate the energy value of DDGS in a high-forage diet for growing heifers. These researchers showed that supplementing DDGS or dry-rolled corn to the ration 3 times weekly decreased forage intake and body weight gain compared with daily supplementation, but feeding DDGS improved body weight gain and gain:feed compared with dry-rolled corn. They calculated the TDN of DDGS to be 118 to 130% the value of corn when fed as a supplement to a grass-hay diet for growing heifers.

Stalker et al. (2004) conducted two experiments to evaluate the effects of supplemental degradable protein requirements when DDGS was fed as an energy source in forage based diets. Diets were formulated to be deficient (> 100 g/day) in degradable protein, but contained

excess metabolizable protein. Results of this study showed that adding urea to meet the degradable protein intake requirement is not necessary when DDGS is used as an energy source in forage based diets.

Morris et al. (2005) showed that when individually fed heifers were provided high or low quality forage diets with supplementation of either 0, 0.68, 1.36, 2.04, or 2.72 kg DDGS per day, forage intake decreased and average daily gain increased. These results suggest that DDGS can be an effective forage supplement to increase growth at times when availability of forage may be limited.

Islas and Soto-Navarro (2011) evaluated the effects of supplementation of DDGS on forage intake and digestion of beef heifers grazing small-grain pasture and showed that supplementation with DDGS up to 0.6% of body with increased fat intake, as well as fat and NDF digestibility with no adverse effects on intake, digestibility, and characteristics of ruminal fermentation. Based on these results, DDGS can be successfully used as a supplement to increase lipid intake without negatively affecting forage intake or digestibility in cattle grazing small grains pasture.

Conclusions

Corn DDGS is an excellent energy and protein source for beef cattle in all phases of production. It can be effectively used as an energy source and be fed up to 40% of ration dry matter intake for finishing cattle with excellent growth performance and carcass and meat quality. However, at this high feeding rate excess protein and phosphorus will be fed.

Although controversial, there is no consistent effect of feeding DDGS on *E. coli* O157:H7 shedding in beef cattle. Dietary level of DDGS and type of corn processing (dry rolled corn, high moisture corn, steam flaked corn) may affect the response to *E. coli* O157:H7 shedding. Currently, there is no scientific evidence suggesting that the level of DDGS fed is a cause for *E. coli* O157:H7 contamination in ground beef,

The best applications for using DDGS in beef cow diets are in situations where 1) supplemental protein is needed (especially when feeding low quality forages) to replace corn gluten feed or soybean meal, 2) a low starch, high fiber energy source is needed to replace corn gluten feed or soy hulls, and 3) when a source of supplemental fat is needed.

For growing heifers, adding urea to meet the degradable protein intake requirement is not necessary when DDGS is used as an energy source in forage based diets. DDGS can be an effective forage supplement to increase growth at times when availability of forage may be limited, and DDGS has 18 to 30% higher TDN value than dry-rolled corn for developing heifers.

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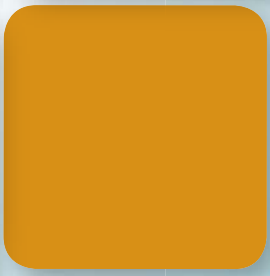
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CHAPTER 15

Use of Reduced-Oil DDGS in Beef Cattle Diets



Chapter 15

Use of Reduced-Oil DDGS in Beef Diets

Introduction

Only one study has been conducted to determine the effects of feeding reduced-oil DDGS (RO-DDGS) on growth performance and carcass characteristics of beef feedlot cattle. No studies have been conducted to determine the effect of DDGS oil extraction on net energy content.

Research results

Researchers at the University of Nebraska (Gigax et al., 2011) evaluated growth performance and carcass characteristics of 96 finishing steers fed diets containing 1) 42.5% dry rolled corn (DRC) and 42.5% high moisture corn (HMC), 2) 25% DRC and 25% HMC with 35% wet distillers grain plus solubles containing 6.7% crude fat (RO-DDGS), and 3) 25% DRC and 25% HMC with 35% wet distillers grain plus solubles containing 12.9% crude fat (normal fat DDGS[NF-DDGS]). Growth performance and carcass data are summarized in **Table 1**. Feedlot steers fed the NF-DDGS had increased final body weight, ADG, and hot carcass weight compared to steers fed the DRC-HMC diet or the RO-DDGS diet. Steers fed the DRC-HMC diet had the same dry matter intake, ADG, and feed:gain as steers fed the RO-DDGS diet. These results indicate that feeding RO-DDGS has a lower energy value and will reduce ADG and feed conversion compared to NF-DDGS. However, the RO-DDGS source used in this study still contains similar energy content compared to corn, and provides growth performance and carcass characteristics equivalent to feeding a dry-rolled and high moisture corn diet. These results suggest that the energy value of RO-DDGS is decreased by 8.5% compared to NF-DDGS, based on differences in feed conversion. However, the energy feeding value of RO-DDGS is equal to corn indicating that it is still a more economical energy and protein source than corn.

Using the NRC (1996) model to estimate relationships between feedlot cattle growth performance and diet composition, an estimate for NE_g can be calculated for RO-DDGS and used to estimate the impact of the degree of oil extraction in DDGS relative to energy value. Using data from Gigax et al. (2011), for each 1 percentage point decrease in oil content of DDGS (12.9% crude fat used in this study), NE_g decreases up to 1.3%. Until more research is conducted on growth performance effects and impacts on energy value in feedlot cattle, this relationship is the best estimate available for adjusting RO-DDGS price.

Table 1. Growth performance and carcass characteristics of yearling feedlot steers fed diets containing corn (dry-rolled and high moisture), reduced-oil DDGS (RO-DDGS), and normal-fat DDGS (NF-DDGS).

	DRC-HMC¹	RO-DDGS²	NF-DDGS³
Initial body wt., kg	403	402	402
Final body weight, kg ⁴	587 ^a	587 ^a	604 ^b
Dry matter intake, kg/day	11.1	11.1	11.1
ADG, kg	1.55 ^a	1.55 ^a	1.68 ^b
Feed:Gain	7.19	7.19	6.58
Hot carcass weight, kg	370 ^a	370 ^a	380 ^b
Marbling score ⁵	614	591	617
12th rib fat, mm	11.9	13.2	13.5
Loin muscle area, cm ²	864.2	831.5	845.4

¹DRC = dry-rolled corn, HMC = high moisture corn.

²RO-DDGS contained 6.7% crude fat (dry matter basis).

³NF-DDGS contained 12.9% crude fat (dry matter basis).

⁴Calculated from hot carcass weight adjusted to a 63% yield.

⁵450 = Slight 50, 500 = Small 0

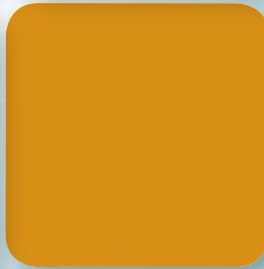
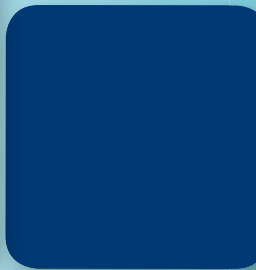
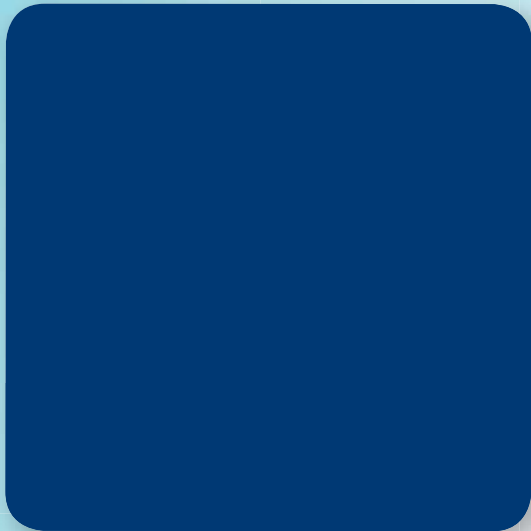
^{a,b}Means with different superscripts are different (P < 0.05).

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CHAPTER 16

Is there a Connection Between Feeding DDGS and E. coli 0157:H7 Shedding in Beef Cattle?



Chapter 16

Is There a Connection Between Feeding DDGS and *E. coli* O157:H7 Shedding in Beef Cattle?

Introduction

Consumption of ground beef is the most frequently implicated cause of *E. coli* O157:H7 outbreaks in humans, and food products from cattle have been linked to approximately 75% of *E. coli* O157:H7 outbreaks (USDA-APHIS, 1997; Vugia et al., 2007). Cattle are a major reservoir of *E. coli* O157:H7. Due to repeated hemorrhagic colitis outbreaks in humans that are linked to the consumption of ground beef, as well as animal contact, manure management, or water runoff contaminated with cattle manure, the connection between cattle and *E. coli* O157:H7 has been firmly established both epidemiologically, and in public perception (Jay et al., 2007; Keen et al., 2007; Steinmuller et al., 2006).

Research results first published in 1998 showed that an abrupt shift from grain to hay-based rations significantly reduced generic *E. coli* populations (Diez-Gonzalez et al., 1998). These results generated several subsequent research studies that have yielded variable results (Hancock et al., 2000; Hovde et al., 1999; Keen et al., 1999). Callaway et al. (2008) published a thorough review of the current state of knowledge about the effects of diet and other cattle management factors on *E. coli* and O157:H7 populations. The focus of this chapter is to summarize research results related to feeding wet or dried distiller's grains with solubles on shedding of *E. coli* O157:H7.

Does Feeding DDGS Increase Shedding of *E. coli* O157:H7?

Bacteria are present everywhere in the environment and their presence in corn co-products does exist. The Center for Veterinary Medicine at the FDA conducted a survey of plant-derived protein animal feed ingredients in 2003, of which 79 samples were collected from a variety of oil-seed meals and cereal grain based products. Some of the samples showed presence of *Salmonella*, *E. coli*, and/or *Enterococcus* bacteria.¹

Distillers grains were first shown to increase the shedding of *E. coli* O157:H7 in cow-calf operations in Scotland (Synge et al., 2003). In a subsequent study, other researchers found that feeding brewer's grains to cattle also increased *E. coli* O157 shedding, and increased the odds of shedding by more than 6-fold (Dewell et al., 2005). In 2007, there was a dramatic increase in interest in identifying and understanding the possible reasons for the increases in *E. coli*

¹ <http://www.fda.gov/AnimalVeterinary/NewsEvents/FDAVeterinarianNewsletter/ucm095381.htm> viewed 5-30-2012

O157:H7 in ground beef contamination in the United States. Because of the exponential increase in ethanol and distiller's grains production during this same time period, there were some suspicions that feeding distiller's grains were contributing to this problem. As a result, researchers began conducting studies to determine if there was a relationship between feeding distiller's grains with solubles and the increased incidence of *E. coli* O157:H7 in beef. A series of controversial studies conducted by researchers at Kansas State University (Jacob et al., 2008a,b,c), showed low prevalence and inconsistent responses to *E. coli* O157:H7 shedding in feedlot cattle fed distillers grains diets. Despite these inconsistent results, these researchers concluded that feeding distiller's grains increased fecal *E. coli* O157:H7 shedding in beef feedlot cattle.

Subsequent to the Kansas State University reports, researchers at the University of Nebraska (Peterson et al., 2007) fed up to 50 percent (DM basis) wet distiller's grains diets and showed that *E. coli* O157:H7 shedding occurred, but the level of shedding was no different than cattle fed diets containing no distillers grains. These results were not in agreement with those reported by Jacob et al. (2008a,b,c). Furthermore, Nagaraja et al. (2008) collected manure samples from 700 cattle fed either control and DDGS diets for 150 days and showed that the overall prevalence of *E. coli* O157:H7 shedding was low (5.1 percent) and feeding DDGS had no effect. The most recent study conducted by Jacob et al. (2009), showed no differences in fecal prevalence of *Escherichia coli* O157:H7 and *Salmonella* spp. in cattle fed dry-rolled corn or DDGS.

Currently, there is no scientific evidence suggesting that the levels of DDGS being fed is a cause for *E. coli* O157:H7 contamination in ground beef. Furthermore, if there is a possible connection between feeding of distiller's grains and *E. coli* shedding, the mechanism has not been elucidated. Some researchers have hypothesized that a possible connection may be due to intermediate end-products of yeast fermentation (e.g. vitamins, organic acids), but there has been no research conducted to confirm this. *In vitro* studies have not detected any effects of distiller's grains on *E. coli* O157:H7 populations in mixed ruminal and fecal fluid fermentations (Callaway et al., 2008). It is important to recognize that bacterial contamination (including *E. coli* O157:H7) in the meat supply can occur during many segments of the food chain, and is not restricted to feed or feed ingredients.

Conclusions

Food-borne pathogenic bacteria continue to be a significant threat to human health in many countries around the world, despite the implementation of food safety regulations. Although post-harvest sanitation strategies have reduced *E. coli* O157:H7 presence in meat products, implementation of pre-harvest intervention strategies can further reduce the risk of food borne pathogens in food animals before they enter the food chain. Some feedstuffs appear to alter shedding levels of *E. coli* O157:H7, but these effects have not always been consistent. Fasting and feeding poor quality forages have been shown to increase shedding of *E. coli* O157:H7 in cattle, but abruptly switching cattle from a high grain diet to a high-quality hay-based diet has been shown to reduce *E. coli* O157:H7 populations. More research is needed to identify the mechanism (e.g., competitive exclusion, physical removal, forage quality, tannins, lignin, other

phenolics) by which feeding forage impacts the microbial populations of the ruminant intestinal tract, including the ecology of *E. coli* and *E. coli* O157:H7 populations, in order to implement practical dietary modifications.

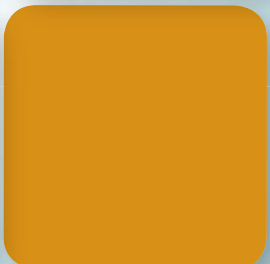
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CHAPTER 17

Use of DDGS in Dairy Cattle Diets



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Introduction

Wet and dry distiller's grains are excellent feed ingredients for use in lactating dairy cow rations. Of all U.S. livestock and poultry industries, dairy and beef cattle continue to be the largest consumers of distiller's co-products. Distiller's grains are high in energy, readily fermentable fiber, and protein for lactating dairy cows as well as calves and replacement heifers. Refer to Chapter 4 "**Nutrient Composition and Digestibility of DDGS: Variability and *In Vitro* Measurement**" for a detailed description of DDGS nutrient values to use in dairy ration formulation. An excellent literature review on the use of distiller's products in dairy cattle diets was published by Schingoethe et al. (2009), and is excellent supplemental reading for this chapter of the Handbook.

Nutritional Value of DDGS for Dairy Cattle

Schingoethe et al. (2009) summarized various studies involving the feeding value of distiller's grains with solubles for dairy cattle. Distiller grains with solubles are a good source of crude protein source (>30% CP on a dry matter basis) which is high in ruminally undegradable protein (~55% of crude protein). Distiller's grains with soluble are also an excellent source of energy (net energy for lactation is approximately 2.25 Mcal/kg of dry matter). The intermediate fat concentration (10% on a dry matter basis) and readily digestible fiber (~39% neutral detergent fiber) contribute to the high energy content in DDGS. Lactation performance is usually similar when cows are fed wet or dried distillers grains with solubles, but some research results show a slight advantage for feeding wet distillers grains with solubles. Distiller's grains can be used as a partial replacement for both concentrates and forages, but generally DDGS is used as a concentrate replacement.

Adequate effective fiber is needed to avoid milk fat depression when DDGS is used to replace forages in lactating cow diets. Lactating dairy cow diets can contain 20% or more DDGS on a dry matter basis as long as diets are nutritionally balanced. Feeding DDGS diets containing up to 30% DDGS provide similar or increased milk production compared with when cows are fed traditional feeds. Although DGS can be added at levels in excess of 30% of the diet on a dry matter basis, gut fill may limit dry matter intake and production in diets if more than 20% wet distiller's grains are added. The fiber in DDGS, is usually considered to be a replacement for high-starch feed ingredient such as corn, and as a result, minimizes problems with acidosis but does not necessarily eliminate it.

DDGS in Lactating Dairy Cow Rations

In order to understand the effects of feeding level and moisture content (wet vs. dry) of distiller's grains on dry matter intake, milk production, and milk composition, Kalscheur (2005) conducted a meta-analysis of data from 23 previous experiments and 96 treatment comparisons that involved feeding distiller's grains to lactating dairy cows. These studies were published between 1982 and 2005. Although the quality and nutrient composition of distiller's grains may have improved over this time period, all studies were included in the analysis to determine the overall effect of feeding distiller's grains to dairy cows. To evaluate the level of dietary inclusion of distiller's grains on lactation performance, treatments were divided into 5 categories of feeding levels: 0%, 4 to 10%, 10 to 20%, 20 to 30%, and greater than 30% on a dry matter basis. The form of the distiller's grains (wet or dried), was also used to separate responses in the analysis.

Effect of feeding distiller's grains on dry matter intake

Dry matter intake (DMI) was affected by both dietary inclusion level and form of the distiller's grains fed (**Table 1**). Intake was increased by the addition of distiller's grains in dairy cow diets. For cows fed DDGS, intake increased as the dietary DDGS inclusion level increased, and was greatest for cows fed between 20 and 30% DDGS. These cows consumed 0.7 kg more feed (DM basis) than cows fed the control diets containing no DDGS. Cows fed greater than 30% DDGS consumed about the same amount of feed as cows fed control diets.

While DMI was increased for cows fed diets containing up to the 20 to 30% DDGS, DMI of cows fed WDGS diets was greatest at lower inclusion levels (4 to 10% and the 10 to 20% levels). When WDGS was included at concentrations greater than 20%, DMI decreased. In addition, cows fed over 30% WDGS ate 2.3 kg/d less DMI than the control group, and 5.1 kg/d less than those fed the 4 to 10% levels.

In general, distiller's grains are considered to be highly palatable, and research supports this because DMI is stimulated when distiller's grains are included up to 20% of the DM in dairy cow diets. Decreases in feed intake at higher inclusion levels may be caused by high dietary fat concentrations, or in the case of WDGS, high dietary moisture concentrations.

Effect of feeding distiller's grains on milk production

Milk production was not impacted by the form of distiller's grains fed, but there was a curvilinear response to increasing distiller's grains in dairy cow diets (**Table 1**). Cows fed diets containing 4 to 30% distiller's grains produced the same amount of milk, approximately 0.4 kg/d more, than cows fed diets containing no distiller's grains. When cows were fed the highest dietary inclusion rate (>30%) of distiller's grains, milk yield tended to decrease. These cows produced 0.8 kg/d less milk than cows fed no distiller's grains. Cows fed more than 20% WDGS had decreased milk production, which was most likely related to decreased DMI.

Table 1. Dry matter intake and milk yield of dairy cows fed increasing levels of distiller's grains as either dried or wet.

Inclusion level (DM basis)	DMI, kg/d			Milk, kg/d		
	Dried	Wet	All	Dried	Wet	All
0%	23.5 ^c	20.9 ^b	22.2 ^b	33.2	31.4	33.0
4 – 10%	23.6 ^{bc}	23.7 ^a	23.7 ^a	33.5	34.0	33.4
10 – 20%	23.9 ^{ab}	22.9 ^{ab}	23.4 ^{ab}	33.3	34.1	33.2
20 – 30%	24.2 ^a	21.3 ^{ab}	22.8 ^{ab}	33.6	31.6	33.5
> 30%	23.3 ^{bc}	18.6 ^c	20.9 ^c	32.2	31.6	32.2
SEM	0.8	1.3	0.8	1.5	2.6	1.4

^{a,b,c} Values within a column followed by a different superscript letter differ ($P < 0.05$).

No superscript within a column indicates that there was no significant difference between distiller's grains dietary inclusion level.

Effect of feeding distiller's grains on milk composition

Milk fat percentage varied among dietary distiller's grains inclusion levels but was not significantly affected by dietary level or form (**Table 2**). Milk composition responses observed in this extensive dataset do not support the theory that feeding distiller's grains results in milk fat depression. Many factors can affect milk fat depression. First, when formulating lactating dairy cow diets, it is important to include sufficient fiber from forages in order to maintain adequate rumen function. Distiller's grains are comprised of 28-44% neutral detergent fiber, but this fiber is finely processed and rapidly digested in the rumen. As a result, fiber from distiller's grains is not considered ruminally effective fiber and should not be considered equal to forage fiber. Second, high levels of fat provided from distiller's grain may also impact rumen function leading to milk fat depression, but it is often a combination of dietary factors which lead to significant reduction in milk fat percentage.

Milk protein percentage was not different among cows fed diets containing 0 to 30% distiller's grains, and the form of the distiller's grains did not alter milk protein composition (**Table 2**). However, milk protein percentage decreased 0.13 percentage units when distiller's grains was included at concentrations greater than 30% of the diet compared to cows fed control diets. At the higher dietary inclusion levels, distiller's grains most likely replaced all other sources of protein in the diet. At these high levels of dietary inclusion, lower intestinal protein digestibility, lower lysine concentrations, and an unbalanced amino acid profile may all contribute to a lower milk protein percentage. It should be noted that the lower milk protein percentages were most evident in studies conducted in the 1980's and 1990's. Newer studies are not as consistent in showing this effect. Lysine is very heat sensitive, and can be negatively affected in DDGS by high temperatures used during the production and drying in some ethanol plants. Improved processing and drying procedures in fuel-ethanol plants built in recent years, have improved amino acid digestibility of DDGS.

Table 2. Milk fat and protein percentage from dairy cows fed increasing levels of distiller's grains.

Inclusion level (DM basis)	Fat, %	Protein, %
0%	3.39	2.95 ^a
4 – 10%	3.43	2.96 ^a
10.1 – 20%	3.41	2.94 ^a
20.1 – 30%	3.33	2.97 ^a
> 30%	3.47	2.82 ^b
SEM	0.08	0.07

^{a,b} Values within a column followed by a different superscript letter differ ($P < 0.05$).

No superscript within a column indicates that there was no significant difference between distiller's grains dietary inclusion level.

Other Factors to Consider when Formulating DDGS Diets for Lactating Dairy Cows

Dietary inclusion level of distiller's grains is not the only factor to be considered when formulating lactating dairy cow diets. Several other dietary factors that affect milk production and milk composition when distiller's grains are added to the diet should be considered. These include: wet vs. dry distiller's grains with soluble, type of forage, ratio of forage to concentrate, high oil content of distiller's grains, and formulating diets on an amino acid basis. The impact of these dietary factors on milk production and milk composition was evaluated using the same 23 published reports as described previously. There were 96 treatment comparisons included in this database.

Type of forage

To evaluate whether type of forage had an impact on cow performance, each diet was identified by the ratio of corn silage to alfalfa. Twenty-three diets contained 100% corn silage, 38 diets contained 55 to 75% corn silage, 19 diets contained 45 to 54% corn silage, and 16 diets contained only alfalfa silage or hay (0% corn silage) as the forage source. In general, a combination of forages is preferred over using single forage sources in order to balance nutrient requirements and provide effective fiber for normal rumen fermentation. However, the type of forages included in dairy cow diets is mostly dictated by local supply. In some areas, alfalfa can be grown effectively, and therefore, it may be the predominant forage included in dairy cow diets, whereas in other regions of the U.S., corn silage is the predominant source.

Results from this review showed that forage type had no impact on dry matter intake, milk production, or milk fat composition. However, forage type did affect milk protein composition. Cows fed diets containing 55 to 75% corn silage produced milk with the highest concentration of protein (3.04%). Cows fed diets containing 100% alfalfa/grass forage with 0% corn silage resulted in the lowest concentration of milk protein (2.72%). Cows fed 45 to 54% corn silage

and 100% corn silage produced milk with intermediate levels of protein (2.98% and 2.82%, respectively). Cows fed diets with a blend of corn silage and alfalfa produced milk with greater milk protein percentage suggesting that diets formulated with one forage source are more likely to be insufficient in amino acids needed to maximize milk protein percentage.

Forage:concentrate ratio

Forage to concentrate ratio is another dietary factor that may affect lactation performance of the dairy cow when distiller's grains are included in the diet. To evaluate the effect of forage to concentration ratio, treatments were classified into one of three categories: diets containing <50% forage, diets containing 50% forage and 50% concentrate, and diets containing >50% forage. Dry matter intake, milk production, and milk protein percentage were not affected by the forage to concentrate ratio. However, the percentage of milk fat was reduced by 0.36 percentage points in diets containing <50% forage. These results support the hypothesis that lack of adequate forage in the diet, which is likely due to insufficient effective fiber, is a major contributing factor for causing reduced milk fat percentage, and does not simply result from the inclusion of distiller's grains in the diet. Upon initial consideration, neutral detergent fiber (NDF) levels appear adequate because of the fiber provided by distiller's grains. However, this fiber has a small particle size and does not provide effective fiber needed for normal rumen function. Results from a recent experiment conducted at South Dakota State University tested this hypothesis directly (Cyriac et al., 2005). As forage level decreased in the diet from 55 to 34%, milk fat percentage decreased linearly from 3.34 to 2.85%, even though the concentration of NDF remained similar across diets. Therefore, when formulating diets containing high levels of distiller's grains, it is important to be certain that they contain adequate levels of effective fiber from forage. The remaining fiber from distiller's grains will be quickly digested and used to produce VFA's in the rumen.

High oil content of distiller's grains

The relatively high oil content of distiller's grains is a potential concern when it is included in dairy cow diets. Corn oil in distiller's grains is relatively high in linoleic acid (~60%), which is a long-chain, unsaturated fatty acid. High levels of vegetable oil can potentially cause incomplete biohydrogenation in the rumen resulting in milk fat depression. Results from this review of previously published studies did not reveal a strong relationship between dietary feeding level of distiller's grains and milk fat depression. However, it is possible that there could be interactions between the concentration of oil and the lack of effective fiber in distiller's grains which could result in milk fat depression.

Formulating diets on an amino acid basis

This literature review also evaluated the effect of formulating dairy cow diets on an amino acid basis vs. a crude protein basis. Data used in this analysis included experiments where rumen-protected lysine and methionine, or a high protein feedstuff (e.g. blood meal) providing a significant source of lysine was added to the diets. Lysine may be deficient in dairy cow diets

where corn feedstuffs are the predominant ingredients. Results from this analysis suggest that milk protein percentage tended to increase when diets included a source of supplemental lysine. However, additional research is needed to determine if supplemental lysine would allow for additional amounts of distiller's grains to be included in dairy cow diets.

Performance results from recent studies

Kleinschmit et al. (2006) conducted a study to evaluate the effects of feeding total mixed diets containing 20% DDGS from 3 different sources on milk production and composition in dairy cows. The DDGS replaced a portion of the ground corn and soybean meal in the diets and they had a forage-to-concentrate ratio of 55:45. Dry matter intake (21.4 kg/d) was similar among diets, but cows fed diets containing DDGS had greater milk yield (34.6 vs. 31.2 kg/d), 4% fat-corrected milk (32.7 vs. 29.6 kg/d), and energy-corrected milk (35.4 vs. 32.3) compared with cows fed the diet with no DDGS. Cows fed DDGS had improved feed efficiency compared with cows fed the control diet (1.78 vs. 1.63). Milk fat yield was greater in cows fed DDGS compared with those fed the control diet (1.26 vs. 1.14 kg/d), but milk protein percentages (3.28, 3.13, 3.19, and 3.17% for control, DDGS-1, DDGS-2, and DDGS-3, respectively) were higher for cows fed the control diet compared with DDGS diets, and tended to be lower for cows fed DDGS-1 than for DDGS-2 and DDGS-3. However, milk protein yields tended to be greater for cows fed DDGS than for those fed the control diet (1.09 vs. 1.02 kg/d). Results from this study suggest that the DDGS sources used in this study did not affect lactation performance.

Anderson et al. (2006) determined the effects of feeding 10% or 20% dried or wet distiller's grains with soluble in 25% corn silage, 25% alfalfa hay, and 50% of concentrate mixes to dairy cows on lactation performance. Feeding dried or wet distiller's grains with solubles improved feed efficiency and energy-corrected milk/kg of DMI by increasing yield of milk, protein, and fat while dry matter intake tended to decrease.

Kleinschmit et al. (2007) compared feeding 15% DDGS to lactating dairy cows using corn silage, alfalfa hay, or a combination of corn silage and alfalfa hay as the primary forage source in the diets. They observed that replacing corn silage with alfalfa hay in diets containing 15% DDGS increased milk yield, and tended to linearly increase milk protein yield in cows during late lactation. Furthermore, feeding alfalfa hay as the sole forage source improved feed efficiency compared with diets containing corn silage.

Janicek et al. (2008) conducted two studies to evaluate the effects of feeding 0%, 10%, 20%, and 30% DDGS where DDGS replaced a portion of the forage and concentrates in the diets. Dry matter intake increased when feeding 30% DDGS compared to 0% DDGS, but milk production, and the percentages of milk fat and protein were not different between the control and DDGS diets. Therefore, these results suggest that lactating dairy cow rations can contain as much as 30% DDGS and support satisfactory lactation performance and milk composition.

Sasikala-Appukuttan et al. (2008) compared the effectiveness of using 10% and 20% corn condensed distiller's solubles (CCDS) with 18.5% DDGS, and a combination of 18.5% DDGS and 10% CCDS, on dry matter intake, milk yield and milk composition of lactating Holstein cows. The diets were formulated to provide 17% crude protein with variation in acid detergent

fiber, neutral detergent fiber, and fat concentration (2 to 4%). Their results showed that CCDS is as effective as DDGS in replacing soybean meal and corn grain in the total mixed ration.

Feeding DDGS to Lactating Dairy Cows in Hot, Humid Sub-Tropical Climates

Most of the DDGS research involving dairy cattle has been conducted in temperate climates. To study the production responses of lactating dairy cows in hot, humid climates, the U.S. Grains Council sponsored a feeding trial on a commercial dairy farm in central Taiwan from September to November, 2003 (Chen and Shurson, 2004). The objectives of this feeding trial were to compare the feeding value of DDGS with corn, SBM, and roasted soybeans in lactating dairy cow rations and test the feasibility of DDGS in dairy rations in a hot and humid sub-tropical environment.



DDGS storage conditions during the U.S. Grains Council sponsored commercial dairy trial in Taiwan.



Lactating Holstein dairy cows used in the U.S. Grains Council sponsored DDGS dairy trial in Taiwan.

Fifty primiparous Holstein cows were randomly assigned to the control and DDGS treatment groups based on their Days In Milk (DIM), pre-treatment milk production, and body condition score (BCS). The average DIM of two groups was the same (149 d). The average milk production of the control and DDGS group at grouping was 22.3 kg and 22.4 3.7 kg, respectively. The average BCS of the control and DDGS group at grouping was 3.0 kg and 3.1 kg, respectively. The feeding trial consisted of a two-week adjustment period to allow the cows to adapt to the pen, followed by an eight-week experimental period for data collection.

Cows were fed a total mixed ration (TMR) containing either 0% (control) or 10% (DDGS) DM from DDGS. DDGS partially replaced some of the soybean meal, corn, steam-flaked corn, and roasted soybeans in the TMR ration. The rations were formulated using Cornell Net Carbohydrate and Protein System (Barry, et al., 1994) to meet the requirement of metabolizable protein (MP), metabolizable energy (ME), calcium, and phosphorus.

Average daily dry matter intake (DMI) of the control and DDGS groups were 17.8 and 17.6 kg, respectively. The addition of DDGS to the ration did not influence DMI (**Table 3**), but the actual DMI was lower than the DMI prediction by Cornell Net Carbohydrate and Protein System (version 4.26; Barry, et al., 1994). This difference was likely due to the heat-stressed conditions of cows during the trial.

The average milk production of all cows in the control and DDGS groups on each Dairy Herd Improvement (DHI) day is shown in **Figure 1**. Cows in the DDGS group tended to have a higher average milk production than cows in the control group. Cows fed DDGS produced more milk

than the cows in the control group. The increase in milk production of cows fed the DDGS ration was likely due to the higher feeding value of DDGS. Therefore, DDGS has an advantage of supporting higher milk production of mid-lactating cows under heat-stressed conditions. Both groups showed a significant drop in milk production in the last DHI test. The temperature-humidity index increase during this period of time and feeding poor corn silage were possible reasons for this decline.

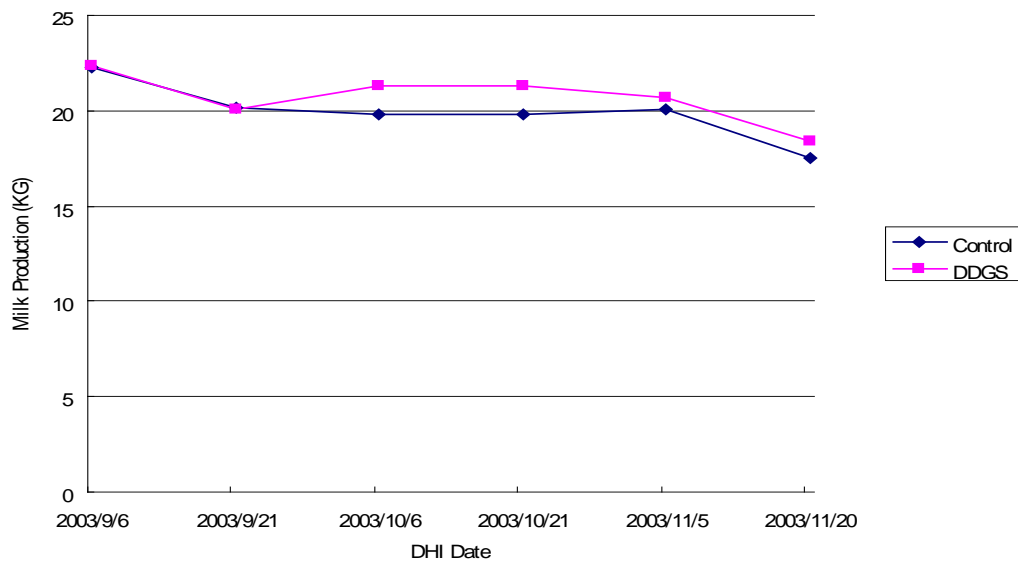


Figure 1. Average Milk Production of Cows fed the Control and DDGS TMR.

As shown in **Table 3**, cows fed DDGS produced significantly more milk (0.9 kg/d) than the cows in the control group. The ration containing DDGS provided more fat and energy to cows in the DDGS group, which likely explains the higher level of milk production. Although milk fat percentage was not different between dietary treatments, cows fed DDGS tended to produce more milk fat per day than cows in the control group, which was likely due to the higher level of milk production of cows fed DDGS. Although the addition of 10% DDGS in the ration decreased milk protein percentage, the amount of milk protein produced per day was not affected. One of the concerns regarding the use of DDGS in lactating dairy cow rations is its high fat content, which may interfere with ruminal fermentation and may decrease microbial protein production and milk protein. However, the higher level of milk production of cows in the DDGS group compensated for the negative effects of feeding DDGS on milk protein percentage. Body condition scores of cows were not significantly different between dietary treatments.

Table 3. Effects of Feeding TMR¹ with and without 10% DDGS on the Milk Production, Milk Composition and Body Condition Score of Mid-Lactating Cows under Heat-stressed Conditions.

Response variable	Treatment (T)		Pen (P)		SE	T	P- value	
	Control	DDGS	1	2			P	T×P
DMI, kg/d ²	17.8	17.6	17.8	17.6	0.20	0.32	0.29	0.012
Milk, kg/d	19.5	20.4	19.8	20.1	0.44	0.04	0.46	0.003
Fat, %	4.51	4.45	4.43	4.53	0.13	0.61	0.41	0.69
Fat, kg/d	0.86	0.91	0.87	0.91	0.03	0.10	0.22	0.07
Protein, %	3.45	3.32	3.41	3.37	0.04	0.001	0.17	0.73
Protein, kg/d	0.66	0.68	0.67	0.67	0.02	0.40	0.97	0.02
Lactose, %	4.85	4.90	4.92	4.83	0.03	0.07	0.004	0.84
Total Solids, %	13.5	13.4	13.5	13.4	0.16	0.36	0.77	0.63
MUN, mg/dL ³	11.2	11.8	12.3	12.8	0.50	0.23	0.80	0.04
SCC, 10 ⁴ /ml ⁴	26.9	35.4	35.9	26.4	13.8	0.54	0.49	0.76
BCS ⁵	2.96	3.01				0.21		

¹ TMR = total mixed ration² DMI = dry matter intake³ MUN = milk urea nitrogen⁴ SCC = somatic cell count⁵ BCS = body condition score

Feeding DDGS to Growing Dairy Heifers

Although DDGS is considered to be an excellent energy and protein source for ruminants, there is very little information on feeding DDGS to growing dairy heifers. Kalscheur and Garcia (2004) suggested that data from experiments on feeding DDGS to growing beef cattle could be extrapolated, with caution, to expected responses for growing dairy cattle. When wet or dried distiller's grains were fed to growing beef calves, there were no differences in growth rate or body protein accretion (Kalscheur and Garcia, 2004). However, when dried rolled corn was replaced with wet distiller's grains or DDGS, to provide 40% of dry matter intake, growth rate and feed conversion were improved (Kalscheur and Garcia, 2004). Growing cattle fed wet distiller's grains generally have higher feed conversion than cattle fed DDGS. At high DDGS feeding levels, variable amounts of heat-damaged protein among DDGS sources are less of a concern for growing cattle because they consume protein in excess of their requirements (Kalscheur and Garcia, 2004). Therefore, DDGS can be added to growing heifer rations at levels up to 40% of dry matter intake to achieve excellent growth rate and feed conversion.

Conclusions

Corn DDGS is a good source of protein, fat, phosphorus, and energy for lactating dairy cows. Distiller's grains can be included in dairy cow diets up to 20% of the diet without decreasing dry matter intake, milk production, and milk fat and protein percentage. Inclusion of DDGS from 20 to 30% also supports milk production equal to or greater than diets with no DDGS. However, milk production from cows fed diets containing wet distiller's grains decreases when wet distiller's grains are included at more than 20% of the diet. Milk fat percentage varies, but was

not significantly changed by the inclusion of distiller's grains in the diet. Milk protein percentage decreases at the highest dietary inclusion rates of distiller's grains. More research is needed on feeding distiller's grains from new ethanol plants to determine if improved quality corresponds to improved performance. Consequently, distiller's grains from today's ethanol plants may not affect milk protein percentage as did distiller's grains from the 1980's and 1990's. In addition, studies investigating rumen function are needed to determine the impact of distiller's grains on milk fat concentration.

Distiller's grains can replace more expensive sources of protein, energy, and minerals in dairy cow diets. However, when balancing diets containing DDGS, nutritionists must follow acceptable nutritional guidelines to prevent imbalances of nutrients. Corn DDGS can be effectively used in a total mixed ration by mid-lactating dairy cows under heat-stressed climatic conditions, and is a high quality co-product that can be used effectively in the dairy industry in sub-tropical and tropical regions of the world. Although there has been limited research to evaluate feeding DDGS to growing dairy heifers, DDGS has been added to growing beef cattle rations at levels up to 40% of dry matter intake to achieve excellent growth rate and feed conversion. There is no reason to expect that these results cannot also be achieved when feeding DDGS to growing replacement heifers.

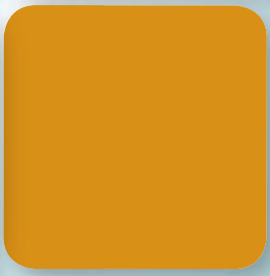
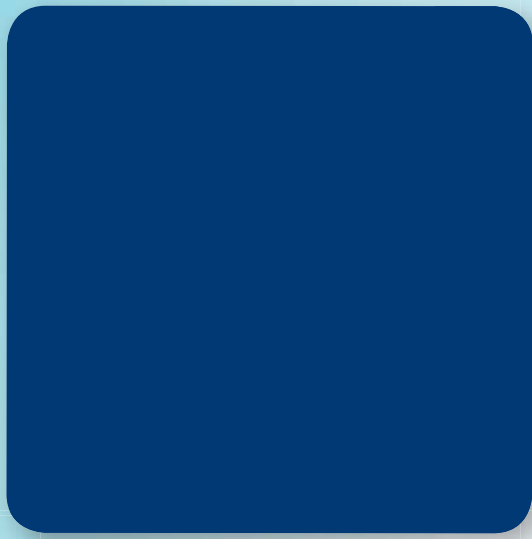
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CHAPTER 18

Use of Reduced-Oil DDGS in Dairy Cattle Diets



Chapter 18

Use of Reduced-Oil DDGS in Dairy Cattle Diets

Introduction

“Typical” DDGS contains 10 to 12% crude fat and can be fed to lactating dairy cows at levels up to 30% of dry matter intake, without negatively affecting milk yield or milk fat content (Schingoethe et al., 2009). However, despite these research results representing numerous experiments, dairy nutritionists have been reluctant to feed more than 10 to 20% of dry matter intake because of concerns of possible depression in milk fat content.

Results from a survey of 10 dairy cattle nutritionists showed that the primary reason that distillers grains was restricted in dairy diets was due to its high fat content, and half of these nutritionists believed that the high concentrations of unsaturated fatty acids in distillers grains reduced fat content of milk (Owens, 2009). Furthermore, almost all (90%) of these nutritionists indicated that the dietary inclusion rate of distillers grains could be increased in dairy diets if a portion of the oil was removed, but believed that the cost of distillers grains should be reduced proportionately based on the reduction in energy content due to oil extraction. These nutritionists estimated that the price of oil extracted distillers grains should be reduced by 2 to 50% (average 24%). These results are consistent with those of 2 other surveys showing that variation in crude fat content of distillers grains was a concern to dairy producers (NASS, 2007), and fat content was a significant factor in their decisions about using distillers grains in their diets (Garcia, 2012, personal communication).

Results from these surveys clearly indicate that high fat content and high concentrations of unsaturated fatty acids in distiller’s grains are a primary concern for dairy nutritionists and dairy producers. Therefore, partial oil removal from DDGS is an advantage for lactating dairy cows and may allow increased dietary inclusion rates in order to avoid excess total dietary fat and its potential negative effects on milk fat concentration and yield.

Relationship of fatty acid composition in distiller’s grains and their effects on the rumen environment

The oil in distillers grains is comprised primarily of unsaturated fatty acids, with linoleic acid (C18:2) and oleic acid (C18:1) representing 59% and 25% of total fatty acid content, respectively. Bauman and Griinari (2001) showed that the presence of unsaturated fatty acids in the rumen and an altered rumen environment causing incomplete bio-hydrogenation are the two conditions that can reduce milk fat. The unsaturated fatty acid concentration in the rumen is a major factor that contributes to changes in the microbial population and an increase in the conjugated linoleic acid isomer trans-10-cis-12 (Jenkins et al., 2009), which, along with other intermediaries, are potent inhibitors of milk fat synthesis (Griinari et al., 1998). In addition, the free fatty acid content of oil in distiller’s grains can negatively affect rumen fermentation (Jenkins

et al., 1993). Chalupa et al. (1984) showed that when fatty acids are supplied as triglycerides to the diet, there were no significant changes in rumen fermentation, but when free fatty acids were fed, production of propionic acid increased and the production of acetic, butyric, and total volatile fatty acids decreased. Therefore, free fatty acids affect rumen fermentation more than triglycerides, and their antimicrobial activity increases with their degree of unsaturation. Moreau et al. (2011) reported that the free fatty acid content of DDG and DDGS was 7.4% and 9.1%, respectively, compared to corn with 2.3%. Nouredini et al. (2009) reported similar concentrations of total free fatty acids (7.4%) in distillers grains, with the majority (75%) being unsaturated free fatty acids. Therefore, the concentration of free fatty acids in distillers co-products is an important consideration relative to dietary inclusion rates and potential impact on milk fat concentration and yield.

Effects of feeding reduced-oil DDGS on milk production and composition

One study has been published related to the effects of feeding reduced-oil DDGS (RO-DDGS) on milk production and composition in lactating dairy cattle, but no studies have been conducted to determine the effect of DDGS oil extraction on net energy content. Researchers at South Dakota State University (Mjoun et al., 2010a) evaluated lactation performance and amino acid utilization of cows fed increasing amounts of RO-DDGS. Four diets containing 0, 10, 20, or 30% RO-DDGS (on a dry matter basis) and replacing soybean meal, were fed to 22 multiparous and 19 primiparous Holstein cows for 8 weeks. Reduced-oil DDGS contained 34.0% crude protein, 42.5% NDF, 3.5% crude fat, and 5.3% ash.

There was no effect of increasing levels of RO-DDGS on dry matter intake, crude protein intake, or milk production (**Table 1**). Milk production efficiency (defined as energy-corrected milk divided by dry matter intake) tended to increase linearly with increasing levels of RO-DDGS in the diet, but efficiency of nitrogen utilization was not affected. Milk fat percentage increased, and milk fat yield tended to increase linearly with increasing levels of RO-DDGS, whereas milk protein percentage responded quadratically (2.99, 3.06, 3.13, and 2.99%, respectively for diets containing 0 to 30% RO-DDGS), and protein yield was not affected (**Table 1**). Total percentage of milk solids increased, and total milk solids yield tended to increase linearly as the diet inclusion rate of RO-DDGS increased.

Table 1. Dry matter intake, milk yield, and milk composition of dairy cows fed increasing levels of reduced-oil DDGS (RO-DDGS) .

	0% RO-DDGS	10% RO-DDGS	20% RO-DDGS	30% RO-DDGS
Dry matter intake, kg/day	22.7	23.0	23.7	22.2
Crude protein intake, kg/day	4.0	4.1	4.2	4.0
Milk yield, kg/day	34.5	34.8	35.5	35.2
Milk production efficiency ^{1, 2}	1.47	1.53	1.49	1.61
Nitrogen efficiency ³	25.5	27.0	25.8	26.0
Milk fat, % ⁴	3.18	3.40	3.46	3.72
Milk fat yield, kg/day ⁴	1.08	1.19	1.23	1.32
Milk protein, % ⁵	2.99	3.06	3.13	2.99
Milk protein yield, kg/day	1.03	1.07	1.10	1.06
Milk total solids, % ⁴	12.10	12.39	12.40	12.67
Milk total solids yield, kg/day ²	4.15	4.35	4.43	4.45

¹Milk production efficiency = energy-corrected milk divided by dry matter intake.

²Linear increase (P < 0.06)

³Nitrogen efficiency = milk N (kg/day)/N intake (kg/day).

⁴Linear increase (P < 0.05).

⁵Quadratic effect (P < 0.02).

These researchers concluded that adding up to 30% RO-DDGS (dry matter basis) to mid-lactation Holstein cows did not adversely affect milk production or dry matter intake, and increased milk fat percentage and yield. Although feeding up to 30% RF-DDGS supported similar lactation performance as the 0% RO-DDGS, soybean meal diet, amino acid balance may have been optimal when 20% RO-DDGS was fed. However, in a subsequent study, Mjoun et al. (2010b) evaluated ruminal degradability and intestinal digestibility of protein and amino acids in soybean meal, extruded soybeans, and corn distillers grains co-products (DDGS, high-protein DDG, modified wet distillers grains with solubles, and RO-DDGS) and concluded that the amino acid availability from distillers grains co-products is comparable to that of soybean meal. This indicates that RO-DDGS has similar protein digestibility and amino acid utilization compared to other distillers co-products, soybean meal, and extruded soybeans.

Kalscheur (2005) conducted a meta-analysis of 24 experiments and found that “typical”, high fat distiller’s grains only cause a milk fat depression when diets contained less than 50% forage or provided less than 22% NDF from forage. Therefore, RO-DDGS will have less effect on modifying the rumen environment and reducing milk fat concentration and yield.

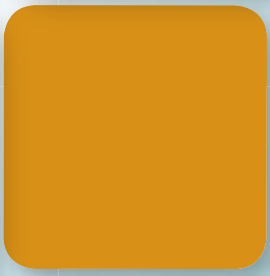
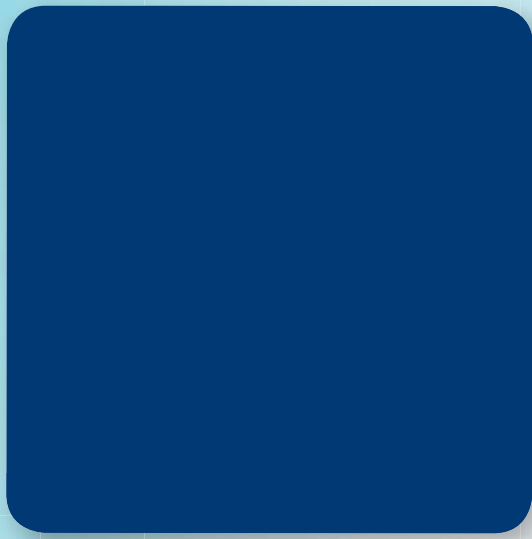
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CHAPTER 19

Use of DDGS in Poultry Diets



Chapter 19

Use of DDGS in Poultry Diets

Introduction

A considerable amount of research has been conducted on the effects of feeding DDGS to poultry. Corn DDGS is an excellent feed ingredient for use in layer, broiler, duck and turkey diets and contains approximately 85% of the energy value in corn, has moderate levels of protein and essential amino acids, and is high in available phosphorus. Layer and broiler diets can easily contain up to 10% DDGS with little, if any formulation adjustments for energy and amino acids. Swiatkiewicz and Korelski (2008) conducted a scientific literature review on the benefits of feeding DDGS to poultry and concluded that DDGS is an acceptable ingredient for use in poultry diets and can be safely added at levels of 5-8% in starter diets for broilers and turkeys, and 12-15% in grower-finisher diets for broilers, turkeys, and laying hens. However, these are conservative dietary inclusion rates assuming that diets are not formulated on a digestible amino acid basis.

Recent research studies (Shim et al. 2011; Loar et al., 2010; Masa'deh et al. 2011) have shown that DDGS can be added to poultry diets at even higher dietary inclusion rates (e.g. 20%) as long as accurate nutrient profiles specific to the DDGS source are used, and diets are formulated on a digestible amino acid basis.

Nutrient Value of DDGS for Poultry

The nutrient composition and digestibility/availability values for DDGS use in poultry diet formulation are described in detail in Chapter 4 “**Nutrient Composition and Digestibility of DDGS: Variability and *In Vitro* Measurement**” in this handbook. Additional information on *in vitro* measurements for amino acid digestibility and phosphorus availability for poultry are described in more detail in this section.

Amino acid digestibility and measurement in DDGS

Pahm et al. (2009) conducted a study to compare the concentration of standardized digestible (SDD) lysine and relative bioavailable lysine in 7 sources of corn DDGS, and to evaluate *in vitro* methods (reactive lysine and color score) to predict the concentration of SDD lysine and bioavailable lysine in DDGS. Results showed that the average SDD lysine and relative bioavailability values of lysine were 61.4 and 69.0%, respectively. There were no differences between the concentration of SDD lysine and the concentration of bioavailable lysine in 5 of 7 sources of DDGS. The concentration of SDD lysine was highly correlated ($r^2 = 0.84$) with the concentration of reactive lysine in DDGS. High Hunter L* scores were correlated with higher ($r^2 = 0.90$) concentration of bioavailable lysine in DDGS. These researchers concluded that the concentration of SDD lysine in DDGS does not overestimate the concentration of bioavailable

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lysine for poultry and values for reactive lysine can be used to estimate the concentration of SDD lysine, whereas Hunter L* color scores can be used to estimate the concentration of bioavailable lysine in DDGS.



Adedokun et al. (2008) determined standardized ileal amino acid digestibility of 5 plant-based ingredients (2 samples of corn DDGS - light and dark colored DDGS; canola meal, corn, and soybean meal) in 5 to 21-d old broiler chicks and turkey poults. After standardization, standardized ileal amino acid digestibility increased with age when chicks were fed DDGS and corn, but not soybean meal or canola meal. In turkey poults, the apparent ileal amino acid digestibility values increased with age for all feed ingredients except the dark DDGS and canola meal, but after standardization, there was no effect of age on amino acid digestibility, except for corn. Results from this study suggest that with the exception of corn, standardization of amino acid digestibility with ileal endogenous amino acid flow from birds fed a nitrogen free diet or a high digestible protein diet was not different for most plant feedstuffs.

Fastinger et al. (2006) evaluated 5 sources of corn DDGS, which varied in darkness of color for amino acid and energy content, color score, TMEn, apparent amino acid digestibility, and true amino acid digestibility using a precision-fed rooster assay. The total lysine content of the DDGS sources ranged from 0.48 to 0.76%, and the darkest DDG source had the lowest lysine content. Apparent and true lysine digestibility was approximately 30 and 15 percentage units lower, respectively, for the dark-colored DDGS source than in the other 4 DDGS sources, and average apparent and true digestibility of the essential amino acids were 10 and 8 percentage units lower for the darkest colored DDGS source, respectively, than the other 4 DDGS sources. The TMEn content of the darkest DDGS source was also lower than the other 4 DDGS sources. These results suggest that when the color score of a DDGS source was measured to have L* between 28 and 34, the amino acid availability and true metabolizable energy content is reduced, particularly for lysine. Dark-colored DDGS is often overheated during the drying

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process, causing reduced total lysine content, lysine digestibility, and TME_n content.

IDEA™ is a patented enzyme-based assay which is commercially available for rapid prediction of amino acid digestibility of poultry feed ingredients (soybean meal, meat and bone meal, poultry by-product meal, and feather meal; Schasteen et al., 2005). In order to determine the applicability of IDEA™ to predict the amino acid digestibility of DDGS, a study was conducted using 28 DDGS samples to compare amino acid digestibility estimates from IDEA™ to the true amino acid digestibility determined in the precision-fed cecectomized rooster assay. True lysine digestibility varied among DDGS samples from 59.1% to 83.6% with an average of 70.3%. There was a strong correlation between IDEA™ estimates and true lysine digestibility determined in roosters ($r^2 = 0.88$), but the correlation between IDEA™ and true digestibility for other amino acids was poor ($r^2 < 0.5$). Results from this study showed that *in vivo* lysine digestibility varies greatly among DDGS sources, with less variability among other amino acids, and that IDEA™ provides good prediction of *in vivo* poultry digestibility of lysine in DDGS, but not for other amino acids.

Phosphorus availability

Phosphorus availability is relatively high in DDGS when fed to poultry. However, to further enhance phosphorus availability in DDGS, Martinez-Amezcuca et al. (2005) conducted two experiments to evaluate the effectiveness of OptiPhos® phytase and citric acid for improving phosphorus availability in DDGS. Based on the tibia ash responses from Opti-phos and citric acid supplementation compared with those from KH_2PO_4 in these experiments, OptiPhos® phytase and citric acid released from 0.04 to 0.07% more phosphorus from DDGS which indicates that both OptiPhos® phytase and citric acid increase the availability of phosphorus in DDGS. In a follow-up study, Martinez-Amezcuca et al. (2006) conducted 3 experiments to determine the effectiveness of OptiPhos® phytase and citric acid for releasing the phosphorus that is not bioavailable in DDGS. Results showed that phosphorus bioavailability in DDGS was 67% and supplemental phytase and citric acid could release from 0.04 to 0.07% phosphorus from DDGS and increased the bioavailability of phosphorus in DDGS from 62 to 72%. These results suggest that phytase and citric acid increase the bioavailability of phosphorus in DDGS, but phytase at 1,000 FTU/kg had no consistent effect on improving AME_n and amino acid digestibility.

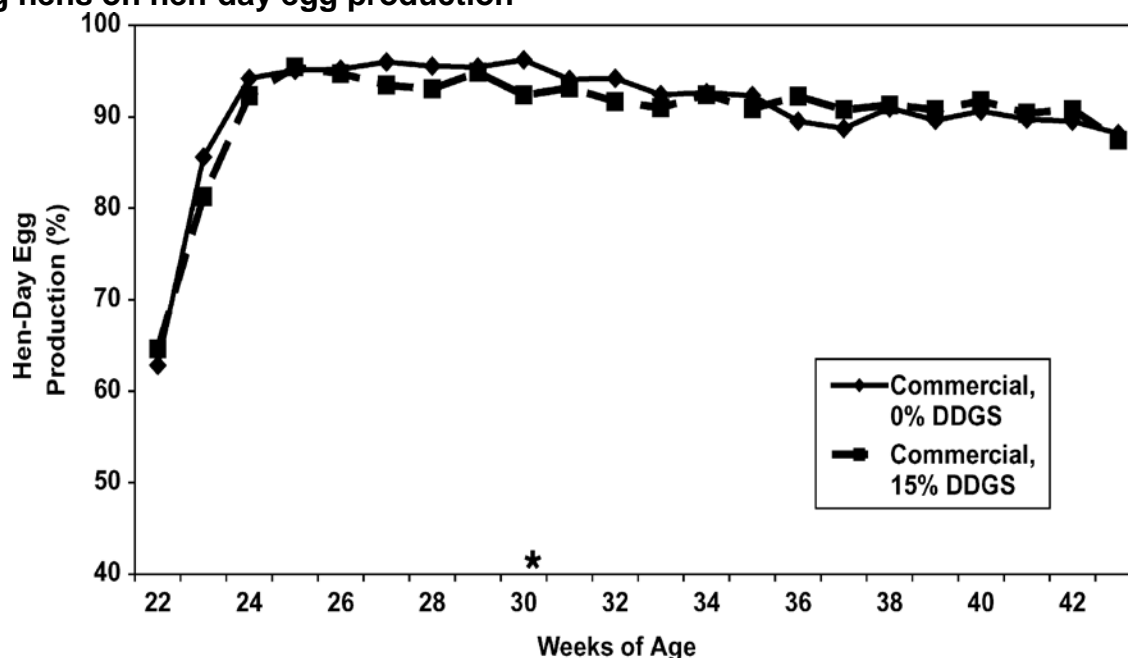
Feeding DDGS to Chicken Layers

There has been a significant amount of recent research conducted on the use of high quality corn DDGS in layer diets confirming that it is an excellent partial replacement for corn, soybean meal and inorganic phosphate and supports excellent layer performance and egg quality. Early research results reported by Matterson et al. (1966) showed that DDGS could be added to laying hen diets at levels of 10 to 20%, accounting for about 30% of the total dietary protein, without synthetic lysine supplementation, and had no effect on egg production. Harms et al.

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(1969) reported that adding 10% DDGS to a layer diet to replace a portion of the dietary protein did not affect egg production or egg weight. Jensen et al. (1974) reported that feeding diets containing DDGS resulted in an improvement in interior egg quality (Haugh units), but it was not a consistent response. Lumpkins et al. (2005) were the first to evaluate the use of high quality, corn DDGS in layer diets. They fed Hy-line W-36 laying hens high energy (2,871 kcal TME_n/kg) and low energy (2,805 kcal TME_n/kg) diets, with and without 15% DDGS from 22 to 42 weeks of age. The DDGS used in this study had color values of L* = 58.52, a* = 6.38, and b* = 20.48. There were no significant differences in egg production for layers fed the 0 and 15% DDGS high energy diets during the entire 22-week experiment, but egg production of hens fed the 15% DDGS diet was consistently lower through 32 wk of age (**Figure 1**). When adding 15% DDGS to the low energy diet, egg production was reduced from 26 to 34 weeks of age, but there was no difference after 34 weeks of age (**Figure 2**). There were no differences in egg weights, specific gravity and shell breaking strength, feed conversion, body weight, or mortality between the four dietary treatments throughout the entire experiment. There was no difference in Haugh units between dietary treatments from 25 to 31 weeks of age. At 43 weeks of age, layers fed the low energy, 15% DDGS diet had lower Haugh units compared to hens fed the high energy, 15% DDGS diet. Furthermore, feeding the 15% DDGS diets had no appreciable effect on egg yolk color. Based upon these results, the researchers concluded that DDGS is a very acceptable feed ingredient in layer diets and the maximal dietary inclusion level of DDGS should be 10 to 12% in high energy commercial diets, but lower dietary inclusion rates may be necessary in lower energy diets.

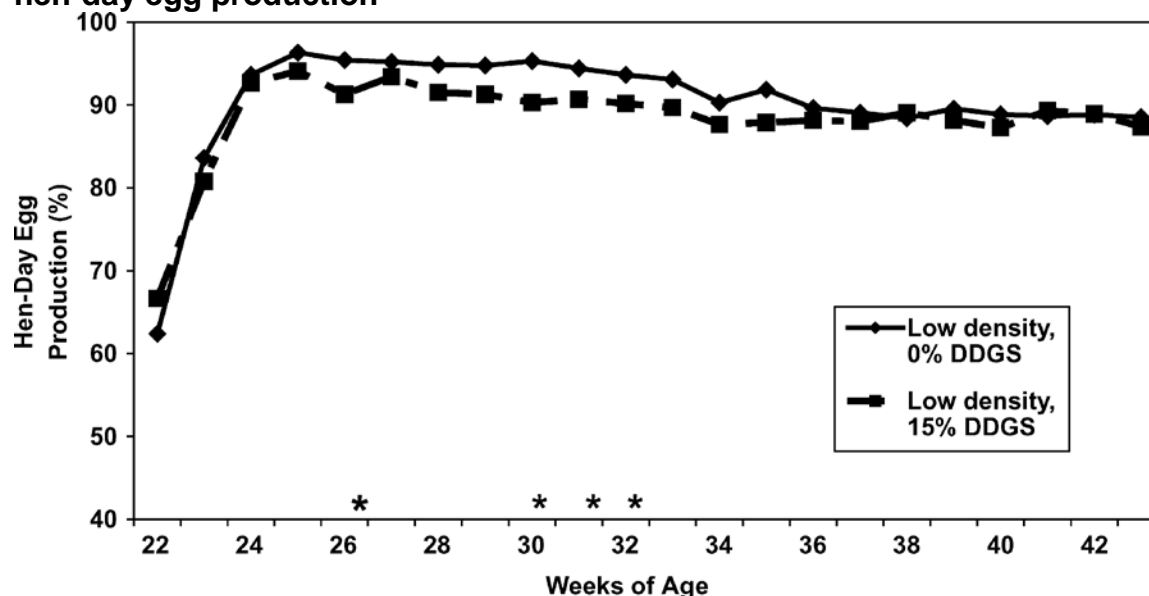
Figure 1. Effects of feeding DDGS in high energy density, commercial diets to laying hens on hen-day egg production¹



*A significant ($P < 0.05$) difference between the 2 treatments

¹Lumpkins et al. (2005)

Figure 2. Effects of feeding DDGS in low energy density diets to laying hens on hen-day egg production¹



*A significant ($P < 0.05$) difference between the 2 treatments

¹Lumpkins et al. (2005)

Similarly, Roberson et al. (2005) conducted two experiments where diets containing 0, 5, 10, or 15% DDGS were fed to laying hens to determine if egg production parameters or yolk color are affected. In the first experiment, a source of golden colored corn DDGS was added to diets fed from 48 to 56 weeks of age and then a brown colored DDGS source was added to diets from 58 to 67 weeks of age. Egg production measurements were not different at most ages. However, as dietary level of DDGS increased, there was a linear decrease in egg production (52-53 weeks of age), egg weight (63 weeks of age), egg mass (51 and 53 weeks of age), and specific gravity (51 weeks of age). Egg yolk color increased linearly as dietary level of DDGS increased throughout the experiment. In experiment 2, egg yolk redness (a^*) increased linearly as dietary DDGS level increased. These results showed that egg yolk color becomes more red within one month of feeding diets containing 10% DDGS or more of a golden colored DDGS, and that egg yolk color becomes more red by two months of feeding diets containing 5% DDGS. These researchers concluded that feeding layer diets containing up to 15% DDGS did not affect egg production, but the variable results in experiment 1 suggest that a level less than 15% DDGS should be used.

Cheon et al. (2008) conducted a layer feeding trial for 10 weeks to investigate the effects of adding light-colored DDGS at levels of 0, 10, 15, and 20% to iso-protein, iso-caloric layer diets on laying performance, egg quality and yolk fatty acid composition. Adding up to 20% DDGS to layer diets had no effect on feed intake, laying rate, total egg mass, mean egg weight and feed conversion. Furthermore, color and breaking strength of eggshell were not affected when feeding increasing levels of DDGS in the diet. In addition, albumin height and Haugh units were not affected by adding up to 20% DDGS to the diet. As expected, yolk color was significantly increased when DDGS was added to the diet. The oleic acid content decreased, and linoleic acid increased in egg yolk as increasing levels of DDGS were added to the diet, but the amount

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of saturated fatty acids in the yolk was not affected by DDGS supplementation. Results of this study conducted in Korea, suggest that light colored DDGS (L^* 56.65) could be used at levels up to 20% in layer diets without any negative effects on laying hen performance, and provide economic benefits to the Korean poultry industry.

The effect of reducing the level of fodder phosphate in layer diets containing corn or rye DDGS on performance, egg shell quality and tibia and humerus bone quality were studied in an experiment by Swiatkiewicz and Koreleski (2007). Feeding diets containing 20% corn DDGS had no effect on laying performance or egg shell and bone quality. When diets containing 20% rye DDGS were fed, layer performance and feed conversion were reduced. Reducing fodder phosphate levels in layer diets containing DDGS, did not affect performance or egg shell thickness, density and strength, elasticity and stiffness of the tibia and humerus bones. These results indicate that the amount of fodder phosphate level can be reduced in diets containing 20% corn DDGS without negative effects on performance, egg shell quality or bone characteristics.

Recently, Masa'deh et al. (2011) fed diets containing 0, 5, 10, 15, 20, or 25% DDGS to laying hens from 24 to 46 weeks (phase 1) and 47 to 76 weeks (phase 2) to evaluate egg production responses for a full production cycle. Diets were formulated to be isocaloric (2,775 and 2,816 kcal/kg of ME) and isonitrogenous (16.5 and 16.0% crude protein) in phases 1 and 2, respectively. Results showed that adding up to 25% DDGS in layer diets had no negative effects on feed intake, egg production, Haugh units, or specific gravity, and improved egg yolk color at the higher inclusion rates. Including DDGS at levels greater than 15% during phase 1 decreased egg weight, but not during phase 2. Nitrogen and phosphorus retention was increased and excretion was decreased when hens were fed the 25% DDGS diets.

Dietary enzyme supplementation in DDGS diets

Refer to **Chapter 24** of this Handbook for a detailed summary of “**Use of Enzymes in DDGS Diets for Poultry and Swine**”. In a study conducted by Swiatkiewicz and Korelski (2005), 132 brown Lohman hens (from 26 to 38 weeks of age) were fed 0, 5, 10, 15, or 20% corn or rye DDGS to determine the effects on laying performance and egg quality. Diets containing 20% DDGS were either not supplemented or supplemented with enzyme preparations that had xylanase and beta -glucanase activity. Dietary levels of corn DDGS had no effect on laying rate, feed conversion, Haugh units, eggshell percent and eggshell breaking strength, but egg yolk color was significantly increased. Feeding diets containing 5, 10 or 15% of rye DDGS did not affect laying performance and egg quality, but feeding the 20% rye DDGS diet decreased egg production. However, the addition of xylanase and beta -glucanase to the 20% rye DDGS diet improved egg laying rate.

In a subsequent study, Swiatkiewicz and Korelski (2006) fed laying hens isocaloric and isonitrogenous diets containing 0, 5, 10, 15 or 20% DDGS, and diets containing 20% DDGS supplemented with non-starch polysaccharide hydrolyzing enzymes and additional amounts of synthetic lysine and methionine. In the first phase of production (26 to 43 weeks of age), dietary DDGS level had no effect the laying rate, daily egg weight, feed intake and feed conversion. In

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the second phase of the cycle (44 to 68 weeks of age), there were no differences in egg production response criteria among groups fed diets containing 0, 5, 10 and 15% DDGS, but feeding 20% DDGS reduced laying rate and daily egg weight. However, when non-starch polysaccharide hydrolyzing enzymes were added to the diet, laying rate and performance improved when feeding the 20% DDGS diet. Dietary level of DDGS had no effect on albumen height, Haugh units, eggshell thickness, density and breaking, or sensory properties of boiled eggs, but egg yolk color score significantly improved when DDGS was added to the diet.

Gady et al. (2008) determined the apparent metabolizable energy (AME) content of corn DDGS and the effect of adding a fungal non-starch polysaccharide hydrolyzing enzyme produced by *Penicillium funiculosum* (Rovabio™Excel) on DDGS energy digestibility in layers. They fed diets containing 10 or 20% corn DDGS in corn and wheat based diets. The AME value obtained with the control corn-wheat based diet was similar to the expected value (3,089 vs. 3,106 kcal/kg DM). The corn DDGS AME value averaged 2,452 kcal/kg DM, and the AME of the control diet was only increased by 34 kcal/kg DM by enzyme supplementation. This increase was less than expected, and may be explained by the lower feed intake of the layer hens fed with the enzyme-treated diet compared to the control diet (99.5 vs. 104.4 g/hen/day). Feed conversion and egg weights were similar and not affected by adding corn DDGS to the diets. The improvement in energy digestibility by enzyme supplementation was greater for diets containing 10 and 20% corn DDGS (43 and 58 kcal/kg DM, respectively), which indicates that adding this enzyme product will improve energy utilization in corn-wheat based diets containing corn DDGS.

Effects of DDGS on molting

Hong et al. (2007) conducted a study to induce molting using DDGS and a non-salt diet to compare the effect of feeding-molting and fasting-molting treatments on performance, egg quality and visceral organ weights of laying hens. They used 108 White Leghorn hens (62 weeks of age) with egg production of over 80% and average body weight of 1.08 kg in this study. The dietary treatments consisted of: control (non-molt treatment), feeding-molting treatment (DDGS and non-salt diet), and fasting-molting treatment. Egg production decreased for 18 days to 0% in the feeding-molting group and for 17 days to 0% in the DDGS-non-salt feeding-molting group. Egg production stopped for 6 days in the fasting-molting group. Egg production restarted after 12 and 16 days in the feeding-molting and fasting-molting groups, respectively. Except for egg yolk quality, egg quality was improved for all molting treatments. Liver, heart and oviduct weights of laying hens decreased with all molting treatments. These results indicate that the feeding-molting treatment (DDGS and non-salt diet) could replace the fasting-molting treatment and reduce animal welfare concerns due to fasting during the molting process.

Mejia et al. (2010) fed 36, 45, and 54 grams/day of DDGS in a non-feed withdrawal molt program compared to feeding similar daily intakes of corn and found that postmolt egg production (5 to 43 weeks) was higher for hens fed the DDGS molt diets compared to those fed the corn diets. No consistent differences were observed for egg mass, egg specific gravity, feed efficiency, or layer feed consumption among the molt treatments for the postmolt period. These

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researchers concluded that limit feeding corn or DDGS in a non-feed withdrawal program will result in long-term post-molt performance comparable to ad libitum feeding of a corn-soybean hull diet.

Effects on manure nutrient content and gas emissions

Ammonia (NH_3) emissions are a major concern for the U.S. poultry industry. Roberts et al. (2007a,b) conducted studies to determine if increasing dietary fiber and reducing dietary crude protein would decrease NH_3 emissions from laying-hen manure. They fed diets containing 2 levels of crude protein (normal and reduced) and 4 dietary fiber sources (corn-soybean meal based control diet, diets containing either 10% corn DDGS, 7.3% wheat middlings, or 4.8% soybean hulls to provide equal amounts of additional neutral detergent fiber). The crude protein levels of the reduced crude protein diets were approximately 1 percentage unit lower than those of the normal crude protein diets, and all diets were formulated on a digestible amino acid and isoenergetic basis. Adding corn DDGS, wheat middlings, or soybean hulls to the diet reduced the 7 day cumulative manure NH_3 emission from 3.9 g/kg of DM manure for the control, to 1.9, 2.1, and 2.3 g/kg of DM manure, respectively, and also reduced the daily NH_3 emission rate. These results show that adding 10% corn DDGS, 7.3% wheat middlings, or 4.8% soybean hulls are effective in reducing NH_3 emissions from laying-hen manure, but reducing the crude protein content by 1 percentage unit did not affect NH_3 emissions.



Hale (2008) compared the effects of feeding a standard industry diet vs. feeding a diet containing 10% DDGS on manure pH, solids content and ammonia emissions. Manure ammonia emissions were reduced by an average of 16.9% over the period of the study, manure pH was reduced by 0.25 SU, and manure solids content was increased by 2.36% when feeding the diet containing 20% DDGS. Wu-Haan et al. (2010) showed that feeding 20% DDGS to laying hens reduces ammonia and hydrogen sulfide emissions with no adverse effects on hen performance.

Feeding DDGS to Broilers

Researchers have consistently observed positive performance and meat quality results when DDGS is added to broiler diets. Results from an early study by Day et al. (1972) showed that weight gain of broilers was increased when low levels of DDGS (2.5 and 5%) were added to the diet compared to broilers fed the control diet. Later, Waldroup et al. (1981) demonstrated that DDGS can be added to broiler diets at levels up to 25% to achieve good performance if dietary energy level is held constant.

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Studies involving the use of high quality corn DDGS have confirmed, and even suggested that higher dietary DDGS can be used effectively. Lumpkins et al. (2004) conducted two experiments to evaluate dietary energy and protein density and DDGS inclusion rate in broiler diets. In the first experiment, two dietary nutrient densities (high= 22% protein, 3050 kcal ME_n/kg and low = 20% protein, 3000 kcal ME_n/kg) contained either 0 or 15% DDGS. Chicks were fed experimental diets from 0 to 18 days of age. Weight gain and feed conversion were the highest for chicks fed the high density diet compared to the low density diet, but performance was not different between chicks fed the 0 or 15% DDGS diets within diet nutrient density level (**Table 1**).

Table 1. Effect of feeding 15% DDGS in high and low nutrient density broiler diets on weight gain and gain efficiency¹

Response criteria	High density, 0% DDGS	High Density, 15% DDGS	Low Density, 0% DDGS	Low Density, 15% DDGS
Wt. gain (day 7), g/d	133	134	130	124
Wt. gain (day 14), g/d	401 ^a	399 ^a	376 ^b	362 ^b
Wt. gain (day 18), g/d	556 ^a	555 ^a	523 ^b	518 ^b
Gain:feed (day 7)	956 ^a	991 ^b	898 ^c	854 ^d
Gain:feed (day 14)	938 ^a	936 ^a	874 ^b	847 ^c
Gain:feed (day 18)	782 ^a	772 ^a	712 ^b	705 ^b

^{a,b,c,d} Means within rows with different superscripts are different (P < 0.05).

¹ adapted from Lumpkins et al., 2004

In the second experiment, Lumpkins et al. (2004) fed chicks isocaloric and isonitrogenous diets containing 0, 6, 12, or 18% DDGS for a 42-day feeding period. Adding 18% DDGS in the diet reduced weight gain during the starter (0 to 16 d) period (**Table 2**), and there was a slight numerical decrease in weight gain when 12% DDGS was added to the diet. However, there was no difference in weight gain between dietary DDGS level during the grower and finisher periods. Overall weight gain (0 to 42d) of chicks fed the 18% DDGS diets was reduced compared to the other DDGS feeding levels because of the reduced weight gain during the starter period. The amino acid profile in soybean meal is more suitable to meet the amino acid requirements of broilers than corn protein sources. Since the percentage of protein provided by corn protein increased from 4.6 to 8.6% when 18% DDGS was added to the diet, and the percentage of protein supplied by soybean meal decreased, it is likely that lysine was deficient and resulted in reduced growth rate and gain efficiency. Feed intake was not affected by dietary DDGS level throughout the experiment. Gain efficiency was reduced when feeding the 18% DDGS diet during the starter period, and there was a numerical decrease in gain efficiency when 12% DDGS was added to the diet (**Table 2**). However, there were no differences in gain efficiency between any of the DDGS feeding levels during the grower and finisher period and throughout the 42-d experimental feeding period. Feeding diets containing 0, 6, 12, or 18% DDGS had no effect on carcass yield. These researchers concluded that high quality DDGS is an acceptable ingredient in broiler diets and recommended a 6% maximum dietary inclusion rate in the starter period and 12 to 15% DDGS in grower and finisher phases of broiler production.

Table 2. Effect of feeding 0, 6, 12, and 18% DDGS in isocaloric and isonitrogenous diets to broilers over a 42 day feeding period on diets on weight gain and gain efficiency ¹

Response criteria	0% DDGS	6% DDGS	12% DDGS	18% DDGS
Wt. gain (d 0 to 16), g/d	414 ^a	416 ^a	399 ^{ab}	387 ^b
Wt. gain (d 17 to 31), g/d	1,052	1,055	1,049	1,039
Wt. gain (d 0 to 42), g/d	2,314 ^a	2,289 ^a	2,291 ^a	2,243 ^b
Gain:feed (d 0 to 16)	746 ^a	739 ^a	715 ^{ab}	702 ^b
Gain:feed (d 17 to 31)	597	600	604	599
Gain:feed (d 0 to 42)	566	554	565	554

^{a,b} Means within rows with different superscripts are different ($P < 0.05$).

¹adapted from Lumpkins et al., 2004

Several additional studies have been conducted to evaluate the use of DDGS at various dietary inclusion rates in broiler diets (Shim et al., 2008; Choi et al., 2008; Wang et al, 2007 a, b, c, Wang et al., 2008 a, b, c; Youssef et al., 2008; Min et al., 2008; and Moran and Lehman, 2008).

Shim et al. (2011) fed corn-soybean meal diets containing 0, 8, 16, and 24% DDGS and poultry fat as a supplemental energy source. Diets were formulated on a digestible amino acid basis using crystalline amino acids. Body weight gain was improved at the end of the starter phase (d 18) when birds were fed DDGS compared to the control diet, and weight gain and feed:gain were similar among dietary DDGS levels at 42 days. Fat pads, breast meat yield, and carcass quality were not different among dietary DDGS levels. These results show that DDGS can be a good alternative ingredient in diets for broilers at levels up to 24% of the diet when diets are formulated on digestible amino acids basis.

Additional research by Youssef et al. (2008) fed diets containing 0, 5, 10 or 15% DDGS from 12 to 35 days of age and showed no significant effects of increased DDGS levels on feed intake, weight gain, excreta quality or digestibility of protein and organic matter. Feed conversion tended to decrease when 15% DDGS was fed. Digestibility of DDGS protein was estimated to be 77%. Results from this study suggest that DDGS can be used as an effective protein source in finishing broiler diets at levels up to 10-15%.

Choi et al. (2008) confirmed the findings by Youssef et al. (2008) and showed that adding up to 15% DDGS in broiler diets had no effect on growth performance, color scores and firmness of breast and thigh muscles, but the unsaturated fatty acid content of meat and yellowness of the shank increased by the addition of DDGS to the diet. They concluded that DDGS can be added up to 15% of the diet to decrease the feed cost by partially replacing some of the corn and soybean meal, without any negative effect on growth performance and meat quality.

Wang et al., (2007 a,b,c; 2008 a,b,c) conducted a series of studies which showed that feeding diets containing up to 30% DDGS may support satisfactory growth performance as long as diets are formulated on a digestible amino acid basis. However, reduced bulk density, pellet quality, and inadequate crystalline amino acid supplementation in the diet may cause reductions in growth performance at dietary DDGS levels greater than 15-20%. Furthermore carcass yield and breast meat yield may be reduced when feeding DDGS levels greater than 15 to 20% of the

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diet. When diets contain 15% DDGS and are formulated on a digestible amino acid basis, abrupt removal of this level of DDGS did not adversely affect performance of broilers.

Min et al. (2008) conducted an experiment to determine the effects of feeding 0, 15, or 30% DDGS with or without 0 or 5% glycerin on growth performance and meat yield. Diets were formulated on a digestible amino acid basis and were fed as pellets. The results of this study demonstrate that 15% DDGS of known nutritional quality can be utilized in diets for growing broilers with no negative effects on growth performance and meat yield if the diets are formulated on a digestible amino acid basis and meet the nutritional requirements of broilers. Higher dietary levels of DDGS may be acceptable, but feed conversion may be reduced unless pellet quality can be improved. Dressing percentage was reduced, as reported in previous studies, when higher levels (>15%) of DDGS is added to the diet, but it appears that adding 5% glycerin as a source of energy provides satisfactory growth and meat yield.

Moran and Lehman. (2008) showed that the inclusion of combined amylase-phytase-protease-xylanase into broiler feeds without antimicrobials over an 8 week feeding period resulted in positive responses in growth performance, skinless boneless meat yield and skeletal integrity, regardless of alfalfa meal and DDGS inclusion and whether metabolizable energy and available phosphorus were below the requirements.

Corzo et al. (2009) conducted a study to evaluate the effects of feeding 0 or 8% DDGS on broiler breast and thigh meat quality. No differences were observed between the DDGS and control treatment for color (CIE L*, a*, b*), ultimate pH, cooking loss, shear values, and acceptability of texture. However, birds fed the control diet had a slightly higher preferred flavor and overall acceptability compared to broilers fed DDGS. Chicken breasts from both treatments received scores of "like moderately" on the hedonic scale, and consumers who liked the chicken breasts "moderately" or "very much" (over 50% of the panelists) could not differentiate between the 2 treatments. There was a slight variation in fatty acid composition between treatments with muscle from birds fed the DDGS diet having a greater percentage of linoleic acid and total polyunsaturated fatty acids, suggesting that it may be more susceptible to lipid oxidation. In general, these data show that feeding an 8% DDGS diet results in high-quality breast and thigh meat with minimal product differences.

Most recently, Loar et al. (2010) evaluated the effects of feeding 0 or 8% DDGS in the starter diet (0 to 14 days) and 0, 7.5, 15, 22.5, or 30% DDGS in grower diets (14 to 28 days). Feed conversion and mortality rates were not affected by dietary inclusion rate of DDGS, but growth rate can be negatively affected by feeding diets containing 15% or more DDGS. However, Shim et al. (2011) fed diets containing isonutritional diets containing 0, 8, 16, and 24% DDGS and showed that broilers fed diets containing 8% DDGS or more had increased growth rate compared to those fed 0% DDGS during the 0 to 18 day starter period. However, body weights were almost identical among DDGS feeding levels at day 42. Pellet durability index was reduced when DDGS was added to the diets but it did not affect growth performance. These results indicate that broilers perform well when fed properly balance diets containing up to 24% DDGS with no negative effects on carcass or meat quality.



Schilling et al. (2010) fed diets containing 0, 6, 12, 18, and 24% DDGS to broilers for 42 days and regardless of dietary DDGS level, yielded high quality breast meat. Thigh meat quality was similar among birds fed diets containing 0 to 12% DDGS, but high dietary inclusion rates resulted in thigh meat that was more susceptible to oxidation.

Turkeys

Noll (2004) summarized results from three trials where diets containing up to 12% DDGS were fed to market toms during the grower-finisher period, and found no difference in body weight gain and feed conversion compared to the control corn-soybean meal-meal diets. A subsequent study by Noll and Brannon (2005) showed that up to 20% DDGS can be included in turkey tom grower or finisher diets but when high protein levels are fed, diets containing 15% DDGS can

improve growth performance. Roberson (2003) conducted two experiments using Large White female turkeys to evaluate the effects of increasing dietary DDGS level on growth performance. In the first experiment, corn-soybean meal diets containing 0, 9, 18, or 27% DDGS were fed to growing turkeys from 56 to 105 days of age. Body weight linearly decreased with increasing level of DDGS in the diet at 105 days of age. However, feed conversion improved from 77 to 105 days of age as dietary DDGS level increased. Roberson (2003) noted that the incidence of pendulous crops increased for birds fed diets with high levels of DDGS. In the second experiment, diets containing 0, 7, or 10% DDGS were fed in the grower period, with half of the birds fed the 10% DDGS in the grower period fed 7% DDGS in the finisher period. There were no differences among dietary treatments for body weight gain or feed conversion in this experiment. He concluded that DDGS can be effectively included at 10% of growing-finishing diets for turkey hens if the proper nutrient values for DDGS are used.

Ducks

The U.S. Grains Council sponsored a recent study conducted at the I-lan Branch of the Livestock Research Institute in Taiwan, where researchers evaluated the effects of feeding diets containing corn dried distiller's grains with solubles on the production performance and egg

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quality of brown Tsaiya duck layers (Huang et al., 2006). After 14 weeks of age up to 50 weeks of age, ducks were randomly assigned to one of four dietary treatments containing 0, 6, 12, or 18% DDGS. Diets were isocaloric and isonitrogenous and contained 2750 kcal/kg ME and 19% CP. Results from this study suggested that adding DDGS at levels up to 18% of the diet for laying ducks had no significant effect on feed intake, feed conversion, or quality of the egg shell. When laying ducks were fed the 18% DDGS diet egg production rate increased in the cold season. Egg weight tended to be higher by including 12% or 18% of DDGS in the diets. Yolk color was linearly improved with increasing amounts of DDGS in the laying duck diets. The xanthophylls in DDGS can be well utilized by the laying ducks. When DDGS was used in duck laying diets, fat percentage of yolk and linoleic acid content of yolk was increased. DDGS can be efficiently used in the diets of duck layers to improve the yolk characteristics without influencing the productive performance.

Summary

Current recommended maximum dietary inclusion levels for corn DDGS are 15% for broilers, turkeys, layers, and ducks, but higher levels of corn DDGS can be used successfully with appropriate diet formulation adjustments for energy and amino acids (Wang et al., 2007a,b,c; 2008a,b,c; 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.

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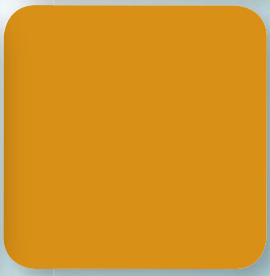
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CHAPTER 20

Use of Reduced-Oil DDGS in Poultry Diets



Chapter 20

Use of Reduced-Oil DDGS in Poultry Diets

Introduction

“Typical” DDGS contains 10 to 12% crude fat and has approximately 85% the energy value of corn for poultry. Most of the energy in DDGS is derived from the crude fat content in poultry because birds have less fiber fermentation in the lower gut than swine, resulting in lower energy utilization of high fiber feedstuffs. Therefore, the impact of oil extraction from DDGS will have the greatest impact on apparent metabolizable energy (AME) and true metabolizable energy (TME) content for poultry compared to other species, and depending on the extent of oil removal in DDGS, may result in substantially lower dietary inclusion rates or elimination from the diet.

Effects of feeding reduced-fat DDGS (RF-DDGS)

One study has been published related to the effects of feeding RF-DDGS on AME_n content in broilers (Rochelle et al., 2011). These researchers evaluated 15 diverse corn co-products, including DDGS and RF-DDGS, from wet milling and dry-grind ethanol plants. The nutrient composition of 5 “typical” DDGS sources and 1 RF-DDGS evaluated in this study are shown in **Table 1**.

Table 1. Nutrient content (dry matter basis) of 5 DDGS sources and reduced-fat DDGS (RF-DDGS).

	DDGS 1	DDGS 2	DDGS 3	DDGS 4	DDGS 5	RF-DDGS
Dry matter, %	86.59	93.18	89.13	90.25	91.20	87.36
GE ¹ , kcal/kg	5,434	5,314	5,547	5,375	5,174	5,076
AME _n ² , kcal/kg	2,685	2,628	3,098	2,593	2,903	2,146
Crude protein, %	31.94	29.62	29.49	29.65	26.48	34.74
Crude fat, %	10.16	11.45	11.71	10.89	11.52	3.15
Crude fiber, %	7.56	7.05	7.95	7.76	7.01	8.69
NDF, %	40.12	34.61	33.41	40.13	27.72	50.96
ADF, %	14.42	11.25	8.62	10.55	9.75	15.82
TDF, %	35.69	30.34	35.90	38.14	32.69	37.20
Starch, %	6.24	7.85	4.94	3.47	3.30	3.04
Cellulose, %	11.72	10.64	8.21	10.12	8.04	12.72
Lignin, %	3.16	1.21	1.00	1.06	2.29	3.49
Ash, %	4.46	4.16	5.41	4.43	4.48	5.16

¹GE = gross energy.

²AME_n = apparent metabolizable energy corrected for nitrogen.

³NDF = neutral detergent fiber.

⁴ADF = acid detergent fiber.

⁵TDF = total dietary fiber.

Gross energy (GE) content of the 5 DDGS sources ranged from 5,174 to 5,547 kcal/kg and averaged 5,369 kcal/kg. The GE content of RF-DDGS was 5.5% lower (5,076 kcal/kg) than the average GE content of DDGS, but was poorly correlated ($r = 0.21$, $P = 0.44$) with AME_n content. The AME_n content of the DDGS sources ranged from 2,593 to 3,098 kcal/kg with an average of 2,781 kcal/kg, whereas the AME_n for the RF-DDGS was 2,146 kcal/kg. Therefore, although oil extraction reduced the GE content by only 5.5%, AME_n content of RF-DDGS was reduced by 22.8%, and was due to not only a 72% lower fat content, but also a 45% increase in NDF content and a slight increase (11%) in ash content compared to the average of the 5 DDGS sources evaluated in this study.

Because of the high variability in crude fat and NDF content relative to AME_n content in distiller's co-products, one cannot simply assume that a 1 percentage unit decrease in crude fat content will accurately estimate its impact on AME_n content. In fact, of all nutrients considered, hemicellulose had the strongest correlation with AME_n ($r = -0.85$, $P = 0.01$), followed by NDF, TDF, and crude fiber ($r = -0.83$, -0.77 , and -0.75 respectively, $P = 0.01$). Hemicellulose is determined by difference between NDF and ADF in this study. Since hemicellulose is the primary fiber component in NDF, TDF, and crude fiber found in corn co-products, it is not surprising that it was the most predictive of AME_n content. Correlations of other fiber measures (ADF, $r = 0.43$, $P = 0.11$; cellulose, $r = -0.44$, $P = 0.10$) were low and not significant. Furthermore, GE, starch, and crude fat were poorly correlated with AME_n ($r = 0.21$, 0.45 , and 0.39 , respectively).

Therefore, these researchers developed prediction equations to estimate AME_n content from nutrient composition of a diverse group of distillers co-products. Using stepwise regression analysis, AME_n can be predicted ($R^2 = 0.89$, $SEM = 191$, $P < 0.01$) as follows:

$$AME_n \text{ (kcal/kg of dry matter)} = 3,517 - (33.27 \times \% \text{ hemicellulose, dry matter basis}) + (46.02 \times \% \text{ crude fat, DM basis}) - (82.47 \times \% \text{ ash, DM basis})$$

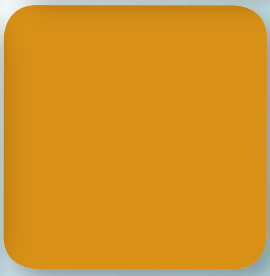
Until more definitive data and prediction equations are published on the effect of RF-DDGS on AME_n content in poultry, this equation is the best prediction available to estimate these effects, but it has not been validated.

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CHAPTER 21

Use of DDGS in Swine Diets



Chapter 21

Use of DDGS in Swine Diets

Introduction

Corn dried distillers grains with solubles (DDGS) has become the most popular, economical, and widely available alternative feed ingredient for use in U.S. swine diets in all phases of production. Corn DDGS is used primarily as an energy source in swine diets because it contains approximately the same amount of digestible energy (DE) and metabolizable energy (ME) as corn, although the ME content may be slightly reduced when feeding reduced-oil DDGS (see **Chapter 22**). Therefore, it primarily partially replaces high energy ingredients, such as corn in swine diets, but can also partially replace some high protein ingredients, such as soybean meal, and inorganic phosphorus. A scientific review has been published by Stein and Shurson (2009) summarizing all of the published scientific information available on feeding DDGS to swine in the literature up to 2009. A link to the entire review is available in **Chapter 35** of this handbook. The purpose of this chapter is to briefly describe the highlights of this comprehensive literature review, and provide an update of research results published from various studies since 2009.

Nutritional Value of DDGS for Swine

The nutrient composition and digestibility/availability values for DDGS use in swine diet formulation are described in detail in **Chapter 4. “Nutrient Composition and Digestibility of DDGS: Variability and *In Vitro* Measurement”**. The high energy (3,674 to 4,336 kcal ME/kg DM), moderate protein (27 to 33%, DM basis) and lysine (0.60 to 1.1%, DM) content, along with its relatively high concentration of phosphorus (0.57 to 0.85%, DM basis) and digestibility (50 to 68%) are the key nutritional components that make it an attractive alternative feed ingredient in swine diets. However, like any feed ingredient, DDGS has some limitations that need to be managed to achieve the greatest economic and performance benefits when added to grower-finisher swine diets. Along with its benefits of being a high energy and digestible phosphorus ingredient, it also appears to provide gut health benefits when fed to growing pigs. Limitations for using DDGS at high (>20%) dietary inclusion rates include reduced pork fat firmness, increased manure volume, nitrogen, and phosphorus excretion, and the need for supplemental crystalline amino acids in the diet. However, these limitations are easily overcome by understanding and using proper diet formulation approaches.

Use of DDGS in Starter Diets

Ten experiments were conducted and summarized by Stein and Shurson (2009) that evaluated feeding diets containing up to 30% DDGS to weanling pigs (**Table 1**). In all experiments conducted, there was no change in ADG compared to control diets containing no DDGS, 80% of the experiments resulted in no change in ADFI, and results from 50% of the experiments

showed an improvement in gain efficiency, with no effect on pig mortality. These results suggest that DDGS can be used effectively in weanling pig diets at levels up to 30%, 14 to 21 days post-weaning (weaning age at 21 days of age), with no adverse effects on growth performance or mortality.

Table 1. Summary of responses from including up to 30% corn or sorghum DDGS in diets for weanling pigs.¹

Item	N	Response to dietary corn DDGS		
		Increased	Reduced	Not changed
ADG	10	0	0	10
ADFI	10	0	2	8
G:F	10	5	0	5
Mortality	2	0	0	2

¹Data calculated from experiments by Whitney and Shurson (2004), Gaines et al. (2006), Linneen et al. (2006), Spencer et al. (2007), Barbosa et al. (2008), and Burkey et al. (2008).
Source: Stein and Shurson (2009).

Two more recent studies confirmed these conclusions. Zhu et al. (2010) conducted 4 experiments to evaluate the effects of including 30% DDGS in late nursery diets on pig growth performance and compare the effects of pelleted and meal diets containing 30% DDGS on growth performance and nutrient digestibility. Their results showed that 30% DDGS can be used in late nursery diets for 10 to 23 kg pigs without affecting growth performance. Pelleting DDGS diets improves pig growth performance and feed efficiency by increasing digestibility of energy and most nutrients. Similarly, Tran et al. (2011) demonstrated that DDGS can be included in diets for nursery pigs at the level of 15% during the entire nursery period, or up to 30% during the late nursery period without compromising growth performance. It appeared that incorporation of lactose in the diet may help maintain growth performance in weanling pigs fed diets containing DDGS, and feeding lactose in combination with DDGS may affect fecal *Lactobacillus* spp. in nursery pigs.

Use of DDGS in Grower-Finisher Diets

Growth performance results from 25 experiments in which corn DDGS was added at levels up to 30% of the diets growing-finishing are summarized in **Table 2** (Stein and Shurson, 2009). The majority of these studies showed no change in ADG (72% of experiments), ADFI (65% of experiments), and G:F ratio (64% of experiments), with the others showing either increases or decreases in performance. Based on the information provided from reports of these 25 experiments, it is difficult to explain why pig performance was maintained in most, but not in all experiments in which DDGS was included in the diets. It is possible that when performance was reduced, the DDGS used in the experiments may have been of a poorer quality (lower nutrient digestibility) than expected. Another possible explanation is that the reduction in performance in some of the experiments may have been due to excess nitrogen from crude protein at high dietary inclusion rates. In most of the experiments where ADG was reduced, a reduction in ADFI was also observed. This reduction in ADFI may have been due to using lower quality DDGS sources because results from other studies have shown that if pigs are given a choice of diets, they prefer to consume diets containing no DDGS (Hastad et al., 2005; Seabolt et al.,

2010). Other researchers have speculated that reduced feed intake observed in some experiments may be due to excessively high sulfur content of the DDGS source used. However, Kim et al. (2011) conducted 4 experiments and showed that dietary S concentration does not negatively affect feed preference, feed intake, or growth performance of weanling or growing-finishing pigs fed diets based on corn, soybean meal, and DDGS. Furthermore, Hilbrands et al. (2012) showed that periodic inclusion and removal of 40% DDGS from diets did not adversely affect growth performance or have important effects on carcass quality regardless of the SID AA digestibility of the DDGS used. These results indicate that it is possible to abruptly incorporate and remove DDGS from grower-finisher swine diets without meaningful detrimental effects on growth performance or carcass quality.

Table 2. Effects of including corn DDGS in diets fed to growing-finishing pigs on growth performance and carcass characteristics.^{1,2}

Item	N	Response to dietary corn DDGS		
		Increased	Reduced	Not changed
ADG	25	1	6	18
ADFI	23	2	6	15
G:F	25	4	5	16
Dressing percentage	18	0	8	10
Backfat, mm	15	0	1	14
% carcass lean	14	0	1	13
Loin depth, cm	14	0	2	12
Belly thickness, cm	4	0	2	2
Belly firmness	3	0	3	0
Iodine value	8	7	0	1

¹Data based on experiments published after 2000 and where a maximum of 30% DDGS was included in the diets.

²Data summarized from experiments by Gralapp et al. (2002), Fu et al. (2004), Cook et al. (2005), DeDecker et al. (2005), Whitney et al. (2006a,b), McEwen (2006, 2008), Gaines et al. (2007a,b); Gowans et al. (2007), Hinson et al. (2007), Jenkin et al. (2007), White et al. (2007), Widyaratne and Zijlstra (2007), Xu et al. (2007; 2010a,b), Augspurger et al. (2008), Drescher et al. (2008), Duttlinger et al. (2008), Hill et al. (2008a), Linneen et al. (2008), Stender and Honeyman (2008), Weimer et al. (2008), and Widmer et al. (2008).

In the Stein and Shurson (2009) summary, 10 of the 18 experiments measuring carcass dressing percentage in pigs fed DDGS diets, showed no differences compared with carcasses from pigs fed corn-soybean meal diets with no DDGS (Fu et al., 2004; McEwen, 2006; 2008; Xu et al., 2007; Augspurger et al., 2008; Drescher et al., 2008; Duttlinger et al., 2008; Hill et al., 2008a; Stender and Honeyman, 2008; Widmer et al., 2008). However, feeding diets containing DDGS resulted in reduced carcass dressing percentage in 8 experiments (Cook et al., 2005; Whitney et al., 2006a; Gaines et al., 2007a and b; Hinson et al., 2007; Xu et al., 2010a; Linneen et al., 2008; Weimer et al., 2008). Previous studies have shown that adding ingredients high in fiber to growing-finishing pig diets may reduce the dressing percentage because of increased gut fill and increased intestinal mass (Kass et al., 1980). This may explain the reduced dressing percentage observed in pigs fed DDGS diets in some experiments, but it is unknown why this effect was not observed in other experiments. Recently, Agyekum et al. (2012) showed that pigs fed a diet containing 30% DDGS have reduced dressing percentage and increased visceral organ mass compared with pigs fed a corn-soybean meal diet, but the addition of a multi-enzyme complex to the DDGS diet did not affect dressing percentage and visceral organ mass compared with pigs fed a corn-soybean meal diet.

Backfat thickness, loin depth, and % carcass lean are generally unaffected by adding up to 30% DDGS to the diet (**Table 2**). Two studies reported a reduction in backfat thickness (Weimer et al., 2008; Xu et al., 2010a), and two studies reported a reduction in loin depth (Whitney et al., 2006a; Gaines et al., 2007b) when DDGS diets were fed. The reduction in loin depth observed in those two studies was likely due to lower ADG and lighter market weights of pigs fed the DDGS diets. Only one study (Gaines et al., 2007b) reported a reduction % carcass lean.

Adding DDGS to grower-finisher swine diets can negatively affect belly and pork fat quality, especially at high (> 20%) dietary inclusion rates. Dried distillers grains with solubles contains approximately 10% corn oil, which is comprised of nearly 60% linoleic acid (long-chain, unsaturated fatty acid). Feeding diets containing high amounts of unsaturated fatty acids, particularly linoleic acid, can reduce fat firmness and increase the amount of unsaturated fatty acids in pork fat. Results from some studies where DDGS was fed to grower-finisher pigs showed that belly thickness was linearly reduced when increasing levels of corn DDGS were added to the diet (Whitney et al., 2006a; Weimer et al., 2008). However, pigs fed DDGS containing diets in these two studies also had reduced ADG, and as a result, were marketed at a lighter weight than the control pigs, which may have resulted in reduced belly thickness. In studies where no differences in belly thickness was observed (Widmer et al., 2008 and Xu et al., 2010b), no differences in the final body weight of the pigs were also observed. All of the studies (3) reporting belly firmness measurements (Whitney et al., 2006a; Xu et al., 2010a; Widmer et al., 2008), showed that belly firmness

was reduced in pigs fed diets containing DDGS compared with pigs fed diets containing no DDGS. This observation is supported by the results from 8 studies showing that the iodine value (ratio of unsaturated to saturated fatty acids) of the belly fat is increased in pigs fed DDGS (Whitney et al., 2006a; White et al., 2007; Xu et al., 2010a; 2008a; Hill et al., 2008a; Linneen et al., 2008; Stender and Honeyman, 2008).



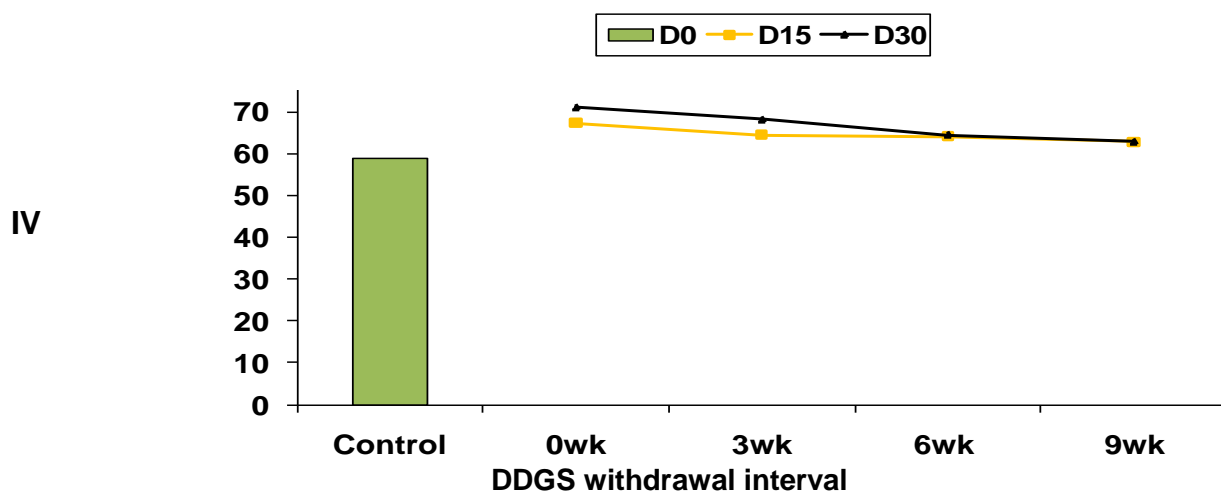
Cromwell et al. (2011) fed diets containing 30 or 45% DDGS and reported no major effects on growth performance, but resulted in bellies from these pigs became softer. Regression analysis indicated that iodine values increased 4.3 units for every 10 percentage unit inclusion of DDGS in the diet.

Carcass fat iodine value can be a reasonable indicator of carcass fat quality because high iodine values result in softer bellies. Since pork fat firmness is consistently reduced when feeding growing-finishing pigs increasing amounts of DDGS, researchers have been evaluating alternative nutritional strategies to reduce the negative effects of DDGS on iodine values. White et al. (2007) showed that the addition of 1% conjugated linoleic acids to diets containing 20 or 40% corn DDGS for 10 d prior to pig harvest, reduced pork fat iodine values and the n6:n3 ratio. Pompeu et al. (2009) confirmed the positive effects of adding conjugated linoleic acid to finishing pig diets containing 30% DDGS on improving the fatty acid profile and pork fat quality. Thus, addition of conjugated linoleic acid to DDGS containing diets during the late finishing

phase is effective for reducing iodine values in carcass fat, but this additive is not commercially approved for use in many countries. A more practical approach for meeting desired pork fat quality standards is to remove DDGS from the diet during the final 3 to 4 weeks prior to harvest (Hill et al., 2008a; Xu et al., 2010b; **Figure 1**).

Other researchers have evaluated pork fat quality when adding supplemental animal fat sources to high inclusion rate DDGS diets. Stevens et al. (2009) showed that feeding a corn-soybean meal diet, with or without 5% choice white grease, during a 26 day dietary DDGS withdrawal program partially recovered some of the adverse effects caused by linoleic acid from the DDGS diet. However, they indicated that a longer DDGS withdrawal period is required for complete recovery of pork fat quality. The addition of a dry animal fat source (4% of the diet) high in saturated fatty acids (70%) did not alleviate the increase in iodine value resulting from the addition of 30% DDGS to the diet (Freitas et al., 2009), which was most likely due to the low digestibility of the fat source used in the study. Benz et al. (2010) fed diets containing various levels of DDGS (0 to 20%) and 6% choice white grease and showed that gilts had greater C18:2n-6, PUFA, and PUFA:SFA ratio and lower C14:0 concentrations in backfat and belly fat, but not jowl fat compared to barrows. Gilts also had greater belly fat IV than barrows, but there were no differences in backfat and jowl fat IV between gilts and barrows. Feeding increasing amounts of DDGS linearly increased the IV of backfat, jowl fat, and belly fat, jowl fat was less responsive to increased dietary levels of DDGS than backfat and belly fat. Pigs fed diets with 20% DDGS and 6% choice white grease exceeded the maximum jowl IV of 73 g/100 g established as a standard by some U.S. pork processing facilities. Pomeranke et al. (2011) also showed that adding 5% beef tallow (saturated animal fat source) was not effective in improving pork fat firmness when feeding 30% DDGS diets. See **Chapter 23** for a more detailed discussion on impacts of feeding DDGS on pork fat quality and feeding solutions to manage this challenge.

Figure 1. Effects of Dietary DDGS Level (0, 15, and 30%) and Withdrawal Interval (0, 3, 6, and 9 Weeks Pre-harvest) on Iodine Value (IV) of Belly Fat.¹



Note: D15-9 wk and D30-9 wk = control, others > control

¹ Xu et al. (2010b)

Use of DDGS in Gestation and Lactation Diets

Several studies have shown that feeding sows diets containing up to 50% DDGS in gestation and up to 30% DDGS in lactation had no negative effects on reproductive performance and milk composition (Wilson et al., 2003; Hill et al., 2008b; Song et al., 2010; Greiner et al., 2008). Wilson et al. (2003) observed an increase in litter size from sows fed a 50% DDGS during gestation and 30% DDGS during lactation in the preceding reproductive cycle. However, this response has not been confirmed in subsequent studies.

DDGS and Manure Management

Limited data are available on the effects of feeding DDGS diets to swine on gas and odor emissions and manure composition. Spiehs et al. (2000) was the first to report that there were no effects from manure obtained from growing-finishing pig fed diets containing 20% DDGS over a 10-week period on hydrogen sulfide (H₂S), ammonia (NH₃), or odor detection levels compared to manure from pigs fed corn-soybean meal diets. In this study, feeding DDGS containing diets tended to increase N excretion, but P retention was not different between dietary treatments. Gralapp et al. (2002) fed diets containing 0, 10, or 20% DDGS to finishing pigs and found no differences in total solids, volatile solids, chemical oxygen demand, or total N or P concentration of manure among dietary DDGS levels. However, odor concentration tended to increase with increasing dietary levels of DDGS. McDonnell et al. (2011) confirmed that increasing the level of DDGS in the growing-finish pig diets increases total nitrogen excretion in manure, but did not observe an increase in ammonia emissions. In contrast to the findings by Spiehs et al. (2000). Li et al. (2011a) demonstrated that feeding diets containing 20% DDGS to growing pigs increase hydrogen sulfide, methane, ammonia, and nonmethane total hydrocarbon emissions from pigs, but organic sources of trace minerals are a promising mitigation strategy to alleviate the adverse effect of DDGS on hydrogen sulfide emissions.

In studies involving sow manure composition, Hill et al. (2008b) showed that adding DDGS to lactating sow diets reduced the concentration of P in the feces compared to feeding a corn-soybean meal diet without DDGS, but it is unknown if total P excretion was reduced because DM digestibility of the diets was not determined. Li et al. (2011b) showed that feeding diets containing 40% DDGS to gestating sows decreased apparent dry matter digestibility of the diet and increased the fecal output, but did not affect the total volume of slurry produced or N, P, or K output in slurry.

Four experiments were conducted to evaluate effects of diet formulation method, dietary level of DDGS, and use of microbial phytase on nutrient balance in nursery and grower-finisher pigs (Xu et al., 2006a;b;c;d). Results of these studies showed that adding DDGS to nursery pig diets generally results in a reduction in dry matter digestibility, an increased fecal excretion, and phytase is more effective than DDGS in reducing total manure phosphorus excretion. Furthermore, diets formulated to contain Ca:available P ratios (2:1 to 3:1) established by NRC (1998) are acceptable when 20% DDGS and phytase are added to nursery diets to minimize P excretion in the manure. Unlike for nursery aged pigs, feeding diets containing DDGS without

or with phytase to growing-finishing pigs resulted in no change in DM digestibility and manure excretion.

Almeida and Stein (2010) conducted 3 experiments to test the hypotheses that pigs fed diets that are equal in digestible P would perform equally regardless of the concentration of total P in the diets, and that the addition of microbial phytase, DDGS, or a combination of phytase and DDGS would result in a reduction in P excretion. Results from this study showed that the addition of phytase increased the standardized total tract digestibility (STTD) of P in corn and SBM, but had no effect on the STTD of P in DDGS. Most importantly, diets can be formulated based on STTD values without compromising pig performance, and dietary phytase, DDGS, or the combination of phytase and DDGS will reduce P excretion by growing pigs. In a follow-up study, Almeida and Stein (2012) conducted an experiment where they supplemented corn and corn co-products swine diets with 500, 1,000, or 1,500 FTU of microbial phytase/kg. Their results showed a linear increase in STTD of P in corn (from 40.9 to 67.5, 64.5, and 74.9%, respectively), DDGS (from 76.9 to 82.9, 82.5, and 83.0%, respectively), HP-DDG (from 77.1 to 88.0, 84.1, and 86.9%, respectively), and corn germ (from 40.7 to 59.0, 64.4, and 63.2%, respectively). They concluded that microbial phytase has a much greater effect on STTD of P in corn and corn germ than in DDGS and HP-DDG. Therefore, adding DDGS to swine diets reduces manure phosphorus content when diets are formulated in a digestible or available P basis.

Effect of Feeding DDGS on Gut Health of Growing Pigs

Whitney et al. (2006 b,c) 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, adding DDGS to the diet did not positively affect lesion prevalence and length, proliferation of *L. intracellularis*, or severity of lesions. In the second experiment, the *L. intracellularis* dosage rate for challenging pigs was reduced by 50% compared to the first experiment, and feeding a diet 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. When the combination of DDGS and antimicrobial (BMD and chlortetracycline) were fed, no additional advantages were observed in reducing the length, severity, or prevalence of lesions. These results indicate 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 numerous research studies conducted in each phase of swine production, 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	45 ¹
Developing gilts	30
Gestating sows	50
Lactating sows	30
Boars	50

¹Lower inclusion rates may be warranted in certain pork markets where specific pork fat quality standards must be met.

These recommendations assume the use of high quality, highly digestible DDGS sources that are free from mycotoxins. Nursery diets containing up to 30% DDGS will support growth performance equivalent to feeding pigs fed corn-soybean meal based diets provided diets are formulated on a digestible amino acid and available phosphorus basis. Similarly, grower-finisher diets containing levels up to 45% 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, due to concerns of reduced belly firmness and soft pork fat at high levels of DDGS inclusion, some markets may require feeding no more than 20% DDGS in grower-finisher diets continuously, or withdrawing it from the diet 3 to 4 weeks before harvest to achieve desired pork fat quality. Likewise, developing gilt diets can contain up to 30% 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.

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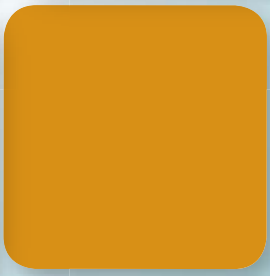
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CHAPTER 22

Use of Reduced-Oil DDGS in Swine Diets



Chapter 22

Use of Reduced-Oil DDGS in Swine Diets

Introduction

Traditionally, corn DDGS has contained 10 to 11% crude fat and has a metabolizable energy (ME) content similar to corn for swine (Stein and Shurson, 2009). However, over the past 2 years, an increasing number of ethanol plants have invested in centrifugation technology to extract some of the oil from the thin stillage before removing water to make condensed distillers solubles and blending with the coarse grains fraction and drying to make DDGS. Currently, approximately 50% of the U.S. ethanol industry is removing a portion of the oil from thin stillage prior to producing DDGS. Industry experts are predicting that 80% of the ethanol industry will be extracting oil by the end of the year 2012.

The rapid adoption of oil extraction technology is driven by high economic returns. For example, a 100 million gallon ethanol plant can invest \$3 million in capital (i.e. building, two centrifuges, tubing) and operating expenses (electricity) to extract 9.07 million kg of oil/year. Current market price for crude corn oil is \$0.88/kg resulting in \$8 million in gross revenue/year. Therefore, the initial capital investment for implementing this technology can be recovered in less than 5 months of operation. Approximately 90% of this crude oil is marketed to the biodiesel industry whereas the remaining 10% is sold for use in poultry feed.

Therefore, the implementation of oil extraction technology has led to a wider range of crude fat content in DDGS (5 to 12%) than in previous years. Since oil contains 2.25 times more energy than carbohydrate (i.e. starch), corn oil removal reduces the ME content in DDGS. This reduction in energy content will affect the economic value and usage rates of DDGS in all animal feeds to varying degrees. The question is, how much? Knowing this, DDGS end-users are demanding price discounts on reduced-oil DDGS (RO-DDGS) because of expected reductions in energy value. This reduces the market price for DDGS and ethanol plant revenue from DDGS sales, but this reduction is more than offset by the increase in revenue from the sale of crude corn oil. Nutritionists want to know the extent of reduction in energy content due to partial removal of corn oil in order to make appropriate adjustments in diet formulations (e.g. diet inclusion rates, adding other sources of energy) to meet desired dietary energy levels.

DE and ME estimates and variability among “typical” DDGS sources

Dried distillers grains with solubles is primarily an energy source, but also supplies significant amounts of digestible amino acids and available phosphorus to swine diets. Recent studies have been conducted to determine DE and ME content of various sources of DDGS and develop prediction equations using chemical analysis measures to estimate actual energy content (Stein et al., 2006; Pedersen et al. 2007; Anderson et al. 2011; Stein et al., 2009; Mendoza et al., 2010). The average and ranges of GE, DE, and ME content of DDGS sources

evaluated in these studies are shown in **Table 1**, and are compared to the energy values for corn.

As shown in **Table 1**, average GE of DDGS samples was relatively consistent across the five studies (5,311 to 5,593 kcal/kg DM), but the overall range in GE was more variable (5,177 to 5,691 kcal/kg DM). Average DE estimates among the five studies was 3,950 kcal DE/kg DM, but ranged from 3,382 to 4,593 kcal/kg DM. Average ME of DDGS samples from 4 of the 5 studies reporting ME values was 3,784 kcal ME/kg DM, but like DE values, ranged from 3,381 to 4,336 kcal ME/kg DM. This range of 955 kcal/kg DM among DDGS sources is problematic when attempting to manage dietary energy values with high inclusion rates of DDGS. For comparison purposes, corn ME averaged 3,928 kcal/kg DM (range was from 3,805 to 4,103 kcal/kg DM) among the 4 studies that reported ME values (**Table 1**), and was higher than the value published (3,843 kcal/kg DM) in NRC (1998). Therefore, the average ME value of DDGS is approximately 96% of the value of corn, but can range from 88.9 to 105.7% of the value of corn.

Table 1. Comparison of GE, DE, and ME estimates among DDGS sources and corn, and CP, NDF, and crude fat levels from 5 studies.

	Stein et al. (2006)	Pedersen et al. (2007)	Anderson et al. (2011)	Stein et al. (2009)	Mendoza et al. (2010)
No. samples	10	10	6	4	17
Avg. GE, kcal/kg	5,426	5,434	5,420	5,593	5,311
Range GE, kcal/kg	5,372-5,500	5,272-5,592	5,314-5,550	5,483-5,691	5,177-5,421
Avg. DE, kcal/kg	3,556	4,140	4,072	4,029	3,954
Range DE, kcal/kg	3,382-3,811	3,947-4,593	3,705-4,332	3,920-4,252	3,663-4,107
Avg. ME, kcal/kg	ND	3,897	3,750	3,790	3,700
Range ME, kcal/kg	ND	3,674-4,336	3,414-4,141	3,575-3,976	3,381-3,876
ME/DE, %	ND	94.1	92.1	94.1	93.6
Avg. CP, %	30.9	32.2	31.3	31.8	30.3
Range CP, %	28.2-32.7	29.8-36.1	29.5-34.1	30.5-33.1	27.3-33.3
Avg. NDF, %	45.2	27.6	40.4	40.1	34.6
Range NDF, %	41.8-49.1	23.1-29.7	33.4-49.1	35.1-45.2	25.3-43.1
Avg. Crude fat, %	ND	11.7	11.4	13.2	11.7
Range Crude fat, %	ND	9.6-14.3	10.2-12.1	10.9-14.1	8.7-14.6
Corn DE, kcal/kg	3,845	4,088	3,885	4,181	3,893
Corn ME, kcal/kg	ND	3,989	3,805	4,103	3,813

Crude protein levels of DDGS sources used in these studies were relatively consistent, but the range in crude fat and NDF content (two primary contributing factors to DE and ME content) among sources within studies, and among studies, was highly variable (**Table 1**). Although, the variation in DE and ME estimates among DDGS sources can largely be attributed to nutrient composition differences among sources, it is also likely that different methodologies used for conducting metabolism studies, different laboratory procedures used to measure nutrients, and lab to lab variation among studies had significant contributions to this variability. For example,

the average and range in NDF values in the Pedersen et al. (2007) study were much lower than those reported in the other 4 studies. It is unclear if NDF composition was actually lower in these samples evaluated by Pedersen et al. (2007), or if a different analytical method was used compared to NDF procedures used in other studies. Urriola et al. (2010) reported that apparent total tract digestibility (ATTD) of NDF among 8 corn DDGS sources averaged 59.3%, but ranged from 51.6 to 65.8%, and ATTD of total dietary fiber ranged from 39.4 to 56.4%. These results indicate that considerable variability in fiber digestibility exists among DDGS sources, which is likely a significant contributing factor to the variability in DE and ME content among DDGS sources. Recent unpublished data from Pomeroy et al. (2011) showed that fecal digestibility values of fatty acids are higher than ileal fatty acid digestibility values, MUFA and SFA digestibilities are higher when growing pigs are fed DDGS compared to a corn-soybean meal diet, but PUFA digestibility was lower (66.5% vs. 77.3% for a 30% DDGS diet compared to corn-soybean meal diet). Because corn oil in DDGS is predominantly PUFA, and because the crude fat content of DDGS can vary substantially, these factors also contribute to differences in ME variability among DDGS sources.

Several researchers have shown that apparent fat digestibility is significantly reduced when dietary fiber increases (Dierick et al., 1989; Noblet and Shi, 1993; Shi and Noblet, 1993). Just (1982a,b) showed that apparent fat digestibility decreases by 1.3 to 1.5 percentage units for each additional 1 percentage unit of crude fiber in the diet, and the depressive influence of crude fiber depends to some degree on the source of a feedstuff. Noblet and Shi (1993) demonstrated that apparent digestibility of fat decreased linearly with increasing dietary NDF content, and at the same time, the fat digestibility increased with increasing dietary fat level. These research results indicate that there are many factors that contribute to our ability to obtain accurate estimates of ME in various sources of DDGS. Because of the need to obtain source specific ME estimates among DDGS sources, we need to develop, validate, and implement rapid, accurate, and inexpensive “nutritional tools” to estimate actual energy values among DDGS sources.

Research results on reduced-oil DDGS

Results from 3 recent studies have been published that estimated the effect of reduced oil on ME content for growing pigs (Dahlen et al., 2011, Jacela et al., 2011, Anderson et al., 2011). In the studies by Jacela et al. (2011) and Anderson et al. (2011), oil was removed by hexane extraction, whereas Dahlen et al. (2011) compared the DE and ME content of DDG (with no solubles) with DDGS, which was slightly higher in oil content (10.02% DM basis), and produced by the same ethanol plant. It is important to realize that the processes used to produce reduced fat DDGS in these studies are different than the centrifugation technologies used to extract oil in ethanol plants currently. Therefore, these data are not applicable for predicting the ME content of reduced fat DDGS, but have been erroneously used by some industry professionals to obtain initial estimates. The nutrient content of the reduced fat sources evaluated in these studies is shown in **Table 2**.

The results from these studies are problematic for estimating the impact of oil extraction on ME content because of the wide disparity in DE and ME estimates based on crude fat content. For example, the de-oiled DDGS evaluated in the Anderson et al. (2011) study contained the lowest crude fat content (3.15%) and the highest NDF content (50.96%), but had the highest DE content (3,868 kcal/kg ME) of the 3 sources. Like the de-oiled DDGS source evaluated by Anderson et al. (2011), the de-oiled source evaluated by Jacela et al. (2011) was also obtained from a VeraSun ethanol plant using similar production technology. However, it had slightly higher crude fat (4.56%), much lower NDF (35.58%), and had the lowest DE content (3,100 kcal/kg), despite having similar GE content as the sample evaluated in the Anderson et al. (2011) study. This large discrepancy indicates significant differences in DE methodologies, analytical methods, and laboratory error between these 2 studies. Furthermore, the ME and NE estimates for the de-oiled DDGS in the Jacela et al. (2011) study were calculated using equations developed for complete feeds, which were not specifically developed for use in corn distillers co-products, making these estimates highly questionable. The estimates of impact from a 1% reduction in crude fat on ME content from the Dahlen et al. (2011) study are also problematic. First, comparing the ME content of DDGS with DDG from the same source is not valid in this context because the nutrient in condensed solubles component is absent in DDG resulting in a lower ash and higher fiber content, which biases the estimate of ME from a 1 percentage unit reduction in crude fat.

In the Anderson et al. (2011) study, crude fat among 6 DDGS sources ranged from 10.16 to 12.10% and ME content ranged from 3,414 to 4,141 kcal/kg. Calculating the impact of a 1 percentage unit reduction in crude fat using the de-oiled DDGS as the reference point, individual values were 59, 1, 41, -28, 25, and 1 kcal/kg DM. The wide disparity in ME estimates, and even a negative value, indicates that relating ME content only to crude fat content results in erroneous ME estimates.

Kil et al. (2010) conducted a study to determine the effect of extracted versus intact corn oil and dietary NDF on endogenous fat losses and ileal and total tract digestibility of fat in growing pigs. They showed that extracted corn oil has greater apparent and true digestibility than intact corn oil at the terminal ileum and over the entire intestinal tract, but purified NDF had little effect on apparent and true digestibility of corn oil. They also showed that apparent ileal and total tract digestibility of corn oil increased curvilinearly as dietary fat concentration increased regardless of the form of fat. Endogenous fat losses contribute more to the total output of fat, and therefore have a greater effect on apparent digestibility of fat at smaller amounts of dietary fat than greater amounts. These results provide additional insight into why we cannot simply assume that a linear reduction in crude fat content in DDGS will result in a linear reduction in ME content.

Table 2. Comparison of nutrient composition and energy values of reduced-oil DDGS (RO-DDGS) and DDG (DM basis).

Item	DDG – Dahlen et al., 2011	De-oiled DDGS – Jacela et al. 2011 ¹	De-oiled DDGS – Anderson et al., 2011
DM,	90.33	87.69	87.36
GE, kcal/kg DM	5,536	5,098	5,076
DE, kcal/kg DM	3,232	3,100	3,868
DE/GE	58.38	60.80	76.20
ME, kcal/kg DM	2,959	2,858 ²	3,650
ME/GE	53.45	56.06	71.91
ME/DE	91.55	92.19	94.36
ME kcal/1% fat reduction	5.0	ND	17.0 ⁴
NE, kcal/kg DM	ND	2,045 ³	ND
CP	34.98	35.58	34.74
Crude fat	8.80	4.56	3.15
NDF	ND	39.46	50.96
ADF	20.37	18.36	15.82
Ash	2.57	5.29	5.16
Arg	ND	1.50 (82.7)	1.44
Cys	0.60	ND	0.61
His	ND	0.93 (74.6)	0.89
Ile	ND	1.38 (74.5)	1.25
Leu	ND	4.15 (83.8)	4.12
Lys	1.04	0.99 (50.4)	1.00
Met	0.65	0.67 (80.4)	0.64
Phe	ND	1.92 (80.8)	1.51
Thr	1.22	1.26 (68.9)	1.26
Trp	0.20	0.22 (78.0)	0.18
Val	ND	1.75 (73.8)	1.76
Ca	0.03	0.06	0.07
P	0.61	0.87	0.84

¹Values in () are standardized ileal digestibilities of amino acids.

²ME value was calculated as $ME = 1 \times DE - 0.68 \times CP$ ($R^2 = 0.99$; Noblet and Perez, 1993).

³NE value was calculated as $NE = (0.87 \times ME) - 442$ ($R^2 = 0.99$; Noblet et al., 1994).

⁴Average reduction compared to the average fat and ME content of 6 DDGS sources. Individual values were 59, 1, 41, -28, 25, and 1 kcal ME/1% reduction in crude fat among 6 DDGS sources with crude fat content ranging from 10.16 to 12.10% and ME content ranged from 3,414 to 4,141 kcal/kg.

DE and ME Impact of Reduced-Oil in DDGS

In order to directly determine the impact of RO-DDGS on ME content for swine, the University of Minnesota and USDA-ARS conducted a study (unpublished) to determine the relationship between crude fat and ME content, as well as develop prediction equations to accurately estimate these effects. A total of 11 DDGS samples from different sources ranging in crude fat content from 8.6 to 13.2% were fed to finishing pigs to determine actual DE and ME content. Samples were also analyzed for gross energy and nutrient composition (**Table 3**) to determine changes and correlations in nutrient content as oil is extracted from DDGS.

Table 3. Energy and nutrient composition of 11 DDGS sources (DM basis)

DDGS Source	GE, kcal/kg	ME/GE	ME, kcal/kg	Crude fat, %	NDF, %	Crude protein, %	Starch, %	Ash, %
8	5,167	69.57	3,603	13.2	34.0	30.6	1.3	5.3
11	5,130	69.26	3,553	11.8	38.9	32.1	1.1	4.9
9	4,963	71.83	3,550	9.7	28.8	29.8	2.8	5.0
6	4,963	70.68	3,513	9.6	33.0	30.1	3.4	4.9
7	4,938	69.36	3,423	10.1	38.2	30.3	2.2	5.0
2	5,075	67.01	3,400	11.1	36.5	29.7	3.9	4.3
4	4,897	68.69	3,362	8.6	35.7	32.9	0.8	5.1
3	5,066	66.04	3,360	10.8	38.6	29.7	1.6	4.6
10	4,948	67.46	3,327	10.0	35.9	32.7	1.0	5.3
1	5,077	65.06	3,302	11.2	44.0	27.7	1.8	4.4
5	5,043	64.70	3,277	11.1	39.7	31.6	0.9	5.0

By comparing the ME and crude fat content of DDGS sources 11 and 9, there was a 2.1 percentage unit difference in crude fat content, but only reduced ME by 3 kcal/kg DM. However, comparing DDGS sources 8 and 5, there was also a 2.1 percentage unit difference in crude fat content, but the ME content was 326 kcal/kg DM lower in source 5 compared to source 8. This indicates that relating ME content to crude fat concentration alone will not provide an accurate estimated of ME content among reduced-oil DDGS sources. Theoretically, as oil is removed from DDGS, all other nutrients should increase in concentration and ME content will decrease. However, it is not as simple as calories lost for each percentage of oil extracted from DDGS. As shown in **Figure 1**, there is a very high correlation between gross energy (GE) and crude fat content indicating that accurate ME prediction equations will require using GE since the correlations with neutral detergent fiber (NDF), total dietary fiber (TDF), crude protein (CP), and ash are low. As crude fat content decreases, crude protein and ash increase slightly, but TDF and NDF also decrease. It is surprising and unclear why TDF and NDF decrease when crude fat is removed from DDGS. However, other studies reported in the scientific literature have

shown the same relationship between NDF, ADF, and crude fat content of DDGS, and NDF and ADF values are highly variable among DDGS sources (**Figure 2**). Therefore, the theory that NDF increases as fat is extracted is incorrect, and due to the high variability in NDF content among reduced oil DDGS samples, it must be taken into account when estimating ME content.

Figure 1. Effect of oil extraction (EE) from DDGS on GE (gross energy), NDF (neutral detergent fiber), TDF (total dietary fiber), CP (crude protein), and ash content.

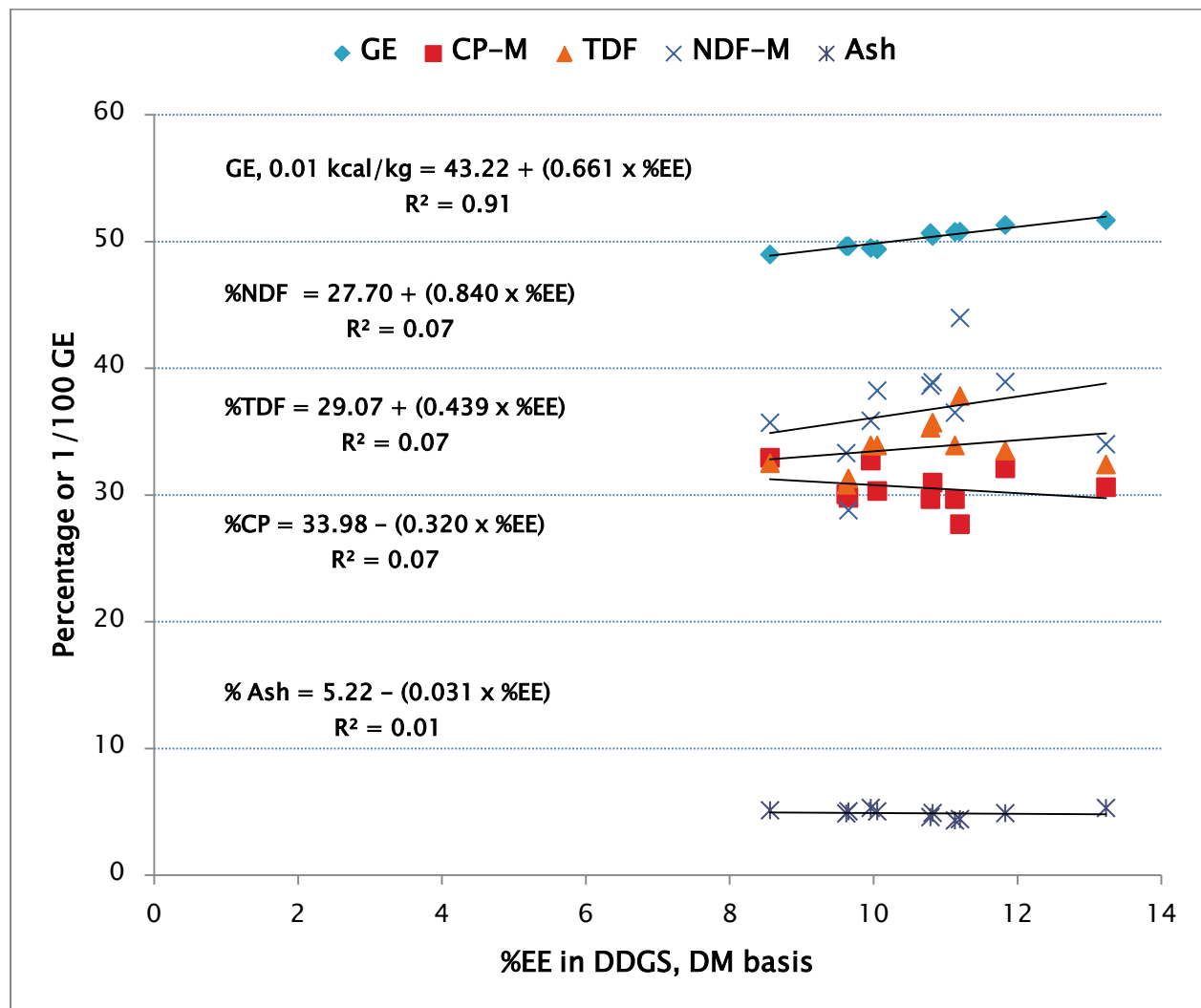
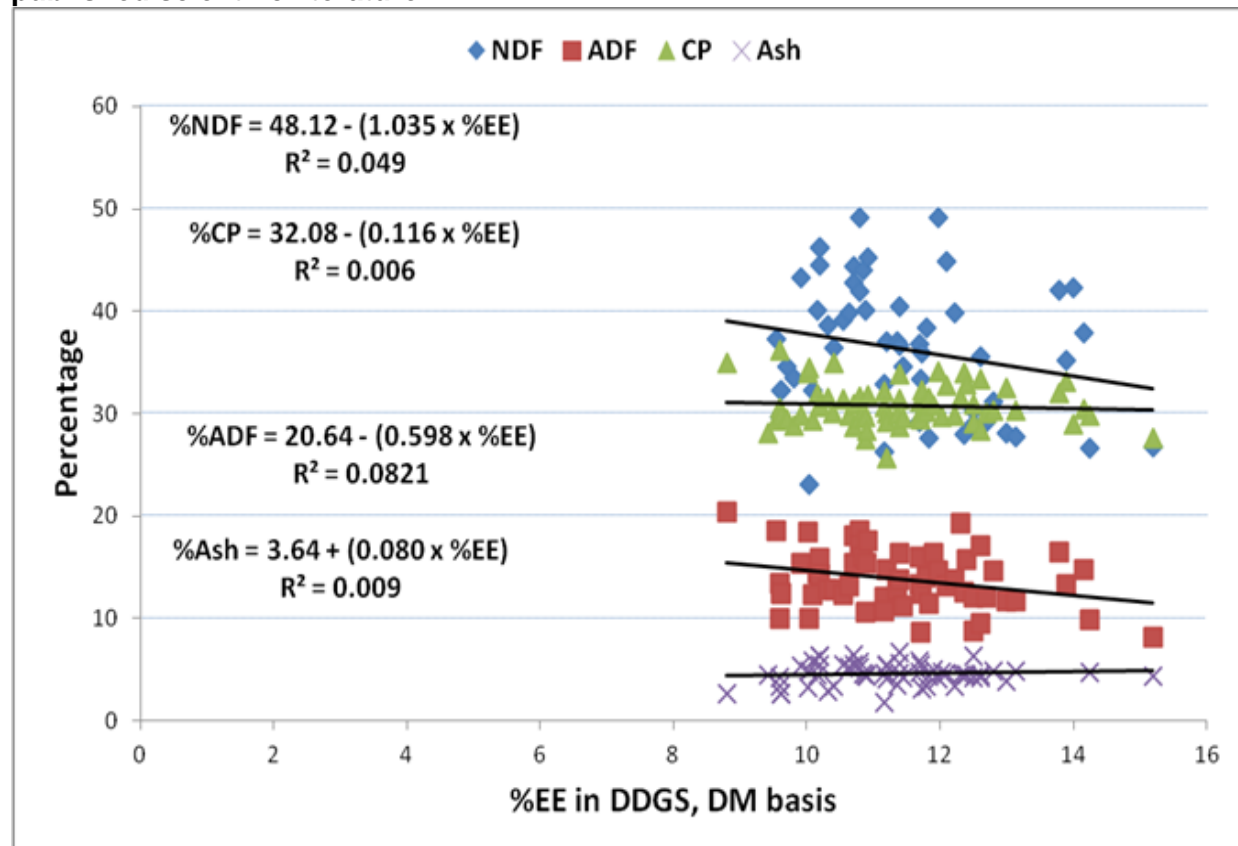


Figure 2. Effect of corn oil content (ether extract = EE) from DDGS on NDF (neutral detergent fiber), CP (crude protein), ADF (acid detergent fiber) and ash content from the published scientific literature.



As shown in **Figure 3**, there is NO significant impact of reduced oil on DE and ME content of DDGS ($R^2 = 0.05$ to 0.11). In other words, if we force the prediction of ME content from a 1% reduction in oil the prediction is very poor ($R^2 = 0.11$), but the average ME content would be reduced by 30 kcal/kg DM (**Figure 3**). Therefore, in order to achieve accurate ME estimates for RF-DDGS, we must use more accurate prediction equations. The most predictive equation derived from using multiple regression analysis was:

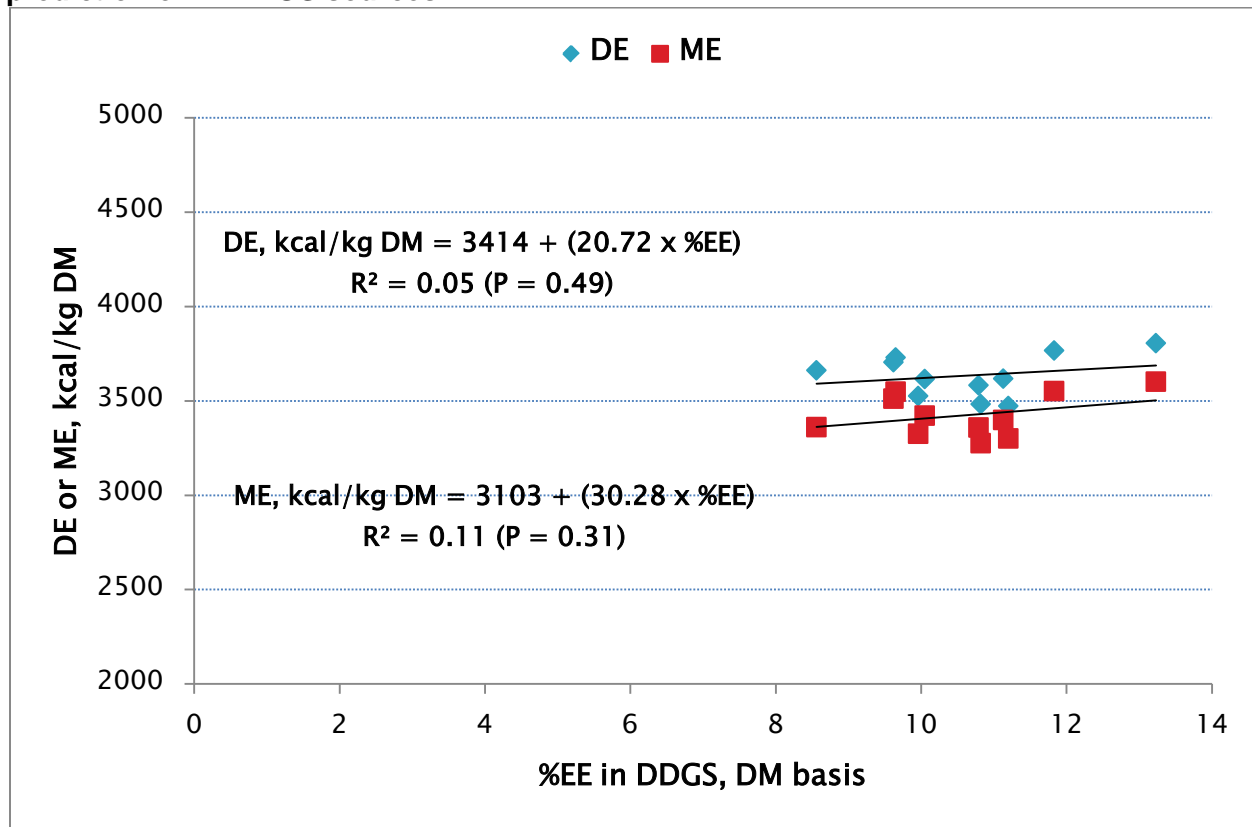
$$\text{ME kcal/kg DM} = 1,352 + (0.757 \times \text{GE kcal/kg}) - (51.4 \times \% \text{TDF}) \quad \text{SE} = 50 \quad R^2 = 0.84$$

However, it is difficult to obtain GE and TDF estimates from most commercial laboratories to use in this equation. As a result, the following equations can be used to estimate ME content of RF-DDGS for swine with a reasonable degree of accuracy:

$$\text{ME kcal/kg DM} = 4,440 - (68.3 \times \% \text{ADF}) \quad \text{SE} = 58 \quad R^2 = 0.76$$

$$\text{ME kcal/kg DM} = 3,711 - (21.9 \times \% \text{NDF}) + (48.7 \times \% \text{Crude fat}) \quad \text{SE} = 75 \quad R^2 = 0.65$$

Figure 3. Relationship between DDGS crude fat content and DE and ME content prediction of 11 DDGS sources.



What Are the Implications of Reduced-oil DDGS for Swine and Other Animal Market Sectors?

- The impact of RO-DDGS on ME content for swine is low.
- Crude fat content of DDGS should not be used to estimate ME content for swine.
- The most accurate prediction equation to estimate ME in RO-DDGS requires determinations for gross energy and total dietary fiber (TDF). These measurements are difficult to obtain from commercial laboratories and the cost of TDF determinations is expensive.
- Alternatively, the following 2 equations can be used with less accuracy, but still reasonably predict ME content of RF-DDGS using more common laboratory nutrient content determinations:
 - **ME kcal/kg DM = $4,440 - (68.3 \times \% ADF)$**
 - **ME kcal/kg DM = $3,711 - (21.9 \times \% NDF) + (48.7 \times \% \text{Crude fat})$**
- It is likely that pigs are able to utilize a significant portion of fiber in RO-DDGS for energy. However, poultry have less ability to obtain energy from fiber due to limited lower gut

fermentation, and as a result, would be expected to be impacted more by RO-DDGS than swine.

- Due to the large quantities of DDGS containing varying amounts of crude fat, marketing or purchasing DDGS on a “Pro-fat” basis is not advised because of the disproportionate changes in fat and crude protein content resulting from oil extraction and their relative impacts on nutritional value for swine. End-users should specify and negotiate price based on a minimum crude protein and minimum crude fat content.
- Removal of oil from DDGS reduces its energy value. Since DDGS is used primarily as an energy source in swine diets, the estimated price discount should be based on the estimated reduction in ME content of the DDGS source being considered, relative to the ME content of “typical”, normal fat (10 to 11% on an as-fed basis) DDGS.
- It is likely, based on the number of ethanol plants implementing oil extraction technology, and the extent of oil extraction from DDGS within a source, that the relative consumption rates among livestock and poultry market segments will change. It is expected that more RO-DDGS will be used in the dairy industry because higher dietary inclusion rates can be used without as much risk of milk fat depression. Beef feedlot cattle will continue to use it at relatively high inclusion rates with price adjustments based on estimated reductions in energy value. Swine will also continue to use it with minor price discounts for energy, and may use increasing amounts depending on oil content in order to minimize negative effects on pork fat quality. Of all food animal species, poultry will likely be impacted the most by reduced-oil DDGS, and depending on the extent of reduction in energy value, diet inclusion rates may be dramatically reduced.

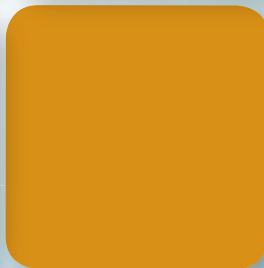
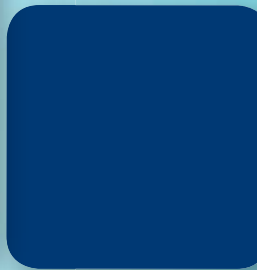
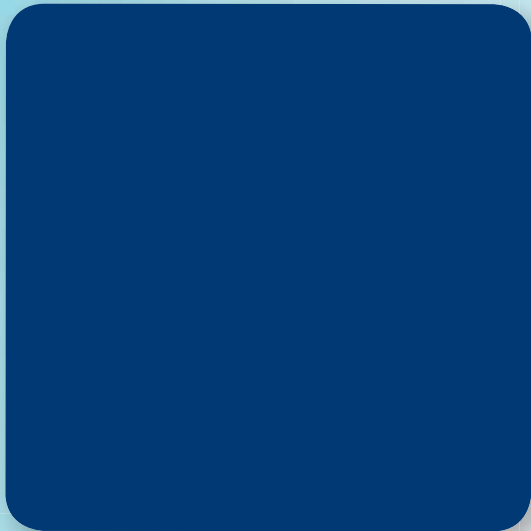
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CHAPTER 23

Managing Pork Fat Quality When Feeding High Amounts of DDGS to Growing-Finishing Pigs



Chapter 23

Managing Pork Fat Quality When Feeding High Amounts of DDGS to Growing-Finishing Pigs

Introduction

The effects of diet on pork fat firmness have been known for many years. In 1926, researchers at the U.S. Department of Agriculture demonstrated that feeding diets containing peanuts or soybeans dramatically decreased the firmness of carcass fat of pigs compared with feeding corn-based diets (Ellis and Isbell, 1926). However, until recently, the relationship between diet and fat firmness has not been a significant concern in the pork industry, but with the substantial reductions in feed costs resulting from feeding high dietary levels (> 30%) of DDGS to growing-finishing pigs, soft carcass fat has become a significant issue in many countries and markets.

The firmness of pork fat is an important characteristic of overall pork quality and is directly controlled by the fatty acid composition of the fat, which significantly affects shelf life and flavor of pork (Wood et al., 2003). In addition to pork quality, fatty acid composition of pork fat also influences the processing characteristics of pork. Soft fat may not have the necessary rigidity for efficient high-speed slicing of bacon and may slow other pork processing activities. Consequently, pork processors prefer firm fat in pork products which means that the fat must be relatively high in saturated fatty acids. In contrast, many consumers want to reduce their consumption of saturated fats and therefore, they generally prefer fat with elevated unsaturated fatty acids which makes the fat softer. As a result, managing pork fat quality is a challenge because of conflicting demands that are being placed on the pork industry.

The biology of pork fat firmness

Pork fat firmness is directly related to the ratio of saturated (SFA) and polyunsaturated fatty acids (PUFA) that are comprised in the fat (Wood et al., 2003). The PUFA to SFA ratio is commonly referred to as the iodine value (IV), which is based on the laboratory procedure using iodine to measure the number of double bonds (degree of unsaturation) in fats and oils. Fats containing a high proportion of SFA (fatty acids containing no double bonds) are solid at room temperature and have a relatively low IV. As the degree of unsaturation (presence of double bonds) in fatty acids increases, the melting point declines, IV increases, and fats are liquid at room temperature. Therefore, as IV increases, pork fat becomes increasingly softer. In pork fat, IV and the resulting fat firmness is heavily influenced by the ratio of linoleic acid to stearic acid (Wood et al., 2003; Nishioka and Irie, 2006). Hugo and Roodt (2007) reviewed the scientific studies from several researchers and suggested that acceptable firmness of pork fat is achieved when it contains 12 to 15% linoleic acid and more than 41% saturated fatty acids.

The fatty acid composition of pork fat results from the amount and composition of dietary fat as well as endogenous fatty acid synthesis. Fatty acids obtained from the diet are deposited in the pig's body with no alterations, while endogenous synthesis is comprised primarily of saturated

fatty acids. Therefore, carcass fat of pigs will reflect the fatty acid profile of dietary fat (Ellis and Isbell, 1926; Averette Gatlin et al., 2002; Jackson et al., 2009), as modified by endogenous fatty acid synthesis. Genetically lean pigs with low amounts of carcass fat and fed diets containing a high proportion of PUFA will tend to possess softer fat than pigs with a higher propensity for fat deposition fed similar diets because lean pigs have lower endogenous fatty acid synthesis. Increasing dietary fat concentration depresses de novo fat synthesis in pigs (Azain et al., 2004) which causes a greater influence of dietary fat on composition of carcass pork fat.

How is pork fat firmness measured?

Several physical measures have been evaluated for quantifying pork fat firmness including Instron compression tests, Durometer, Hardness meter, and Penetrometer, but their accuracy has produced mixed results (Apple et al., 2010). The belly flop or belly flex test has been widely used to measure the degree of flex demonstrated by a pork belly that is suspended over an elevated stick (Thiel-Cooper et al., 2001; Rentfrow et al., 2003; Whitney et al., 2006). A belly that demonstrates minimal flex is indicative of firmer fat. However, other factors such as belly thickness, temperature of the belly, orientation of the belly on the stick (skin side up or skin side down), and moisture content of the belly can all influence results (Apple et al., 2010).

Iodine Value (IV) is a chemical measure of the ratio of unsaturated fatty acids to saturated fatty acids and is one of the most common measures of pork fat firmness. Iodine value can be measured directly in the laboratory but most commonly it is calculated from the fatty acid composition of a fat sample using a prediction equation (AOCS, 1998). Typical IV of pork fat can range from 55 to 95 with higher values indicating softer fat. Recently, Apple (2010) questioned the accuracy of IV in quantifying fat firmness because longer chain fatty acids are not included in the equation developed by AOCS (1998). Meadus et al. (2010) included seven additional long-chained fatty acids when calculating IV, and it appears that this equation provides a better prediction of fat firmness, but needs to be validated.

Currently, there are no accurate, inexpensive, and fast methods of determining pork fat firmness in commercial pork processing facilities. Consequently, it is difficult to quantitatively differentiate pork carcasses based on pork fat firmness.

Where should fat firmness be measured?

Pigs deposit fat in several locations in their bodies and there are differences in fatty acid composition among these depots which could influence the assessment of fat firmness if only one depot is sampled. Cromwell et al. (2011) demonstrated that the inner layer of backfat of pigs contains a higher percentage of SFA and a lower concentration of PUFA compared with the outer layer of backfat. Wiegand et al. (2011) found weak and inconsistent correlations of IV among four fat depots of pigs fed diets with varying energy concentrations with and without ractopamine. They indicated that jowl fat IV is not a good predictor of belly fat IV because pigs were harvested at similar bodyweights but differing physiological maturities. However, others have reported more consistent IV among fat depots. If the outer and inner layers of backfat are collected as one sample and not segregated, IV of backfat is very similar to IV of belly fat

(Averette Gatlin et al., 2003; Jacela et al., 2011). In contrast, Xu et al. (2010b) found that IV of backfat is lower than IV of belly fat, but these two estimates become more similar as IV of the carcass increases. Leick et al. (2010) reported the IV, total monounsaturated fatty acids (MUFA), total PUFA, and MUFA to PUFA ratio of jowl fat was significantly correlated to that of belly fat. In their study, jowl fat underestimated IV of belly fat by about 5%, but Jacela et al. (2011) found the jowl fat IV was essentially the same as belly fat IV. Because belly fat is difficult to sample directly without damaging it, it seems that both backfat and jowl fat provide reasonable estimates of belly fat firmness realizing that jowl fat may slightly underestimate belly fat IV.

Genetic and management factors that affect pork fat firmness

Genetic improvement of pigs

Carcass fat of modern genetic lines today is significantly less than from pigs harvested 10 or 15 years ago. High lean genotypes have decreased de novo fatty acid synthesis, which is primarily saturated fat, and results in a carcass with fat composition that more nearly reflects the composition of dietary fat. If the dietary fat is supplied by vegetable oil sources that are higher in polyunsaturated fatty acids, rather than animal fats, carcass fat will become softer.

Gender

Gilts have carcasses with more lean and less fat than barrow carcasses of the same weight and physiological maturity. As a result, gilts fed diets containing high concentrations of PUFA generally have a higher IV than barrow carcasses.

Management factors

In general, housing conditions that reduce feed intake such as reduced space allowance, limited feeding, and high environmental temperatures often reduce carcass fat. As carcass fat is reduced, the impact of diet fatty acid composition on IV of pork fat increases.

Effects of DDGS on pork quality

Adding DDGS to grower-finisher diets does not affect muscle quality, eating characteristics, and shelf life of pork, but can negatively affect belly and pork fat quality, especially at high (> 20%) dietary inclusion rates (Xu et al., 2010a). Inclusion of DDGS in diets for growing-finishing swine clearly decreases fat firmness and increases flex or softness of pork bellies (Stein and Shurson, 2009). This response is primarily due to the high concentration (58%) of linoleic acid (C18:2) in the corn oil present in DDGS. Increasing concentrations of DDGS in finishing pig diets up to 30% (Xu et al., 2010b) or 45% (Cromwell et al., 2011) results in linear increases in IV of carcass

fat and linoleic acid content of carcass fat coincident with a linear decrease in belly firmness. Similarly, Widmer et al. (2008) found decreased belly firmness when diets contained 20%, but not 10% DDGS.

Feeding and formulation strategies to minimize DDGS effects on pork fat quality

Withdrawal or reducing dietary DDGS level in late finishing period

In order to minimize the negative effects of feeding high dietary levels of DDGS on pork fat firmness, the most practical strategy is to remove or significantly reduce the amount of DDGS in the diet during the late finishing phase. Xu et al. (2010b) showed that feeding 30% DDGS diets up to 3 weeks before harvest and then withdrawing it from the diet, resulted in backfat and belly fat having an IV less than 70, which is considered acceptable by current U.S. pork industry standards. Hill et al. (2008) showed similar results. A total withdrawal of dietary DDGS can also be made abruptly because there appears to be no detrimental effects of this sudden dietary change on pig performance (Hilbrands et al., 2009; 2011).

Adipose tissue in pigs is dynamic because fats are continually being deposited and mobilized depending on the physiological state of the pig. This high degree of adipose tissue activity allows rather rapid changes to occur in the composition of fat in adipose tissue. Wood et al. (1994) suggested that the majority of change in fatty acid composition of adipose tissue occurs within 25 days of a dietary change. Similarly, IV of belly fat declined 5% in just 21 days after DDGS was removed from diets of finishing pigs (Xu et al., 2010a). Even faster changes have been reported by Warnants et al. (1999) when they noticed that about 50% of the change in linoleic acid incorporation into backfat occurred 14 days following a dietary switch from 2.5% tallow to 15% full-fat soybeans. Within 6 weeks of the diet switch, a plateau in backfat fatty acid composition was achieved. Similarly, Averette Gatlin et al. (2002) concluded that significant changes in fatty acid composition and IV of pork fat could be achieved in as little as 6 weeks.

Therefore, dietary changes in fat composition 3 to 6 weeks before harvest will have significant influences on composition and firmness of fat in pork carcasses. Complete removal of supplemental dietary fat or high-fat ingredients will have the most significant effects. Switching from a diet with a relatively high concentration of unsaturated fat to a diet containing a more saturated fat or reducing the dietary concentration of unsaturated fat will change composition of carcass fat, but it may not achieve the degree of hardness in carcass fat that is desired.

Feeding reduced-oil DDGS

With a significant number of U.S. ethanol plants extracting oil from DDGS, feeding a lower fat DDGS source (3 to 9% crude fat) compared to traditional DDGS sources (10 to 12 % crude fat) can decrease PUFA content of belly fat and increase firmness of bellies harvested from finishing

pigs (Dahlen et al., 2011). However, the metabolizable energy (ME) content of DDGS is also reduced when a portion of the oil is removed from DDGS, making it a less valuable energy source in the diet. In another study, Jacela et al. (2011) did not observe similar decreases in PUFA content of belly fat when feeding reduced-oil DDGS (3.5% crude fat), but they supplemented diets with choice white grease to standardize energy density of the diets which likely influenced fatty acid composition of the carcass.

Formulate diets on an Iodine Value Product (IVP) basis

The iodine value product (IVP) concept is a feed formulation strategy that is being used with some success to manage pork fat quality. It was developed by Madsen et al. (1992) and is based on the concept that if the diet and carcass IV's are known, diet formulation adjustments can be made to get closer to the target IV for pork fat in the carcass. Iodine product value involves a calculation including the amount of fat and the IV of the fat in each ingredient in the diet to meet a desired final diet IV specification. This formulation method was later revised by Boyd et al. (1997), where the IV of backfat = $0.32(\text{IVP}) + 52.4$ and $\text{IVP} = \text{IV of the diet oil} \times \% \text{ diet oil} \times .1$. Using IVP does not always result in desired final carcass IV because there are several confounding factors such as growth rate, genetics, and health that likely underestimate the impact of linoleic acid on pork fat firmness. The IVP of corn DDGS is quite high (112) compared to corn (47), barley (23), wheat (23), and soybean meal (18). Therefore, use of IVP in diet formulation is another tool that can help manage pork fat quality concerns when feeding DDGS diets to growing-finishing pigs. Cast (2010) indicated that IVP is not an absolute number but can be used to guide improvement in IV of carcass fat. He suggested that one must know the IVP of current diets being fed and the resulting IV of the target fat depot. With this information, one can re-formulate diets to achieve a lower IV and then monitor effects on IV of carcass fat. This approach will be farm-specific but can be useful.

Use alternative cereal grains in finishing diets

Choice of cereal grain used in finishing diets can influence pork fat firmness. Lampe et al. (2006) compared corn and barley diets for finishing pigs and found that barley diets significantly reduced PUFA, and increased SFA content of subcutaneous fat, resulting in a reduction of IV by about 4 units. Feeding growing-finishing pigs wheat and barley-based diets results in lower IV in pork fat than when feeding corn-soybean meal diets. Beltranena et al. (2009) showed that IV of pork fat in western Canada diets (wheat, barley, and canola meal) is lower compared to U.S. corn-soybean meal based diets, and withdrawing corn DDGS from wheat and barley based diets is a good strategy for reducing pork fat IV, compared to feeding 30% DDGS continuously. Benz et al. (2011) found that a sorghum-based finishing diet reduced IV of jowl and back fat by approximately 2 units compared with a corn-based diet. In contrast, no differences in fatty acid composition or IV of carcass fat were observed when Carr et al. (2005) compared corn, wheat, and barley in swine diets. Han et al. (2005) also reported no differences in fatty acid composition of backfat when feeding corn or wheat-based diets. It appears that there may be beneficial effects on fat firmness when corn is replaced in the diet by other cereal grains with lower linoleic acid content, but this response is not always observed.

Addition of saturated fats to DDGS diets

Adding more saturated animal fat sources to DDGS diets have resulted in inconsistent responses on pork fat quality. Stevens et al. (2009) showed that feeding corn-soybean meal-DDGS diets, with or without 5% choice white grease (pork fat), during a 26-day DDGS withdrawal program resulted in a partial recovery of some of the adverse effects on pork fat quality caused by the increase in linoleic acid contributed from DDGS. However, they indicated that a longer DDGS withdrawal period is required for complete recovery of pork fat quality. The addition of a dry animal fat source (4% of the diet) high in saturated fatty acids (70%) did not alleviate the increase in IV resulting from the addition of 30% DDGS to the diet (Freitas et al., 2009). This was most likely due to the low digestibility of the saturated fat used in the study. Recently, research at the University of Minnesota (Pomeroy et al., 2011) showed that adding 5% tallow to 30% DDGS diets did not improve belly firmness. Based on the results of these studies, we need to learn more about fatty acid digestibility among various fat sources in order to understand how they may or may not impact pork fat quality in pigs fed DDGS diets.

Feeding conjugated linoleic acid (CLA)

Conjugated linoleic acid is approved for use in swine growing-finishing diets in the U.S. and can influence the quantity and composition of fat deposited by pigs. Dietary CLA at concentrations between 0.12 and 0.6% significantly decreased tenth rib backfat depth of pigs at harvest (Thiel-Cooper et al., 2001; Weber et al., 2006). In addition, dietary CLA decreases the IV of pork fat (Thiel-Cooper et al., 2001; Dugan et al., 2004; Weber et al., 2006; White et al., 2009). These changes in fatty acid composition of pork fat occur because CLA suppresses activity of desaturase enzymes that are involved in synthesizing unsaturated fatty acids (Smith et al., 2002). As a result of changes in enzyme activity and fatty acid composition, CLA increases firmness of pork bellies when contained in the diet at 0.50 to 1.0% (Thiel-Cooper et al., 2001; Weber et al., 2006; Larsen et al., 2009).

The consistent improvement in fat firmness from feeding CLA suggests a unique application for its use in diets containing high levels of DDGS. White et al. (2009) fed pigs 0, 20, or 40% DDGS with or without 0.6% dietary CLA and found no interaction between dietary DDGS and CLA for measures of fat firmness which indicates that CLA has the same effects on fat firmness regardless of dietary DDGS content. Furthermore, these researchers found that CLA could partially reverse the negative effects of dietary DDGS on fat hardness. More recently, Ochoa et al. (2010) fed barrows 0 or 30% DDGS in diets with 0, 0.5 or 1.0% dietary CLA. They also found no interaction between DDGS and CLA, but observed an increase in carcass lean content and improved belly firmness when 1.0% CLA was added to the diet. However, backfat IV was not affected. Therefore, it appears that the addition of CLA to the diet during the late finishing phase may be used to reduce IV of carcass fat, but it is not currently used in the U.S. because of cost, and is not available or approved for use in other countries.

Feeding crude glycerol

Glycerol is the three-carbon component of triglycerides that remains after production of biodiesel. Crude glycerol can be used as an energy source for pigs if it is economical and available. Diets containing 5% glycerol can decrease the concentration of PUFA, linoleic, and linolenic acid in backfat while increasing the concentration of the monounsaturated fatty acid, oleic acid (Mourot et al., 1994). Lammers et al. (2008) reported that linoleic acid concentration of fat in pork loin chops decreased as dietary glycerol increased to 10%. These slight changes in fatty acid composition of carcass fat may result in increased pork fat firmness. Schieck et al. (2010) fed growing-finishing pigs diets containing 8% crude glycerol for 8 or 14 weeks before harvest. They found a 40% improvement in belly firmness (measured by the belly flex test) for pigs receiving glycerol for 8 weeks compared to pigs receiving no dietary glycerol. Unfortunately, these researchers did not measure the fatty acid composition of bellies, but these limited data suggest that dietary glycerol may have some utility in improving fat hardness of pork carcasses.

Conclusions

Pork fat firmness decreases linearly with increasing levels of DDGS in the diet for growing-finishing pigs, and the effects are greater in lean pigs compared to fat pigs. Iodine value of pork fat varies among carcass location and should be considered when measuring pork fat to meet desired pork fat IV standards. Currently, the most effective and practical approaches to minimize the negative effects of feeding diets containing high levels of DDGS include: 1) Reduce or withdraw typical DDGS (10 to 12% crude fat) from the diet during the last 3 to 6 weeks prior to harvest; 2) Feed reduced-oil DDGS; 3) Formulate diets to an IVP specification and monitor the effects on carcass fat; and 4) Substitute wheat, barley, or sorghum for corn in grower-finisher diets.

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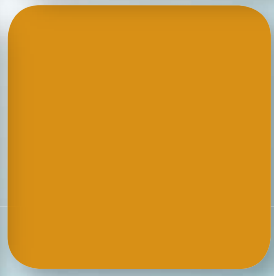
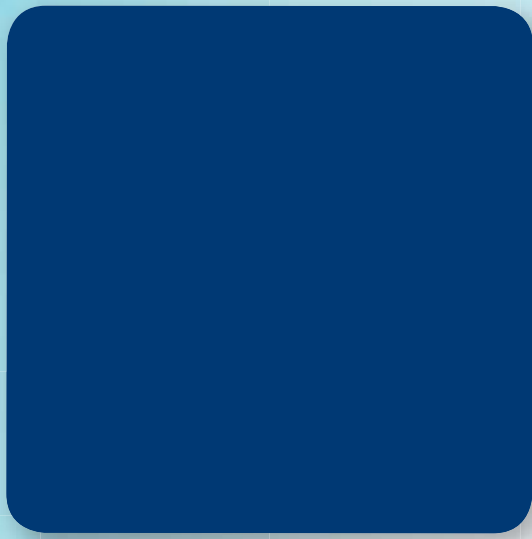
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CHAPTER 24

Use of Enzymes in DDGS Diets for Poultry and Swine



Chapter 24

Use of Enzymes in DDGS Diets for Poultry and Swine

Introduction

Plant carbohydrates can be classified into three categories: 1) simple sugars and their conjugates (glucose, fructose, etc.); 2) storage reserve compounds (starch); and 3) structural carbohydrates (cellulose, hemicellulose, etc.). Simple sugars and storage compounds are primarily digested in the upper gastrointestinal tract, although not completely, while structural carbohydrates are only partially degraded by the microflora in the cecum and large intestine (Slominski, 1991). Because most of the starch is removed from corn during ethanol production, the resultant co-product, dried distillers grains with solubles (DDGS), contains concentrated levels of protein, minerals, and fiber (Spiehs et al., 2002; Pedersen et al., 2007; Anderson, 2009). With pigs' ability to utilize moderate, but not high levels of fiber in the nursery (Whitney and Shurson, 2004; Weber et al., 2008) and finisher (Whitney et al., 2006) period, there is a need to increase the ability of the pig to utilize the energy associated with the structural carbohydrates contained in corn-derived co-products (Muley et al., 2007). With the large amount of corn being utilized for ethanol production in the U.S., the amount of high fiber corn co-products available for animal feeds continues to increase. In order to minimize the cost associated with dietary energy and amino acids, it is essential that we develop and evaluate technologies that increase digestibility of energy and other nutrients. Use of exogenous enzymes is one of these technologies that offer promise for improving the nutritional value of high fiber corn co-products, particularly DDGS.

Fiber in Swine Nutrition

Definition

Unfortunately, "fiber" is perhaps the most poorly understood constituent of swine diets, and is generally described as a complex and highly variable component of plant-based feedstuffs (**Figure 1**, NRC, 2007). It is important to note that the analytical methods used to characterize "fiber" often overlap or exclude fractions of other distinctly different carbohydrate fractions in a feedstuff, and consequently, our ability to adequately relate analytical measures to fiber utilization has been problematic. Some fiber types are more digestible than others, and although they cannot be broken down by mammalian enzymes, they can be fermented by bacteria in the hindgut (Grieshop et al., 2001). These fiber types are often termed "nonstarch polysaccharides" (NSP), where up to 90% of the cell walls of plants are made up of NSP; of which, cellulose, hemicellulose, and pectins are most abundant (Selvendran and Robertson, 1990). Other less abundant NSP include fructans, glucomannans, galactomannans, mucilages, β -glucans, and gums. Cellulose is found in tightly bound aggregates in plants, while hemicellulose and pectins have sugar side chains that allow them to be more readily broken down. Lignin is not a

polysaccharide per se, but is a high molecular weight polymer, and is not considered a functional dietary constituent because it is indigestible by swine (Grieshop et al., 2001).

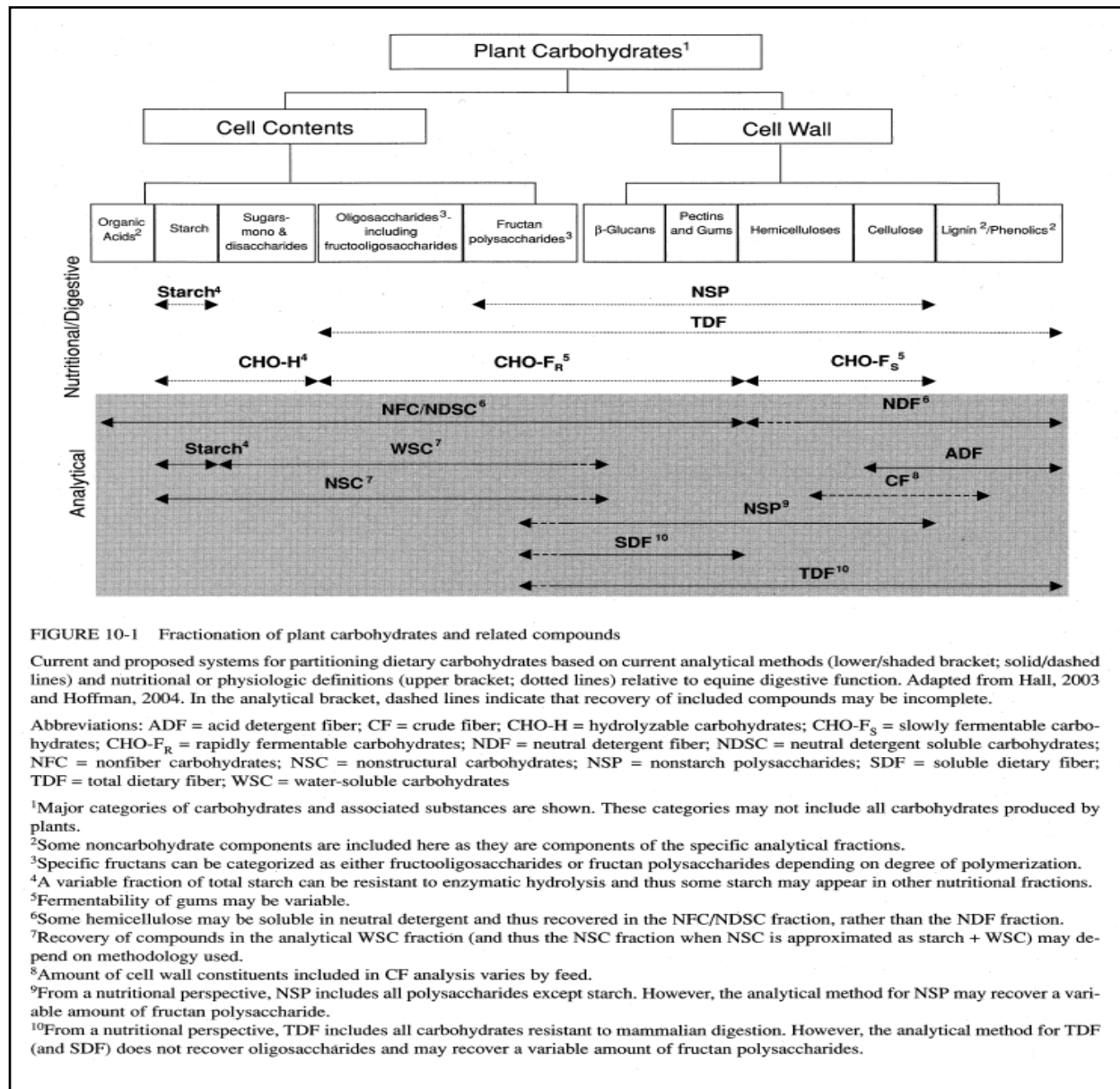


Figure 1. Nutritional and analytical classifications used to characterize plant carbohydrates.

As shown in **Figure 1**, common analytical methods used to measure complex carbohydrates in high fiber feed ingredients and feeds include: crude fiber, acid detergent fiber (ADF), neutral detergent fiber (NDF), soluble and insoluble fractions of total dietary fiber (TDF), and non-starch polysaccharides (NSP). Each of these fiber methods measures several fractions of complex carbohydrates, but they do not adequately relate to the energy value of feeds for swine.

Energy value of fiber

The digestibility of “fiber” in swine diets can vary drastically between 0 and 97% depending upon the source of fiber (Bach Knudsen and Hansen, 1991), processing method (Fadel et al., 1989), and concentration in the diet (Stanogias and Pearce, 1985; Goodlad and Mathers, 1991). However, many NSP are partially fermentable in the hindgut and can be used to produce volatile fatty acids (VFA) such as acetate, propionate, and butyrate. These VFA are rapidly absorbed and have been shown to supply between 5 and 28% maintenance energy requirement of the pig (Farrell and Johnson, 1970; Imoto and Namioka, 1978; Kass et al., 1980; Latymer and Low, 1987; Rérat et al., 1987; Yen et al., 1991). However, the loss of energy due to methane, hydrogen, and fermentation heat decrease the amount of energy available to the pig from fermentation of fiber in the hindgut (Grieshop, 2001), thereby decreasing the efficiency of energy utilization (Giusi-Perier et al., 1989, Noblet et al., 1994).

Fiber alters the gastrointestinal tract

1. Weight

Feeding high fiber diets results in a general increase in the total empty weight of the gastrointestinal tract (Kass et al., 1980; Stanogias and Pearce, 1985; Anugwa et al., 1989) and increased gastrointestinal secretions (Grieshop et al., 2001). Jørgensen et al. (1996) showed that growing-finishing pigs fed diets containing high dietary fiber (NSP + lignin) (268 g/kg dry matter, DM) as compared to pigs fed diets low in dietary fiber (59 g/kg DM), had a significantly heavier stomach, cecum, and colon weights, as well as a longer colon.

2. Enterocyte proliferation

Intestinal epithelial cell proliferation rate is stimulated by high NSP diets (Jin et al., 1994; Howard et al., 1995) leading to an increase in cell turnover rate. Growing pigs fed diets containing 10% wheat straw had a 33% increase in the rate of jejunal and colonic cell proliferation, and a 65% increase in cells undergoing cell death (Jin et al., 1994).

3. Endogenous fluid secretion

The secretion of endogenous fluids is also increased when feeding high fiber diets to pigs (Wenk, 2001). Secretions of saliva, gastric juice, and pancreatic juice were doubled when dietary fiber content was increased from 50 to 180 g/kg in 50 kg pigs (Zebrowska et al., 1983).

4. Maintenance energy requirement

With the many changes in the characteristics of the gastrointestinal tract due to feeding a high fiber diet, the maintenance energy requirements of pigs may be increased by the extra metabolic demand due the nutrient needs for visceral organ development and maintenance (Grieshop et al., 2001; Wenk, 2001). Consequently, methods to improve fiber digestion would reduce these negative effects of fiber on animal metabolism.

5. Gastric emptying and satiety

The rate of gastric emptying may decrease with the addition of certain forms of NSP. Guar gum and pectin increase the viscosity of the digesta (Grieshop et al., 2001) and water

retention (Johansen et al., 1996). Growing pigs fed a high energy (starch, casein, soybean oil, and tallow) diet supplemented with 40 to 60 g/kg guar gum had a reduced rate of gastric emptying of 33 to 52% after feeding, and a 27% reduction in DM concentration of the digesta (Rainbird, 1986; Rainbird and Low, 1986). High fiber diets may also contribute to earlier satiety resulting from gastric signals due to the elongation of the stomach wall. Feeding an increased amount of dietary fiber may lead to increased volume of digesta in the stomach, decreased transit time, and increased satiety. This is important in gestating sows where it has been shown that sows satisfied physically and nutritionally appeared to be less stressed and exhibited decreased physical activity (Rijhen et al., 1999).

6. Digesta passage rate and nutrient utilization

The passage rate of digesta can also be affected by feeding diets high in fiber. Some studies have shown increasing daily DM flow at the terminal ileum when increasing levels of NDF were added to the diet (Schulze et al., 1995). Others have also shown up to a 14 and 23% increase in rate of passage when 75 to 300 g of bran or oatmeal by-products, respectively, was added to the diet (Potkins et al., 1991). These results suggest that the differences in rate of passage through the total digestive tract may be due to differences in the rate of passage through the large intestine, because neither fiber source had a significant effect on gastric emptying or passage through the small intestine (Potkins et al., 1991). Additionally, particle size of the fiber source may also contribute to the rate of passage. Bardon and Fioramonti (1983) showed that a coarser particle size of wheat bran decreases transit time compared to a finer particle size.

The amount of time the digestive contents spend in the large intestine can also affect the capacity for fermentation. Fiber fermentation in the cecum and colon results in the production of VFA, mainly acetic, propionic, and butyric acids which are viable sources of energy. However, the energy density and digestibility of the diet usually decreases with the addition of NSP (Grieshop et al., 2001). In addition, NSP reduces lipid absorption due to a partial inhibition of both lipolysis and intestinal fat absorption (Borel et al., 1989). Nonstarch polysaccharides also decrease dietary nitrogen (N) retention due to increased secretion of endogenous N, which leads to increased bacterial N excretion (Grieshop et al., 2001). Although minerals do not contribute energy directly to the diet, an impact of NSP on mineral utilization should also be considered (i.e., deficiencies or excesses could lead to physiological conditions that may ultimately affect energy absorption). However, the impact of NSP sources on mineral utilization appears to be minimal (Kornegay and Moore, 1986; Grieshop et al., 2001).

Mechanical Processing Effects on Fiber Utilization

Data pertaining to the effect of corn and corn co-product processing (mechanical or chemical) on changes in fiber utilization in non-ruminants is lacking or inconsistent. Teitge et al. (1991) reported that pelleting and micronizing, but not steam-flaking, resulted in a greater response to a dietary pentosanase in broilers fed diets containing rye, while Brenes et al. (1993a) indicated that autoclaving lupins had no impact on chick performance. Autoclaving high-tannin peas, in contrast to low-tannin peas, improved apparent metabolizable energy and apparent protein digestibility in Leghorn chicks (Brenes et al., 1993b). In 80 kg pigs fed barley-based diets,

pelleting had no effect on ileal or fecal apparent digestibilities of DM, energy, crude protein (CP), fat, or fiber (NSP + lignin), although it did increase pre-ileal apparent digestibility of starch (Graham et al., 1989). In contrast to Teitge et al. (1991), Graham et al. (1989) reported that pelleting did not improve the digestibility response found when dietary β -glucanase was added to the diet.

Poel et al. (1992) reported that steam processing of faba bean cotyledons did not improve ileal digestibility of CP, either due to the low level of trypsin inhibitor activity present in faba beans, or due to the trypsin inhibitor being sensitive to heat above the 100° C which was used in this study. Likewise, Thacker and Campbell (1999) and Nyachoti et al. (2006) showed little effect of micronization on nutrient digestibility coefficients. Pelleting of diets containing high levels of corn fiber (corn gluten feed), improved N balance, apparently due to the increased availability of tryptophan (Yen et al., 1971). Extrusion is a common heat processing method for feed ingredients used in the commercial feed industry. However, very little is known about the effects of extruding corn and corn co-products on nutritional value (Muley et al. 2007). Therefore, studies are needed to assess the effects of extrusion and other practical feed processing methods of high fiber corn co-products on nutrient digestibility in pigs.

Effects of Exogenous Enzymes on Fiber Utilization

Poultry vs. swine diets

The addition of exogenous enzymes to animal feeds in efforts to improve nutrient digestion is not a new concept and responses have been reviewed in detail (Chesson, 1987; Bedford, 2000). The majority of commercial enzyme products have been targeted toward poultry (Annison and Choct, 1991; Cowan, 1993) and are typically added to diets containing barley, oats, peas, rye, or wheat (Aimonen and Nasi, 1991; Thacker et al., 1992; Viveros et al., 1994; Huberner et al., 2002), with only limited research evaluating enzyme use in corn-soybean meal diets (Saleh et al., 2005).

Enzymes in non-corn based swine diets

Like poultry, the majority of research on adding enzymes to swine diets has focused on non-corn-based diets. Adding a multi-enzyme complex to diets containing barley and wheat has been shown to improve soluble NSP digestibility in 10 kg pigs, although growth performance was not affected (Inbarr et al., 1993). Similarly, variation in responses from enzyme addition in pig diets has also been reported by Nonn et al. (1999), who found no effect of enzyme supplementation on pig growth performance, even though they observed increased digestibility of crude fiber and cellulose. Likewise, Thacker and Campbell (1999) indicated that although enzyme supplementation increased nutrient digestibility coefficients, there was little effect on pig growth performance. In contrast, Omogbenigun et al. (2004) supplemented an enzyme cocktail (cellulose, galactanase, mannase, and pectinase) to a wheat-based diet fed in 6 kg pigs and observed an improvement in growth performance (growth rate and feed efficiency) over a 38 d period. Improved nutrient digestibility has also been reported by Yin et al. (2000) who added

xylanase to diets containing wheat by-products fed to 15 kg pigs and reported improved ileal and total tract apparent digestibility of DM, CP, and energy, especially in diets containing high levels of insoluble NSP. Lastly, adding an enzyme cocktail (fermentation extracts and soluble from *A. niger* and *T. longibranchautum*) to a diet containing 20% soy hulls improved DM and energy digestibility, but not N digestibility, in 33 to 51 kg pigs (Moeser and van Kempen, 2002). With soybean hulls having a large proportion of cellulose relative to other NSP, these data provide some evidence that cellulose digestion can be impacted in addition to hemicellulose and the more soluble forms of fiber.

Enzymes in corn-based swine diets

Limited research has been reported on the impact of exogenous enzymes on nutrient digestibility or pig performance when pigs are fed corn-based diets. Supplementation of β -glucanase to a corn-soybean meal-based diet had no impact on DM, energy, or CP digestibility in 6 kg pigs (Li et al., 1996). Likewise, supplementation of β -mannanase (β -mannanase is a part of hemicellulose) to a corn-soybean meal-based diet failed to show any effect on DM, energy, or N digestibility in 93 kg barrows (Petty et al., 2002). However, adding β -mannanase improved feed efficiency in 6 kg pigs (42 d feeding period) and 14 kg pigs (21 d feeding period), and improved gain and feed efficiency, but had no impact on carcass composition, when fed from 23 to 110 kg (Petty et al., 2002). Kim et al. (2003) utilized a carbohydrase enzyme mixture (α -1,6-galactosidase and β -1,4 mannanase) in corn-soybean meal-based diets fed to nursery pigs and reported an improvement in feed efficiency in two trials (35 d trial, 6.3 to 19.1 kg BW; and a 21 d trial, 8.0 to 15.2 kg BW) and ileal energy digestibility. Supplementation of the carbohydrase enzyme mixture also decreased the concentration of stachyose in the proximal and distal small intestine, and raffinose concentration in the distal small intestine, suggesting that this carbohydrase mixture improved the digestibility of the carbohydrates in soybean meal. In a similar manner, supplementation of several multi-enzyme preparations added to corn and soybean meal-based diets (small amounts of wheat, wheat screenings, barley, millrun, canola meal, and peas) fed to 7 kg pigs for 28 d, improved growth performance and various nutrient digestibility indices in both the ileum and total tract (**Table 1**; Omogbenigun et al., 2004).

Table 1. Effect of enzyme supplementation on growth performance, percent apparent ileal digestibility (AID), and total-tract digestibility (TTD) of nutrients in 7 kg pigs.¹

Performance	Control	Diet ²			Statistics	
		C + Enz A	C + Enz B	C + Enz C	SEM	P-value
ADG, g	224 ^b	252 ^a	263 ^a	249 ^a	7.9	0.02
ADFI, g	432	435	456	414	17.8	0.42
G:F	0.52 ^b	0.58 ^a	0.58 ^a	0.61 ^a	0.02	0.01
AID, %						
DM	60.1 ^b	65.8	66.1 ^a	66.7 ^a	1.5	0.01
Starch	86.7 ^b	92.6 ^a	94.6 ^a	95.3 ^a	1.1	0.02
GE	62.8 ^b	70.0 ^a	69.7 ^a	71.4 ^a	0.9	0.01
CP	62.1 ^b	71.5 ^a	71.4 ^a	73.2 ^a	1.5	0.01
Phytate	59.2 ^b	71.7 ^a	69.1 ^a	69.7 ^a	2.3	0.04
NSP	10.1 ^b	14.9 ^a	16.4 ^a	21.4 ^a	1.4	0.01
TTD, %						
DM	75.6 ^b	78.1	77.2 ^a	80.0 ^a	0.5	0.01
Starch	94.4 ^b	98.6 ^a	97.6 ^a	98.6 ^a	0.7	0.01
GE	77.8 ^b	79.8 ^a	79.8 ^a	81.1 ^a	0.7	0.01
CP	67.1 ^b	71.2 ^a	71.6 ^a	74.2 ^a	1.0	0.01
Phytate	69.4 ^b	96.8 ^a	96.3 ^a	96.0 ^a	3.2	0.01
NSP	48.9 ^b	61.2 ^a	59.6 ^a	66.8 ^a	1.2	0.01

¹Average initial weight, 7.0 kg, 28 d trial, 6 pigs/trt, ADFI on a DM basis. (Omogbenigun et al., 2004)

²Enzyme preparations provided 250 units xylanase, 150 units glucanase, 0.001% amylase, 0.0003% protease, 0.002% invertase, and 400 units phytase per kilogram of diet and differed in the type of plant cell wall degrading activities. Enzyme A contained cellulase, galactanase, and mannanase; Enzyme B contained cellulose and pectinase; and Enzyme C contained cellulose, galactanase, mannanase, and pectinase.

^{abc}Means within a row with different superscripts differ at the P-value shown.

Recently, Ji et al. (2008) evaluated a β -glucanase-protease enzyme blend added to a corn-soybean meal diet and fed to 38 kg pigs (**Table 2**). Pigs fed the enzyme blend diet had increased total tract digestibility of DM, energy, CP, TDF, and phosphorus (P), but only increased ileal digestibility of NDF, while CP appeared to have decreased ileal digestibility. The authors suggested that the increase in ileal NDF digestibility (and hemicellulose), with no change in fecal digestibility due to enzyme supplementation, may have shifted some of the digestion of these nutrients from the hindgut to the small intestine, which would avoid the fermentative loss of energy and presumably increase the energetic efficiency of fiber digestion.

Table 2. Effect of enzyme supplementation on percent apparent ileal digestibility (AID) and total-tract digestibility (TTD) of nutrients in 38 kg pigs.¹

AID, %	Diet ²			Statistics	
	Basal	B + 0.05%	B + 0.10%	B vs Enz	0.05 vs 0.10
DM	70.86	69.13	70.50	0.33	0.25
Energy	70.93	69.48	70.71	0.44	0.31
CP	78.29	75.51	76.54	0.04	0.37
Starch	97.95	98.01	98.12	0.51	0.59
NDF	1.21	9.52	10.05	0.02	0.88
ADF	4.33	4.36	5.22	0.91	0.84
TDF	NA	NA	NA	NA	NA
Crude fat	61.40	62.94	62.18	0.49	0.68
P	49.62	49.54	49.00	0.86	0.80
TTD, %					
DM	87.42	88.61	88.50	0.01	0.62
Energy	86.51	87.42	87.26	0.01	0.51
CP	86.47	88.08	87.39	0.01	0.10
Starch	99.24	99.26	99.31	0.53	0.44
NDF	54.62	55.62	56.05	0.36	0.77
ADF	64.84	61.40	65.92	0.40	0.01
TDF	60.61	65.36	65.61	0.01	0.86
Crude fat	80.14	80.51	78.24	0.51	0.09
P	53.80	61.73	57.83	0.01	0.01

¹Average initial weight, 38.2 kg, 4x4 Latin Square with 14 d periods (4 d adapt, 5 d fecal collection, 3 d transition, 2 d ileal collection). (Ji et al., 2008)

²Enzyme contained 660 β -glucanase units/g and 22 hemoglobin units/g.

Recently, it has been reported that adding an enzyme preparation to diets containing 30% DDGS increased growth performance in nursery pigs (Spencer et al., 2007). Whether addition of dietary enzymes will enhance growth performance in finishing pigs fed diets containing increased levels of corn fiber remains unknown. Unfortunately, the results of studies where there are no effects of supplemental enzymes on pig growth performance go largely unreported in the scientific literature, which has led to a paucity of peer-reviewed data being available to pork producers, swine nutritionists, and other pork industry professionals.

Phytase Alone and in Combination with Other Enzymes

The impact of dietary phytase supplementation on the digestibility of energy has not been consistent. While most studies (Adeola et al., 2004, 2006; Liao et al., 2005; Jendza et al., 2006; Beaulieu et al., 2007) have observed no impact of phytase on energy digestibility, others (Brady et al., 2002; Shelton et al., 2003; Jendza et al., 2005; Veum et al., 2006) have reported positive effects. Recent results from Kerr et al. (2010) were also inconclusive, suggesting that if there is an effect of phytase on energy digestibility, it is relatively small in magnitude and highly variable.

The impact of phytase, with or without other enzymes, on nutrient (and energy) digestibility is lacking. Olukosi et al. (2007) supplemented diets comprised of corn, wheat midds, soybean meal, and canola meal with either phytase or an enzyme cocktail (xylanase, amylase, and protease) alone, or in combination, and fed them to 10 to 23 kg pigs (**Table 3**). These data suggest that even though phytase improved pig gain and feed efficiency, addition of the enzyme cocktail, alone or in combination with phytase, had no impact on pig performance. Neither the addition of phytase nor the enzyme cocktail, alone or in combination, had any consistent effect on DM, energy, or N digestibility, but each improved P digestibility. The effects, however, were not additive. In an additional experiment with wheat replacing corn in the diet (23 to 52 kg BW, 42 d trial), there were no effects of phytase or xylanase (500 U and 4,000 U/kg, respectively) on pig performance, or on N and energy digestibility (Olukosi et al., 2007). Phytase, but not xylanase, improved phosphorus digestibility.

Table 3. Growth performance and apparent total tract digestibility of 10 to 23 kg pigs receiving phytase, or a cocktail of xylanase, amylase, and protease.¹

Dietary treatment	Pig performance			Apparent total tract digestibility, %			
	ADG, g	ADFI, g	G:F, g:kg	DM	GE	N	P
Negative control	398	1140	363	80.2	79.8	80.1	38.3
NC + Phytase ²	483	1070	457	80.1	78.1	80.2	49.9
NC + Enzyme ³	393	1050	380	82.3	80.1	81.2	48.3
NC + Ph + En	479	1210	415	80.0	79.0	80.0	51.1
SEM	10.4	30	13.7	0.20	0.43	0.43	0.87

¹ There were 4 replicate pens each of barrows and gilts (1 pig/pen) in the 28 d trial.
² Phytase was added at the rate of 500 phytase units/kg diet.
³ Cocktail of 400 U of xylanase, 4,000 U of amylase, and 2,500 U of protease per kg of diet.

Results from experiments evaluating the impact of phytase, with or without other enzymes, on nutrient (and energy) digestibility in diets containing DDGS are also lacking and inconsistent. While addition of 500 units phytase improved P digestibility in diets containing 20% DDGS in starter or finisher pigs, it did not improve DM digestibility (Xu et al., 2006a,b). In contrast, Lindemann et al. (2009) reported that 64 to 123 kg pigs fed diets containing 20% DDGS supplemented with 250 or 500 U/kg phytase exhibited greater DM, energy, and N digestibility than unsupplemented pigs, but there were no further improvements in fecal DM, energy or N digestibility with additional xylanase supplementation.

Energy and Fiber in Corn Co-products

Gross energy (GE) in DDGS averages 5,434 kcal/kg DM and is greater than the concentration of GE in corn (**Table 4**; Stein and Shurson, 2009). However, the digestibility of energy, measured as a percentage of GE, is lower in DDGS than in corn (Stein and Shurson, 2009). The DE and ME content of DDGS is 4,140 and 3,897 kcal/kg DM, respectively (Pedersen et al., 2007). These values are similar to the DE and ME content in corn (**Table 4**). The net energy

value of DDGS has not been determined, but research is currently being conducted to measure these values.

Table 4. Concentration of energy in corn and 10 sources of corn distillers dried grains with solubles (DDGS) fed to growing pigs.¹

Item	Corn	DDGS			
		Average	SD	Lowest value	Highest value
GE, kcal/kg DM	4,496	5,434	108	5,272	5,592
ATTD ² of energy, %	90.4	76.8	2.73	73.9	82.8
DE, kcal/kg DM	4,088	4,140	205	3,947	4,593
ME, kcal/kg DM	3,989	3,897	210	3,674	4,336

¹ Data from Pedersen et al. (2007) (Adapted from Stein and Shurson, 2009).
² ATTD = apparent total tract digestibility.²

Since most of the starch in corn is converted to ethanol, DDGS contains approximately 35% insoluble and 6% soluble dietary fiber (Stein and Shurson, 2009; **Table 5**). The ATTD of dietary fiber averages 43.7%, but ranges from 23 to 55%. This variation in fiber digestibility is believed to influence digestibility of energy in DDGS. Apparent ileal digestibility and total tract digestibility of dietary fiber in DDGS is higher than in corn, and presumed to be improved as a result of the processing and fermentation processes used in ethanol plants (Urriola et al., 2010). However, less than 50% of total dietary fiber is fermented over the entire digestive tract, indicating that more than 50% passes through pigs without being fermented (Urriola et al., 2010). As a result, there is a significant amount of non-fermented carbohydrate in DDGS that could potentially be utilized to a greater extent if appropriate exogenous enzymes can be developed to enhance the utilization of these substrates in DDGS diets.

Table 5. Concentration of carbohydrates and apparent total tract digestibility (ATTD) of dietary fiber in corn distillers dried grains with solubles.^{1,2}

Item	Average	Low value	High value	SD
Starch, total, %	7.3	3.8	11.4	1.4
Starch, soluble, %	2.6	0.5	5.0	1.2
Starch, insoluble, %	4.7	2.0	7.6	1.5
ADF, %	9.9	7.2	17.3	1.2
NDF, %	25.3	20.1	32.9	4.8
Insoluble TDF, %	35.3	26.4	38.8	4.0
Soluble TDF, %	6.0	2.36	8.54	2.1
TDF, %	42.1	31.2	46.3	4.9
ATTD of TDF, %	43.7	23.4	55.0	10.2

¹ N = 46 for data on starch, ADF, and NDF; n = 8 for data on insoluble, soluble, and total dietary fiber.
² Stein and Shurson, 2009.

In a recent collaborative research project between the Agricultural Research Service and the University of Minnesota, the ME concentration of a variety of corn milling co-products were evaluated (Anderson, 2009). Although one of the best fit equations included TDF in the prediction equation, [ME, kcal/kg DM = -1358 + (1.26 × GE) – (30.91 × TDF) – (33.14 × crude fat) (R² = 0.85, SE = 273)], the replacement of TDF with NDF had little impact on the overall equation: [ME, kcal/kg DM = -2161 + (1.39 × GE) – (20.70 × NDF) – (49.30 × crude fat) (R² =

0.77, SE = 337)], implying that for "corn fiber" there are low concentrations of pectans, gums, β -glucans, or fructan polysaccharides (as shown by the difference between TDF and NDF in Fig. 1). This can also be observed by comparing the relatively similar TDF and NDF concentrations in these co-products (**Table 6**). Furthermore, corn "fiber" has a large hemicellulose component as defined by the difference between NDF and ADF.

Table 6. Analyzed composition of corn co-products, DM basis¹

Item	DDGS (WI)	DDGS (IA)	DDGS (SD)	RO-DDGS (SD)	DDGS (BPX)	Drum-DDGS (MN)	Microwave-DDGS (MN)	Dried solubles	Gluten feed
Crude protein	29.62	29.65	31.94	34.74	29.49	32.69	34.12	23.75	24.29
Starch	7.85	3.47	6.24	3.04	4.94	2.12	1.05	6.34	12.57
Crude fiber	7.05	7.76	7.56	8.69	7.95	7.93	8.35	0.08	8.56
TDF	30.34	38.14	35.69	37.20	35.90	35.38	43.18	16.07	40.07
NDF	34.61	40.13	40.12	50.96	33.41	44.87	49.12	2.33	42.66
ADF	11.25	10.55	14.42	15.82	8.62	13.16	14.66	0.49	9.90
Cellulose	10.64	10.12	11.72	12.72	8.21	11.95	13.37	0.79	9.17
Lignin	1.21	1.06	3.16	3.49	1.00	1.72	1.92	0.31	1.05

Item	DHDG corn	Dehy corn germ	Corn germ meal	Bran	Bran + solubles	Gluten meal	HP-DDG (MOR)	HP-DDG (Poet)	HP-DDG (ICM)
Starch	87.96	25.00	15.29	23.25	25.73	11.08	0.51	7.30	5.10
Crude fiber	0.60	4.87	10.69	11.54	4.80	1.44	8.14	9.42	7.87
TDF	2.61	24.78	47.76	53.60	26.65	9.24	28.80	31.28	36.75
NDF	4.27	27.37	61.05	56.86	25.21	12.25	43.52	32.00	51.09
ADF	0.49	6.13	12.49	13.14	5.35	7.57	25.42	12.61	15.11
Cellulose	0.77	5.21	11.71	12.78	5.38	5.95	22.55	12.05	14.25
Lignin	0.33	1.28	1.22	0.89	0.55	2.24	3.40	0.95	1.44

¹Abbreviations: TDF, total dietary fiber; NDF, neutral detergent fiber; ADF, acid detergent fiber; DDGS, distillers dried grains with solubles; RO-DDGS, reduced oil-DDGS; drum- or microwave-dried DDGS; DHDG, dehulled-degermed; HP-DDG, high protein dried distillers grains. Abbreviations within brackets () refers to the state or company where the product was obtained.

These results are similar to those reported by Leathers (1998), where the corn fiber composition from six studies representing different geographic regions showed that hemicellulose is the predominant constituent in corn fiber, followed by xylose (**Table 7**).

Table 7. Major components of corn fiber.

Component	Geographic location					
	A	B	C	D	E	F
Starch	22	11	18	22	20	23
Hemicellulose	40	53	32	47	29	39
Xylose	24	25	20	28	18	19
Arabinose	16	18	10	19	11	11
Cellulose	12	18	24	ND	14	ND
Protein	12	11	ND	ND	11	12

Consequently, when evaluating the effectiveness of exogenous enzymes, the composition of “fiber” must be considered in order for energy and nutrient digestibility to potentially be improved. This is clearly demonstrated by Li et al., (1996) who evaluated the effectiveness of adding β -glucanase to a broad range of diets, differing largely in β -glucan content. Their data showed that supplementation of β -glucanase had no effect on energy digestibility in wheat-, corn-, or rye-soybean meal diets, but did improve energy digestibility in barley-soybean meal diets (**Table 8**), which reflected the dietary differences in β -glucan concentrations.

Table 8. Effect of β -glucanase supplementation on energy digestibility.

Diet	Diet composition, %			β -glucanase supplementation, %			
	NDF	ADF	β -glucans	0	0.05	0.10	0.20
Barley-SBM	8.4	2.3	3.2	85.2 ^b	87.8 ^{ab}	86.4 ^{ab}	88.5 ^a
Wheat-SBM	7.9	2.5	0.8	86.8	88.1	88.4	88.4
Corn-SBM	8.1	1.9	0.3	85.8	84.4	83.8	85.7
Rye-SBM	7.4	2.1	0.7	87.2	88.0	88.1	87.1

Comparison of the Effectiveness of Commercial Enzyme/Additive Products in Nursery and Finishing Swine Diets on Nutrient Digestibility and Growth Performance

Experimental Procedures

Feed additives (**Table 9**) were selected based on their potential to affect energy and fiber digestion, or their ability to modulate the bacterial ecology within the gastrointestinal tract. The basal diets (**Table 10**) were formulated to be adequate in all nutrients relative to the NRC (1998) recommendation for each specific pig weight category over the 5 wk period, and included 30% dried distillers grains with solubles (DDGS) during each phase of growth. Titanium dioxide was added as an indigestible marker at 0.5% of the diet to determine apparent “nutrient” digestibility by the indirect method: $[1 - ((T_{\text{feed}} \times \text{Nutrient}_{\text{feces}}) / (T_{\text{feces}} \times \text{Nutrient}_{\text{feed}}))] \times 100$. Feed additives were added at the manufacturers recommended rates to each diet. For all additives evaluated

in this study, it was assumed that they contained the active ingredients and the level of activity listed on the product label (**Table 9**).

In the nursery experiment, a total of 192 pigs were used representing 3 groups of 64 pigs (11.9 kg average initial BW). Each group of pigs were randomly allotted to 2 rooms (32 pens/room) and subsequently placed into individual stainless steel pens measuring 0.46 m × 1.22 m. Pigs were individually fed their respective experimental diets over a 5 week feeding period. In the finisher experiment, a total of 96 pigs were used consisting of 2 groups of 48 pigs (98.4 kg average initial BW), which were randomly allotted to 2 rooms (24 pens/room), and subsequently placed into individual galvanized pens measuring 0.57 × 2.21 m. Pigs were individually fed their experimental diets over the 5 week feeding period. In each experiment, pigs were allowed *ad libitum* access to feed and water, and each room was maintained with 24-h lighting, was mechanically ventilated, and had a pull-plug manure storage system. Dietary treatments were randomly assigned to pens, with gender and BW maintained as equal as possible within and between groups. Experimental diets were fed in meal form. Fecal samples were collected at the end of week-1, week-3, and week-5 by collecting freshly voided feces into individual plastic bags and immediately storing samples at 0°C until the end of the trial.

At the end of the trial, diets and feces were dried in a τ forced air oven, weighed, ground through a 1-mm screen, and a subsample was obtained for nutrient analysis. Diet and fecal samples were analyzed in duplicate. Carbon, N, and S were analyzed using thermocombustion (VarioMax, Elementar Analysensysteme GmbH, Hanau, Germany). Acid and neutral detergent fiber was analyzed by method # 8 and #9, respectively, using filter-bag technology (Ankom2000, Ankom Technology, Macedon, NY). Ether extract was analyzed using petroleum ether as described by Luthria et al. (2004) using an ASE 350 (Dionex Corporation, Sunnyvale, CA). Gross energy was determined using an isoperibol bomb calorimeter (Model 1281, Parr Instrument Co., Moline, IL), with benzoic acid used as a standard. Phosphorus was digested with concentrated nitric acid following method (II)A (AMC, 1960) in 1N HCl followed by ICP spectrometry (Optima 5300DV, PerkinElmer, Shelton, CT).

Data were subjected to ANOVA (Proc GLM, SAS Inst. Inc., Cary, NC) with group, room, gender, week, and diet included in the model. There were no week × diet interactions, therefore, only the main effects of diet and week are presented, with means are reported as LSMEANS. In addition, only the pre-planned comparison between pigs fed each feed additive and pigs fed the diet containing no additive are presented. The pig was considered the experimental unit in each experiment.

Trade name	Manufacture	Lot # Date	Activity identification	Stated activity
Allzyme SSF	Alltech, Lexington, KY	215612/460369 2/2/2008	Not provided (NP)	NP
Bactocell	Lallemand Animal Nutrition, Milwaukee, WI	8022202 3/3/2008	<i>Pediococcus acidilactici</i>	10 × 10 ⁹ CFU/g
BioPlus 2B	Chr. Hansen, Milwaukee, WI	2821721 1/31/2008	<i>Bacillus licheniformis</i> and <i>Bacillus subtilis</i>	2.2 × 10 ⁹ CFU/g
Econase XT25	AB Enzymes, Darmstadt, Germany	7855 12/19/2007	Endo-1,4-β-xylanase	160,000 U/g
Hemicel	ChemGen Corp., Gaithersburg, MD	NP NP	Hemicellulase	1.4 × 10 ⁶ U/g
Porzyme 9302	Danisco Animal Nutrition, Marlborough, UK	4320849505 8/11/2008	Xylanase	8,000 U/g
Releaz-a-zyme 4M	Prince Agri Products Inc., Quincy, IL	31-2047 5/6/2008	β-glucanase Protease	440 U/g 11 U/g
Rovabio AP10%	Adisseo, Antony, France	NP NP	Endo-1,4-β-xylanase Endo-1,3(4)- β-glucanase	2,200 U/g 200 U/g
Roxazyme G2 G	DSM Nutritional Products Inc., Parsippany, NJ	NP NP	Endo-1,4-β-glucanase Endo-1,3(4)- β-glucanase Endo-1,4-β-xylanase	8,000 U/g 18,000 U/g 26,000 U/g
XPC yeast	Diamond V Mills Inc., Cedar Rapids, IA	300308 NP	<i>Saccharomyces cerevisiae</i> yeast culture	NP

Ingredient	Starter	Finisher
Corn	41.69	61.98
Soybean meal	16.94	4.85
Dried distillers grains with solubles	30.00	30.00
Whey, dried	5.00	-
Fish meal	2.50	-
Soybean oil	0.52	-
Dicalcium phosphate (21%P)	0.34	-
Limestone	0.96	1.11
Sodium chloride	0.35	0.35
Vitamin mix ¹	0.30	0.25
Trace mineral mix ²	0.11	0.10
L-lysine-HCl	0.27	0.33
L-tryptophan	0.02	0.03
Dehulled, degermed corn	0.45	0.475
Antibiotic ³	0.05	0.025
Titanium dioxide	0.50	0.50
TOTAL	100.00	100.00

¹Provided the following per kilogram of starter and finisher diet, respectively: vitamin A, 6,614/5,512 IU; vitamin D₃, 1,653/1,378 IU; vitamin E, 33/28 IU; vitamin B₁₂, 0.033/0.028 mg; riboflavin, 10/8 mg; niacin, 50/41 mg; pantothenic acid, 26/22 mg.

²Provided the following per kilogram of starter and finisher diet, respectively: Cu (oxide), 11/9 mg; Fe (sulfate), 105/88 mg; I (Cal), 1.2/1.0 mg; Mn (oxide) 36/30 mg; Zn (oxide), 90/75 mg; Se (Na₂SeO₃), 0.3 mg.

³Tylosin premix.

Results and Discussion

Nursery pigs

In the starter experiment, most nutrient digestibility coefficients were unaffected by the addition of enzymes, yeast, or microbial cultures (**Table 11**). At the time of writing this manuscript, determinations of P digestibility were not completed. Nitrogen and S digestibility were improved by Roxazyme addition, but other nutrients were unaffected. In a similar manner, Rovabio and BactoCel both improved S digestibility, but all other nutrients were unaffected by their addition. It is unclear what, if any, value improved S digestibility may provide in these diets. In contrast, Porzyme and Hemicel decreased NDF digestibility, but did not affect other nutrient digestibility coefficients. This was an unexpected result since the product labels for these additives indicated the presence of enzymes that should be effective for improving digestibility of corn fiber. Supplementation of Econase, Allzyme, and Releezyme decreased the digestibility of various nutrients. However, regardless of positive or negative impact that enzymes, yeast, or microbial cultures had on the digestibility of various nutrients, there was no impact on pig performance (**Table 13**). Digestibility of GE, N, C, S, ADF, NDF and ether extract increased from week-1 to week-5 ($P < 0.01$). These results suggest that the gastrointestinal tract of the 12 kg pig adapts to dietary fiber from DDGS and nutrient digestibility improves with continuous feeding over time. This finding is consistent with the increased ability of the digestive system in growing pigs to digest nutrients (especially fiber) with increasing age.

Finisher pigs

In the finisher experiment, little impact of enzymes, yeast, or microbial cultures were noted on most nutrient digestibility coefficients (**Table 12**). Improvements in digestibilities were noted for the addition of Roxazyme (ether extract), Allzyme (ADF and NDF), and BioPlus2B (ADF), but the digestibilities of all other nutrients were unaffected. However, the improvement in fiber digestibility from adding Allzyme and BioPlus2B did not result in improved gross energy digestibility. Supplementation of Porzyme, Hemicel, Releezyme, XPC yeast and BactoCel exhibited negative impacts on digestibility of various nutrients. Unlike the nutrient digestibility responses observed for starter pigs, nutrient digestibility did not improve from week-1 to week-5. At the time of writing this manuscript, determinations of P digestibility were not completed. Similar to the results of the starter trial, there was no impact of enzymes, yeast, or microbial cultures on pig performance (**Table 14**).

Many of the enzyme/additive products evaluated in this study contained ingredients that should have been effective in for improving energy/fiber digestibility in 30% DDGS diets. Since we did not confirm the specified enzyme/active ingredient activity for these additives, it may be possible that they did not contain enough activity to provide significant improvements in digestibility for many of the nutrients evaluated. Another possible reason for the lack of growth performance and notable nutrient digestibility responses may have been due to the source of DDGS included in the diet. Urriola et al. (2010) showed that apparent total tract digestibility of dietary fiber can range from 23 to 55% among DDGS sources. Perhaps the DDGS source used in this study was low in digestible fiber, and therefore, the ability of the products evaluated to affect nutrient digestibility could not be achieved. Finally, since these diets were formulated to meet the

nutrient needs of pigs in each growth phase evaluated, the improvements or decreases in nutrient digestibility that did occur were too small to influence overall pig performance.

Table 11. Apparent nutrient digestibility (%) of starter pigs fed exogenous feed additives.¹

Treatment ²	GE	N	C	S	P	ADF	NDF	EE
Control	79.2	79.9	79.9	78.5	NA	40.1	36.6	64.2
Roxazyme	79.6	81.1	80.3	79.9	NA	38.8	39.1	63.3
<i>P value</i> ³	0.40	0.10	0.42	0.06	NA	0.58	0.16	0.61
Porzyme	79.0	79.4	79.7	78.8	NA	36.3	33.2	64.9
<i>P value</i> ³	0.67	0.47	0.61	0.66	NA	0.13	0.07	0.67
Econase	78.3	78.7	79.1	77.0	NA	35.6	32.5	62.8
<i>P value</i> ³	0.07	0.07	0.10	0.04	NA	0.06	0.03	0.45
Rovabio	80.0	80.7	80.7	79.9	NA	38.1	36.5	64.4
<i>P value</i> ³	0.12	0.25	0.14	0.06	NA	0.39	0.97	0.88
Hemicel	78.9	79.0	79.6	79.0	NA	36.3	33.4	65.5
<i>P value</i> ³	0.53	0.17	0.48	0.49	NA	0.12	0.09	0.45
Allzyme	76.5	77.6	77.4	77.5	NA	30.6	27.3	61.5
<i>P value</i> ³	0.01	0.01	0.01	0.17	NA	0.01	0.01	0.14
Releezyme	76.9	77.4	77.7	77.3	NA	30.0	29.9	61.1
<i>P value</i> ³	0.01	0.01	0.01	0.09	NA	0.01	0.01	0.08
XVC yeast	79.6	80.1	80.3	79.4	NA	39.0	36.4	65.9
<i>P value</i> ³	0.40	0.81	0.46	0.26	NA	0.63	0.95	0.33
BactoCel	80.0	80.4	80.3	80.1	NA	39.4	39.3	64.9
<i>P value</i> ³	0.14	0.55	0.42	0.03	NA	0.76	0.15	0.66
BioPlus2B	79.5	80.3	80.0	79.6	NA	37.7	35.0	65.0
<i>P value</i> ³	0.59	0.64	0.85	0.17	NA	0.31	0.39	0.64
<i>P value</i> ⁴	0.01	0.01	0.01	0.01	NA	0.01	0.01	0.08
SE ⁴	0.35	0.48	0.34	0.52	NA	1.714	1.318	1.221
Wk-1 ⁵	76.9	76.0	77.6	75.4	NA	31.4	28.5	70.6
Wk-3	79.2	80.1	79.8	79.3	NA	36.2	35.8	61.9
Wk-5	80.5	82.4	81.2	81.8	NA	42.0	39.1	59.4
<i>P value</i> ⁶	0.01	0.01	0.01	0.01	NA	0.01	0.01	0.01
SE ⁶	0.18	0.25	0.18	0.27	NA	0.93	0.69	0.64

¹ Apparent digestibility calculated using indirect marker methodology. There were 16 to 18 individually fed pigs per dietary treatment.

² Roxazyme G2, 200 g/T (DSM Nutritional Products Inc., Parsippany, NJ); Porzyme 9302, 227 g/T (Danisco Animal Nutrition, Marlborough, UK); Econase XT25, 136 g/T (AB Enzymes, Darmstadt, Germany); Rovabio AP10, 454 g/T (Adisseo, Antony, France); Hemicel, 454 g/T (ChemGen Corp., Gaithersburg, MD); Allzyme SSF, 454 g/T (Alltech, Lexington, KY); Release, 454 g/T (Prince Agri Products Inc., Quincy, IL); XPC Yeast, 1,816 g/T (Diamond V Mills Inc., Cedar Rapids, IA); BactoCel, 100 g/T (Lallemand Animal Nutrition, Milwaukee, WI); BioPlus 2B, 454 g/T (Chr. Hansen, Milwaukee, WI).

³ 'P value' represents comparison of the feed additive to the control diet.

⁴ Model P and SE value for overall diet effect.

⁵ Initial, wk-1, wk-3, and wk-5 BW of 11.88, 13.96, 23.23, and 33.26 kg, respectively.

⁶ Model P and SE value for week.

Table 12. Apparent nutrient digestibility (%) of finisher pigs fed exogenous feed additives.¹

Treatment ²	GE	N	C	S	P	ADF	NDF	EE
Control	81.4	83.8	82.3	82.7	NA	52.9	42.1	46.5
Roxazyme	80.9	81.9	81.7	81.9	NA	49.8	38.1	49.9
<i>P value</i> ³	0.45	0.12	0.35	0.27	NA	0.15	0.14	0.08
Porzyme	79.4	80.9	80.4	80.1	NA	43.8	34.0	44.4
<i>P value</i> ³	0.01	0.01	0.01	0.01	NA	0.01	0.01	0.28
Econase	80.8	82.7	81.8	83.1	NA	50.8	42.0	46.7
<i>P value</i> ³	0.40	0.15	0.45	0.55	NA	0.33	0.95	0.82
Rovabio	81.3	83.7	82.3	82.8	NA	52.7	43.5	45.5
<i>P value</i> ³	0.98	0.92	0.96	0.88	NA	0.93	0.62	0.62
Hemicel	80.7	82.8	81.6	82.4	NA	48.3	37.4	44.3
<i>P value</i> ³	0.30	0.20	0.27	0.74	NA	0.03	0.08	0.25
Allzyme	82.1	84.2	83.00	83.3	NA	56.6	46.9	48.1
<i>P value</i> ³	0.27	0.61	0.29	0.38	NA	0.08	0.08	0.41
Releezyme	79.5	80.7	80.4	79.9	NA	50.0	35.4	38.1
<i>P value</i> ³	0.01	0.01	0.01	0.01	NA	0.18	0.02	0.01
XVC yeast	80.1	82.5	81.1	82.1	NA	50.1	38.4	43.1
<i>P value</i> ³	0.05	0.10	0.05	0.36	NA	0.19	0.18	0.08
BactoCel	80.8	82.3	82.0	82.4	NA	50.1	39.5	49.6
<i>P value</i> ³	0.40	0.05	0.57	0.73	NA	0.19	0.34	0.11
BioPlus2B	81.7	83.2	82.7	82.6	NA	56.3	45.4	38.6
<i>P value</i> ³	0.58	0.46	0.49	0.91	NA	0.10	0.23	0.01
<i>P value</i> ⁴	0.01	0.01	0.01	0.01	NA	0.01	0.01	0.01
SE ⁴	0.45	0.55	0.45	0.47	NA	1.50	1.95	1.38
Wk-1 ⁵	80.6	82.3	81.5	81.7	NA	50.7	40.1	45.3
Wk-3	80.8	82.5	81.8	82.3	NA	51.7	40.5	44.9
Wk-5	81.0	83.0	82.0	82.3	NA	50.8	40.2	44.8
<i>P value</i> ⁶	0.43	0.17	0.39	0.17	NA	0.62	0.96	0.89
SE ⁶	0.24	0.30	0.24	0.25	NA	0.80	1.04	0.73

¹ Apparent digestibility calculated using indirect marker methodology. There were 8 individually fed pigs per dietary treatment.

² Roxazyme G2, 200 g/T (DSM Nutritional Products Inc., Parsippany, NJ); Porzyme 9302, 227 g/T (Danisco Animal Nutrition, Marlborough, UK); Econase XT25, 136 g/T (AB Enzymes, Darmstadt, Germany); Rovabio AP10, 454 g/T (Adisseo, Antony, France); Hemicel, 454 g/T (ChemGen Corp., Gaithersburg, MD); Allzyme SSF, 454 g/T (Alltech, Lexington, KY); Release, 454 g/T (Prince Agri Products Inc., Quincy, IL); XPC Yeast, 908 g/T (Diamond V Mills Inc., Cedar Rapids, IA); BactoCel, 100 g/T (Lallemand Animal Nutrition, Milwaukee, WI); BioPlus 2B, 454 g/t (Chr. Hansen, Milwaukee, WI).

³ 'P value' represents comparison of the feed additive to the control diet.

⁴ Model P and SE value for overall diet effect.

⁵ Initial, wk-1, wk-3, and wk-5 BW of 98.40, 104.90, 119.52, and 132.20 kg, respectively.

⁶ Model P and SE value for week.

Treatment ²	Starter, 12 – 33 kg BW			Finisher, 98 – 132 kg BW		
	ADG, kg	ADFI, kg	G:F	ADG, kg	ADFI, kg	G:F
Control	0.640	1.126	0.572	0.999	3.032	0.333
Roxazyme	0.638	1.100	0.583	0.975	3.084	0.321
Porzyme	0.642	1.131	0.570	0.979	3.077	0.318
Econase	0.653	1.133	0.578	1.051	3.240	0.325
Rovabio	0.648	1.148	0.565	0.906	2.985	0.302
Hemicel	0.629	1.149	0.551	0.933	3.239	0.292
Allzyme	0.651	1.140	0.574	0.961	3.118	0.311
Relezyme	0.639	1.109	0.579	0.983	3.115	0.311
XVC yeast	0.653	1.157	0.568	0.862	2.930	0.294
BactoCel	0.615	1.083	0.568	1.007	3.084	0.328
BioPlus2B	0.645	1.162	0.559	0.988	3.179	0.315
<i>P value</i>	0.87	0.70	0.72	0.60	0.90	0.56
SE	0.016	0.030	0.011	0.057	0.141	0.014

¹ Performance over the 5-wk period. There were 16-18 and 8 individually fed pigs per treatment in the starter and finisher phase, respectively.

² Roxazyme G2, 200 g/T (DSM Nutritional Products Inc., Parsippany, NJ); Porzyme 9302, 227 g/T (Danisco Animal Nutrition, Marlborough, UK); Econase XT25, 136 g/T (AB Enzymes, Darmstadt, Germany); Rovabio AP10, 454 g/T (Adisseo, Antony, France); Hemicel, 454 g/T (ChemGen Corp., Gaithersburg, MD); Allzyme SSF, 454 g/T (Alltech, Lexington, KY); Release, 454 g/T (Prince Agri Products Inc., Quincy, IL); XVC Yeast, 1,816 g/T starter or 908 g/T finisher (Diamond V Mills Inc., Cedar Rapids, IA); BactoCel, 100 g/T (Lallemand Animal Nutrition, Milwaukee, WI); BioPlus 2B, 454 g/T (Chr. Hansen, Milwaukee, WI).

Conclusions

Application of enzymes in an effort to improve nutrient digestibility of plant-based feed ingredients for swine and poultry has been studied for decades. However, with a large diversity and concentration of chemical characteristics existing among plant-based feed ingredients, improvements in nutrient digestibility and pig performance from adding exogenous enzymes to growing pig diets depends on understanding these characteristics in relation to enzyme activity. Essentially, the enzyme must match the target substrate(s), there may need to be a 'cocktail' of enzymes to effectively breakdown the complex matrixes of fibrous carbohydrate structures, and there must be some negative role that these substrates have on nutrient digestibility or voluntary feed intake. With the inverse relationship between fiber content and energy digestibility being well described for several feed ingredients, it is only logical that development of enzymes that degrade fiber, and thereby improve energy digestibility or voluntary feed intake will have a high chance to be beneficial, both metabolically and economically. The results of our study suggest that some of the enzyme/additive products evaluated had variable, but small effects on nutrient digestibility, but none of these products were effective in improving starter and finishing pig growth performance when fed nutritionally adequate corn-soy diets containing 30% DDGS.

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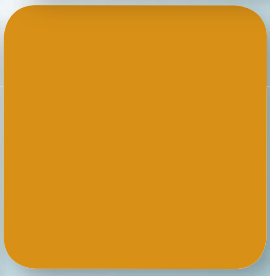
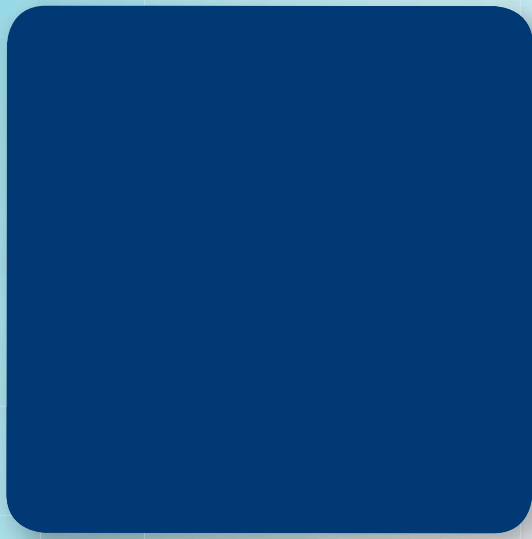
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CHAPTER 25

Use of DDGS in Aquaculture Diets



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Introduction

Aquaculture is one of the fastest growing food producing industries in the world. Historically, fish meal has been used as major component in most aquaculture diets because of its high protein content, well-balance profile of highly digestible amino acids, significant amounts of essential fatty acids, high digestible energy content, as well as its vitamin and mineral content (Abdelghany, 2003). However, the decreased availability of fish meal and increasing cost have caused nutritionists and feed manufacturers to seek less expensive, high quality alternative ingredients, primarily plant-based meals, to partially or completely replace fish meal in aquaculture feeds. Unfortunately, replacement of fish meal with plant-based feed ingredients often results in reduced growth performance (Mbahinzirek et al., 2001; Sklan et al., 2004; Gatlin et al., 2007), unless an adequate amount of other ingredients or dietary supplements are added to these diets in order to meet nutrient requirements, especially amino acids. However, when two or more complimentary plant protein sources (DDGS and soybean meal) are added to the diet, the potential exists to replace all of the fish meal in the diet. Therefore, one of the biggest challenges limiting the successful use of alternative plant-based ingredients in aquaculture feeds is having knowledge of amino acid composition and digestibility.

Aquaculture, like livestock and poultry production around the world, is also subject to increasing environmental regulations. The two nutrients of greatest concern in fish farm effluent water are nitrogen and phosphorus. Soybean meal and DDGS are relatively high in protein, but much lower in phosphorus than fish meal. As a result, substituting DDGS and soybean meal for fish meal in aquaculture diets reduces the total phosphorus level in the diet and lowers the level of phosphorus in fish farm discharge water.

Nutritional Value of DDGS in Aqua Feeds

Corn DDGS is a high energy, mid-protein, high digestible phosphorus ingredient. However, nutrient content and digestibility can vary significantly among sources (Spiehs et al., 2002). Most of the energy in DDGS is derived from its relatively high crude fat content, with lesser amounts contributed from residual starch, fiber, and protein.

The crude fat content of DDGS is approximately 10% (as fed-basis), and approximately 55.7, 7.8, 0.14 % of total fat is linoleic acid, linolenic acid, and DHA, respectively. As a result, DDGS has a high omega 6 to omega 3 ratio. During the past two years, over 50% of the 207 ethanol plants in the U.S. are now extracting some of the oil before making DDGS because of the high profitability of marketing crude corn oil. Therefore, the crude fat content of DDGS has become more variable (5 to 12%), and reduced-oil DDGS will result in reduced digestible energy value.

Starch content in DDGS is low and can range from 1.1 to 7.9 % (dry matter basis) depending on the extent of starch fermentation to ethanol (Anderson et al., 2012). It is not known if the starch present in DDGS is digestible or in the form of resistant starch.

The average values of crude fiber, ADF, NDF, and TDF content in DDGS are 6.6, 11.1, 37.6, and 31.8% respectively, and the majority (96.5%) of TDF is insoluble fiber (Urriola et al., 2010). Neutral detergent fiber content is one of the most variable nutritional components in DDGS and it is unclear whether this is due to high variability in analytical measurement among laboratories or if maize fiber content truly is this variable among DDGS sources. Fiber digestibility of DDGS has not been determined in fish, but studies conducted with other monogastric species indicate that fiber digestibility can be significant, but variable. It appears that fish with greater ability to utilize high fiber diets perform well at high dietary DDGS inclusion rates compared with some species with very little lower gut fermentation.

Despite the relatively high crude protein content in DDGS (27%), lysine, methionine, threonine, and tryptophan concentrations are relatively low relative to the amino acid requirements of fish. Furthermore, lysine is the most variable of all amino acids among DDGS sources, and its digestibility is also variable due to the extent of heating during the DDGS production process among sources. As a result, fish diets requiring high protein levels must be supplemented with crystalline amino acids when significant amounts of DDGS are added. Apparent digestibility of amino acids in DDGS have been determined in rainbow trout diets, and are relatively high (> 90% for all essential amino acids except threonine), but amino acid digestibility has not been determined for other fish species (Cheng and Hardy, 2004a).

The phosphorus content in DDGS (0.75%) is higher than other plant-based ingredients, and much of the phytate phosphorus is released during corn fermentation in ethanol production, making it highly digestible for monogastric species (Stein and Shurson, 2009). However, DDGS phosphorus digestibility and availability values have not been determined in fish.



Vitamins, including riboflavin, niacin, pantothenic acid, folic acid, and choline are about three times higher in DDGS than found in corn (Hertrampf and Piedad-Pascual, 2000). Macrominerals such as calcium, chlorine, and potassium are found in low amounts in DDGS relative to fish requirements and must be supplemented (Hertrampf and Piedad-Pascual, 2000).

Furthermore, zinc, iron, manganese, and copper concentrations in DDGS are lower than typically found in fish meal, but requirements can easily be met with diet supplementation of these micronutrients. Limited data are available regarding the xanthophyll content and

bioavailability in DDGS, or its impact on flesh color in fish, but the few values reported in the literature indicate that it can be highly variable and range from 3.5 to 29.8 mg/kg.

One of the distinct advantages of DDGS compared with other plant-based ingredients is that it does not contain anti-nutritional factors found in soybean meal (trypsin inhibitors; Wilson and Poe, 1985; Shiau et al., 1987), rapeseed meal (glucosinolates and erucic acid), and cottonseed meal (gossypol; Jauncey and Ross, 1982; Robinson, 1991), and contains low levels of phytate compared with other plant derived feed ingredients.

Channel Catfish (*Lctalurus punctatus*)

Tidwell et al. (1990) conducted an experiment over an 11-week period where channel catfish fingerlings were fed diets containing 0, 10, 20, and 40% DDGS by replacing some of the corn and soybean meal. After the 11-week feeding period, there were no significant differences in individual fish weight, percentage survival, feed conversion, or protein efficiency ratio (PER) among dietary treatments (**Table 1**). However, fish fed the 20% DDGS diet were slightly shorter in length compared to fish fed the other dietary treatments.

Table 1. Length, survival, final body weight, feed conversion, and protein efficiency ratio (PER) in channel catfish fingerlings fed diets containing four levels of distillers grains with soluble (DDGS).

	0% DDGS	10% DDGS	20% DDGS	40% DDGS
Length, mm	115.2	114.1	107.4	117.8
Survival, %	67.5	70.0	80.0	90.0
Final body weight, g	17.3	15.2	13.2	16.5
Feed/gain	2.85	3.23	3.20	2.60
PER	0.99	0.87	0.88	1.05

In a study conducted by Webster et al. (1993), cage reared juvenile catfish were fed diets containing 0, 10, 20, or 30% DDGS which partially replaced corn and soybean meal in the diets. There were no differences in individual fish weights, survival, feed conversion, carcass composition, carcass waste (head, skin, viscera), and organoleptic properties of the fillets among dietary treatments. Results from this study indicate that up to 30% DDGS can be added to channel catfish diets with no negative effects on growth performance, carcass composition, or flavor qualities of the fillets. Therefore, DDGS is considered an acceptable ingredient in diets for channel catfish (Tidwell et al., 1990; Webster et al., 1991).

Robinson and Li (2008) conducted two experiments to evaluate the use of cottonseed meal, DDGS, and synthetic lysine as replacements for soybean meal in channel catfish diets. Fish fed the DDGS and soybean meal diet had higher (experiment 1) or similar (experiment 2) weight gain, and feed conversion ratio was lower in both experiments, than fish fed the control diets. Body fat tended to increase for fish fed the DDGS and soybean meal diet compared to fish fed the control diet. Results from this study suggest that adding up to 30% DDGS to channel catfish diets supports satisfactory growth performance when the diet is supplemented with synthetic lysine.

Diets containing 0, 10, 20, 30, and 40% DDGS with supplemental synthetic lysine to partially replace soybean meal and corn meal on an equal protein basis were fed to juvenile catfish (13 g body weight) for 12 weeks (Lim et al., 2009). Growth performance and feed conversion were similar among dietary treatments, but body fat increased and body moisture decreased when fish were fed diets containing DDGS compared to those fed the control diet.

Similarly, Zhou et al. (2010) replaced soybean meal and maize meals in juvenile hybrid catfish (channel catfish × blue catfish *I. Furcatus*) and observed that diets containing 30% DDGS provided good growth, feed conversion, and protein retention. Overall, the results of these studies indicate that relatively high (30%) dietary inclusion rates of DDGS can be used without adversely affecting survival growth or feed conversion.

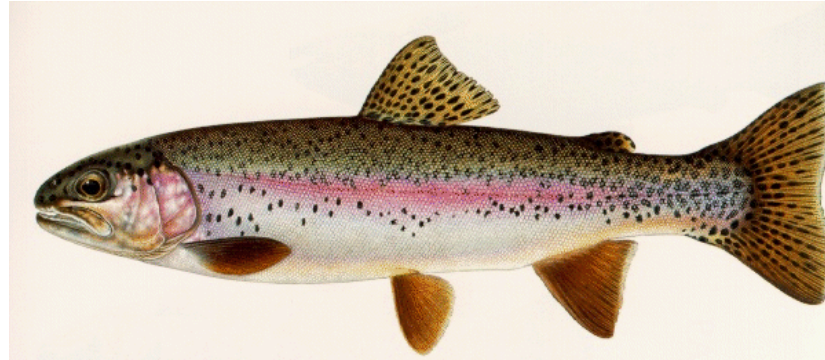


Rainbow Trout (*Oncorhynchus mykiss*)

Feed for carnivorous fish like rainbow trout (*Oncorhynchus mykiss*) requires large amounts of fish meal (300 to 500 g/kg diet). As a result, when fish meal prices are high, nutritionists begin evaluating alternative protein sources such as DDGS to use as partial replacements for fishmeal.

Cheng and Hardy (2004a) reported they had unpublished data indicating apparent digestibility coefficients of nutrients in DDGS were high for rainbow trout. Apparent digestibility coefficients for crude protein (90.4%), essential amino acids (> 90% except for threonine which was 87.9%), and non-essential amino acids (> 86% except for cystine which was 75.9%) for the DDGS source they evaluated. However, they pointed out one of the limitations of using DDGS in rainbow trout diets is the relatively low concentration of lysine and methionine, which are much lower than found in fish meal. Therefore, supplemental synthetic lysine and methionine is

necessary in order to achieve satisfactory growth performance. As a result, Cheng and Hardy (2004a) conducted a 6-week feeding trial to determine the effects of feeding diets containing 0, 7.5, 15, and 22.5% DDGS, with or without synthetic lysine and methionine supplementation, to assess the nutritional value of DDGS in diets for 50 g rainbow trout. Survival rate of all fish used in the study was 100%. Fish fed diets containing 15% DDGS, or replacing 50% of fish meal on an isonitrogenous and isocaloric basis, had similar weight gain and feed conversion compared to fish fed the fish meal-based diet. These results indicate that DDGS, without synthetic lysine and methionine supplementation, can be added to the diet up to 15%, or replace up to 50% of the fish meal to achieve satisfactory growth performance. In addition, DDGS could be used at the 22.5% dietary inclusion level, or replace up to 75% of the fish meal in rainbow trout diets with lysine and methionine supplementation. Furthermore, Cheng et al. (2003) showed that when soybean meal, DDGS, and 1.65 g/kg of methionine hydroxyl analogue (MHA) were added to rainbow trout (50 g in initial body weight) diets to replace 50% of the fish meal, weight gain, feed conversion, crude protein, and phosphorus retention were significantly improved compared to fish fed an equivalent diet without MHA supplementation.



Cheng and Hardy (2004b) also evaluated the effects of phytase supplementation on apparent digestibility coefficients of nutrients in DDGS, as well as growth performance and apparent nutrient retention of rainbow trout fed diets containing

DDGS, phytase, and varying levels of a trace mineral premix. Apparent digestibility coefficients in DDGS diets (30% inclusion rate) containing different levels of phytase (0, 300, 600, 900, and 1200 FTU/kg of diet) ranged from 49 to 59% for dry matter, 79 to 89% for crude fat, 80 to 92% for crude protein, 51 to 67% for gross energy, 74 to 97% for amino acids, and 7 to 99% for minerals. When DDGS was included at a rate of 15% of the diet, and supplemented with lysine, methionine, and phytase, but different levels of trace mineral premix, there were no differences in weight gain, feed conversion, survival, body composition, and apparent nutrient retention among fish fed all diets, except for fish fed a diet without trace mineral supplementation. These results suggest that phytase was effective in releasing most of the minerals, and that trace mineral supplementation could be reduced when phytase is added to rainbow trout diets.

Stone et al. (2005) evaluated the effects of extrusion on nutritional value of diets containing corn gluten meal and corn DDGS for rainbow trout and observed that the extent of fish meal replacement in the diet depends upon the ratio of DDGS to corn gluten meal used. Their results suggest that up to 18% dietary inclusion of these corn co-products could replace about 25% of the fish meal in practical diets without negatively affecting growth performance. They also found that extrusion of diets containing corn DDGS and corn gluten meal was of no benefit compared to feeding cold-pelleted diets.

Tilapia (*Oreochromis niloticus*)

Tilapia (*Oreochromis niloticus*) are one of the most popular warm water fish grown throughout the world. Wu et al. (1994) reported diets containing either maize gluten meal (18%) or DDGS (29%), and 32% or 36% crude protein, resulted in higher weight gains for tilapia (initial weight of 30 g) than fish fed a commercial fish feed containing 36% crude protein and fish meal. In a subsequent study, Wu et al. (1996) evaluated the growth responses over an 8-week feeding period for smaller tilapia (0.4 g initial weight) by feeding diets containing up to 49% DDGS, up to 42% maize gluten feed, or up to 22% maize gluten meal, at dietary crude protein levels of 32%, 36%, and 40%. Of the eight diets fed, the highest weight gain was achieved by feeding the 36% protein commercial control diet and the 40% protein diet containing 35% DDGS. The highest feed conversion was achieved by feeding the control diet (1.05) and two 40% protein diets containing either 35% DDGS (1.13) or 30% gluten feed (1.12). The highest protein efficiency ratio (weight gain/protein fed) was obtained by feeding the control diet (3.79) and two 36% protein diets containing 49% DDGS (3.71) or 42% corn gluten feed (3.55). From these results, these researchers concluded that feeding diets containing 32%, 36%, and 40% protein, and 16 to 49% protein-rich ethanol co-products will result in good weight gain, feed conversion, and protein efficiency ratio for tilapia fry.

When using DDGS in aquaculture diets, it is also important to know if lower protein diets containing higher amounts of maize co-products (DDGS, gluten feed, gluten meal) and synthetic amino acids can support satisfactory growth performance. Wu et al. (1997) evaluated growth performance of tilapia fry (0.5 g initial weight) over an 8-week feeding period by feeding diets containing 28 or 32% protein, synthetic lysine and tryptophan, and 54 to 92% maize co-products. There were no differences in feed conversion (1.76 vs. 1.43) and protein efficiency ratio (1.82 vs. 2.21) among fish fed the 28% protein diet containing 82% DDGS and synthetic lysine and tryptophan, the 67% gluten feed and 26% soy flour diet, and fish fed the control 32% protein diet (FCR = 1.25, PER = 2.05). Based upon these results, DDGS and other maize co-products can be successfully used, along with synthetic amino acid supplementation, to formulate all plant-based diets and replace all of the fish meal when feeding juvenile tilapia.

Tidwell et al. (2000) evaluated growth, survival, and body composition of cage-cultured Nile tilapia fed pelleted and unpelleted DDGS diets in polyculture with freshwater prawn. Growth rate was higher for fish fed the pelleted DDGS diet than for fish fed the unpelleted DDGS diet, but feeding a commercial catfish diet resulted in increased individual weight, individual length, growth rate, and feed conversion compared to fish fed the pelleted or unpelleted DDGS diets. Although growth was significantly increased for fish fed the commercial diet, the cost of production was significantly higher (\$0.66/kg gain) compared to fish fed the unpelleted and pelleted DDGS diets (\$0.26/kg gain and \$0.37/kg gain, respectively). Production of prawn was 1,449 kg/ha and adding tilapia in polyculture increased total pond productivity by 81%. These researchers concluded that feeding DDGS provided economical growth of tilapia and that polyculture of tilapia may improve overall pond efficiency in freshwater prawn production ponds in temperate climates.



Juvenile Nile tilapia (9.4 g in body weight) were fed diets containing 0, 10, 20, 40% DDGS, and 40% DDGS with supplemental synthetic lysine, as partial replacements for soybean meal and corn meal, for 10 weeks, and challenged with *Streptococcus iniae* (Lim et al., 2007). Fish fed the 40% DDGS diet had the lowest weight gain, protein efficiency ratio, whole body protein, and poorest feed conversion, but supplementing the 40% DDGS diet with synthetic lysine improved weight gain and protein efficiency ratio. Feeding diets containing DDGS had no effect on number of days to first mortality, cumulative mortality 14 days post-challenge, or on hematological and immunological parameters. The authors concluded that up to 20% DDGS can be added to the diet as a partial substitute for soybean meal and corn meal without affecting growth performance, body composition, hematology, immune response, and resistance to a *Streptococcus iniae* infection.

Abo-State et al. (2009) replaced soybean in increments between 0 and 100% with DDGS in diets, with or without phytase, and fed them to Nile tilapia (2 g initial body weight). They observed the best growth rate and feed conversion in diets containing 0%, 25%, and 50% DDGS with phytase. Schaeffer et al. (2009) conducted two trials to evaluate the use of DDGS in diets for tilapia (35 g initial body weight). Feeding diets containing 0%, 17.5%, 20%, 22.5%, 25%, and 27.5% DDGS to partially replace fish meal resulted in no difference in apparent digestibility among diets, but weight gain, feed conversion, and protein efficiency ratio (PER) were highest for fish fed the 0% DDGS diet, except the 17.5% DDGS diet which provided better feed conversion and PER. In the second, trial, Nile tilapia were fed 20%, 25%, and 30% DDGS diets with or without a probiotic, and no differences were found for weight gain, feed conversion, or PER among dietary treatments.

Results from these studies indicate that DDGS can be a highly economical feed ingredient in tilapia diets, and can be successfully be used at relatively high dietary inclusion rates if appropriate supplementation of amino acids is done.

Sunshine bass (*Morone chrysops* x *M-saxatilis*)

A recent study conducted by Thompson et al. (2008) evaluated digestibility of dry matter, protein, lipid, and organic matter of two fish meals, two poultry by-product meals, soybean meal, and DDGS in practical diets for sunshine bass. Fish fed DDGS had the lowest apparent digestibility coefficients for protein (65%) and organic matter (17%) compared to menhaden fish meal, which had the highest protein and organic matter digestibility coefficients (86 and 89%, respectively). The quality of the DDGS source used was not defined, but was likely of inferior quality due to the poor protein and organic matter digestibility observed in this study. These results are in contrast to results of several other studies described for other species previously where DDGS inclusion in diets provided satisfactory performance, and indicate that only high quality DDGS sources should be used in aquaculture feeds in order to achieve satisfactory growth performance and nutrient digestibility.

Freshwater Prawns (*Macrobrachium rosenbergii*)

A few studies have been conducted on feeding diets containing DDGS to freshwater prawns. In an initial study, Tidwell et al. (1993a) fed juvenile freshwater prawns (0.66 g) one of three isonitrogenous diets (29% crude protein) containing 0, 20, or 40% DDGS. There were no differences among dietary treatments for average yield (833 kg/ha), survival (75%), individual weight (57 g) and feed conversion (3.1). These results show that levels of up to 40% DDGS can be included in practical diets for prawns stocked at a density of 19,760/ha to achieve good performance.

In a subsequent study, Tidwell et al. (1993b) evaluated the effects of partially replacing fish meal with soybean meal and DDGS in diets for pond-raised freshwater juvenile prawns (0.51 g). Three diets were formulated to contain 32% crude protein and contained 15, 7.5, or 0% fish meal. Fish meal was replaced with a variable percentage of soybean meal and a fixed percentage of DDGS (40%). There were no differences among dietary treatments for average yield, survival, individual weight, and feed conversion. They noted that replacement of fish meal with soybean meal and DDGS increased dietary levels of glutamine, praline, alanine, leucine, and phenylalanine, and decreases in aspartic acid, glycine, arginine, and lysine levels in the diets. Fatty acid profiles of the diets also changed when soybean meal and DDGS replaced fish meal. Concentrations of 16:0, 18:2 n -6, and 20:1 n -9 increased and concentrations of 14:0, 16:1 n -7, 18:1 n 9, 18:3 n -3, 20:5 n -3, 22:5 n -3 and 22:6 n -3 decreased. These results suggest that fish meal can be partially or totally replaced with soybean meal and DDGS in diets for freshwater prawns raised in ponds in temperate areas. Coyle et al. (1996) showed DDGS can be consumed directly by juvenile prawn (> 2 g), and that DDGS may serve a dual role as feed and a pond fertilizer.

Pacific White Shrimp (*Litopenaeus vannamei*)

A study was conducted in the low salinity inland waters in west Alabama to determine the value of replacing fish meal (10%) with poultry meal, pea meal, or DDGS in shrimp diets on a weight basis (Lim et al., 2009). No differences were observed among dietary treatments for growth rate, survival, and feed conversion, indicating that poultry meal, pea meal, and DDGS can successfully replace fish meal as a protein source for shrimp grown in low salinity water.

Potential health benefits of DDGS

Addition of DDGS to aqua feeds appears to have beneficial effects on improving the immune status and resistance to some diseases in fish. Lim and co-workers (2009) have shown that feeding diets containing 40% DDGS to channel catfish provided resistance to *Edwardsiella ictaluri* which was likely due to increased hemoglobin and hematocrit, increased total serum immunoglobulin, and increased antibody titers 21 day post-challenge. Similarly, Lim et al. (2007) showed that feeding 40% DDGS diets to Nile tilapia (*Oreochromis niloticus*) improved resistance to *Streptococcus iniae*. Researchers have presumed that the factors contributing to these positive responses are biologically active compounds derived from yeast, which

comprises approximately 4 to 7% of DDGS. Limited data have been published on the levels of these compounds in DDGS, but the β -glucan content of DDGS is approximately 8%.

Extrusion of DDGS diets

In general, high levels of fiber in DDGS are problematic, especially at high dietary concentrations. Researchers have determined that the most critical factors affecting extrusion and pellet quality of DDGS diets are die geometry, temperature, moisture content, and screw speed. Addition of various binding materials improve pellet durability and unit density. Viable floating feeds containing 60% DDGS can be produced under specific conditions to result in feeds that float with unit density values from 0.24 g/cm³ to 0.61 g/cm³ and durability values ranging from 96 to 98% (Chevanan et al., 2007; 2009).

Conclusions

Use of DDGS in aqua feeds has been limited, but opportunities exist to use significant quantities to achieve satisfactory performance and reduce diet costs. Dietary inclusion rates for DDGS are highest in species with a greater ability to utilize fiber, but vary based on type of ingredients substituted and amounts of other protein sources (e.g. fish meal) included in the diet. Supplemental lysine, methionine, and other amino acids may be needed at high dietary inclusion rates in order to meet requirements due to the relatively low levels of these amino acids in DDGS despite having a moderately high crude protein content. High protein aquafeeds may have lower DDGS inclusion rates unless adequate amino acid supplementation is provided. DDGS is high in linoleic acid but low in other essential fatty acids. Benefits of adding DDGS to aqua feeds include: it is an excellent source of digestible phosphorus, no concerns about anti-nutritional factors, it may provide immunological benefits, and high quality pellets can be produced using the appropriate extrusion conditions. Diet inclusion rates of 20 to 40% DDGS have been successfully used in diets for channel catfish and tilapia, and diets containing 15% DDGS can be used for rainbow trout. More research is needed to better characterize the benefits and limitations of DDGS in aqua feeds and determine optimum dietary inclusion rates.

Based upon recent research studies, maximum dietary inclusion of DDGS are shown in **Table 2**. While none of the scientific reports specified the source or quality of the DDGS used, light colored, golden DDGS sources should be used to ensure the highest nutrient digestibility, especially with high dietary inclusion rates.

Table 2. Current recommendations for maximum dietary inclusion rates of DDGS for various species of fish.

Species	% DDGS	Comments
Catfish	Up to 30%	
Trout	Up to 15%	Without synthetic lysine and methionine supplementation
Trout	Up to 22.5%	With synthetic lysine and methionine supplementation
Salmon	Up to 10%	
Freshwater Prawns	Up to 40%	Can replace some or all of the fish meal in the diet
Shrimp	Up to 10%	Can replace an equivalent amount of fish meal
Tilapia	Up to 20%	Without synthetic lysine and supplementation in high protein diets (40% CP)
Tilapia	Up to 82%	With synthetic lysine and tryptophan supplementation in low protein diets (28% CP)

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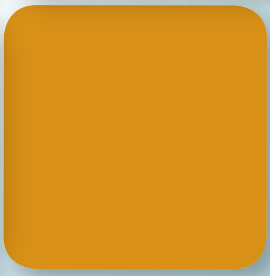
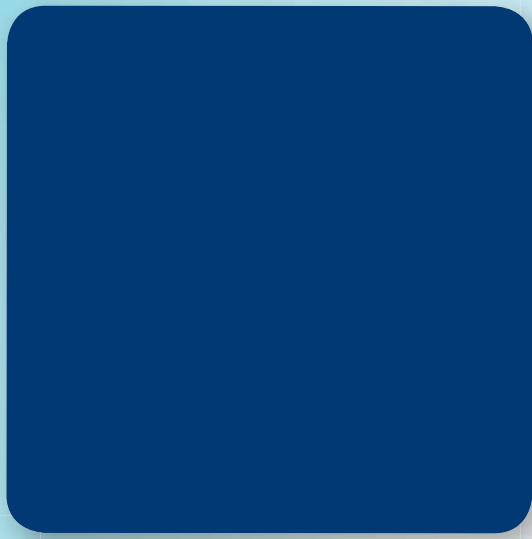
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CHAPTER 26

Use of DDGS in Sheep and Goat Diets



Chapter 26

Use of DDGS in Sheep and Goat Diets

Introduction

While limited studies have been conducted to evaluate the effects of feeding DDGS to sheep and goats compared with other species, DDGS is an economical and excellent feed ingredient in diets for sheep and goats. The high fiber and low starch content of DDGS provides diet formulation flexibility and allows it to safely partially replace a portion of the forage or grain in diets with reduced risk of rumen acidosis compared to feeding grain-based diets (Held, 2006a,b).

Gestating and Lactating Ewes

Ely et al. (1991) fed 20 crossbred ewes with twin lambs from 14 to 56 days post-partum on fescue-hay based diets to provide 75 to 85% of the NRC requirements for protein and energy, a forage to concentrate ratio of 2:1, and diets were supplemented with soybean meal or DDGS. Ewes fed the DDGS supplemented diets lost less weight during lactation, but produced less total milk than soybean meal supplemented ewes. Ewes fed at 75% of the recommended nutrient intake level lost more body weight, but milk production was not affected compared to feeding a diet at 85% of NRC requirements for energy and protein. Lambs from ewes fed the soybean meal supplemented diet, or the 85% of recommended nutrient intake level had improved average daily gain. Neither the soybean meal nor DDGS supplements affected daily milk DM, crude protein, ash, or lactose content. However, ewes fed the DDGS supplemented diet produced 16.5% more milk fat per day. Lambs from ewes fed the soybean meal supplemented or the 85% level of recommended nutrient intake used milk nutrients more efficiently than lambs nursing ewes fed the DDGS supplemented diets or the 75% of the requirement diet. Ewes fed the soybean meal diet had greater DM and crude protein digestibility than ewes fed the DDGS diet.

More recently, when DDGS was used instead of soybean meal as a protein supplement in lactating ewe diets, no differences were observed in ewe body condition score and suckling lamb weight gain (Held, 2006a). A lactation study evaluating the use of DDGS to replace 2/3 of the corn (25% of the diet) resulted in a 12% improvement in reared lamb growth for ewes nursing triplets, but there were no effects for ewes nursing twin and single lambs (Held, 2006a). A possible reason for the comparative differences between soybean meal and DDGS supplementation in Ely et al. (1991) and Held (2006a) reports may be due to differences in dietary nutrient levels fed and the quality of the DDGS sources used.

Radunz et al. (2011) compared ewe and lamb performance of 3 winter-feeding gestation systems to crossbred ewes, haylage, limit-fed corn, or limit-fed DDGS. At parturition, ewe body weight was heaviest for those fed DDGS, lowest for those fed haylage, and intermediate for those fed corn. Ewes fed corn and DDGS had greater body condition scores at parturition than

those fed haylage, and at weaning, ewes fed DDGS had greater body condition scores than those fed corn or haylage rations. Body weight of lambs at birth tended to be heavier from ewes fed corn and DDGS compared to ewes fed haylage, but there was no effect of ewe gestation diet on lamb weaning weight. Body composition of lambs at birth, ewe milk production, as well as preweaning lamb growth rate and mortality were not affected by feeding program. Feeding DDGS reduced feed costs, but ewes had an increased incidence of ketosis prior to parturition. These researchers then evaluated feedlot performance, glucose tolerance, and carcass compositions of lambs weaned from ewes fed the 3 winter-feeding programs.(Radunz et al., 2011b). Their results showed that the type of mid- to late-gestation ewe diet fed affects maternal plasma insulin concentration. Lambs from ewes fed DDGS tended to have greater insulin response than those from ewes fed corn or haylage diets. This difference in insulin resistance was associated with alternations in fat deposition affecting primarily internal fat. However, these changes in carcass composition likely have small practical significance, but provide evidence that changes in maternal metabolism due to winterfeeding system may have long-term impacts on progeny growth and body composition.

Growing-Finishing Lambs

Protein and amino acid utilization of DDGS has been evaluated in growing lambs and results from two studies indicate that it is an excellent protein source. Waller et al., (1980) conducted a lamb metabolism trial to evaluate the effects of feeding combinations of proteins that are slowly degraded in the rumen with urea. Combinations of urea and distillers dried grains (DDG) or DDGS were used to replace urea as sources of supplemental protein and did not significantly affect dry matter or N digestibility of the diets. Archibeque et al. (2008) demonstrated that feeding DDGS improves amino acid nutrition of lambs consuming moderate quality forages.



Schauer et al. (2008) fed 240 Rambouillet wether and ewe lambs (31.7 kg BW) diets containing alfalfa hay, soybean meal, barley, and a trace mineral supplement, and DDGS replaced barley and soybean meal at 0, 20, 40, and 60% of the diet on a DM basis. Sulfur concentrations of diets were 0.22, 0.32, 0.47, and 0.55% for the 0, 20, 40, and 60% DDGS diets, respectively. Thiamin was included at a level of 142 mg/hd/d (DM basis) in all rations for the prevention of polioencephalomalacia. Rations were mixed, ground, and provided *ad libitum*. Lambs were harvested after the 111 d feeding trial and carcass data collected. Final weight, ADG, G:F, mortality, hot-carcass weight, leg score, carcass conformation score, fat depth, body wall thickness, ribeye area, quality and yield grade, and boneless closely trimmed retail cuts were not affected by DDGS inclusion rate, and feed intake increased linearly as level of DDGS inclusion increased. These results suggest that feeding high dietary levels of DDGS results in acceptable lamb performance with no negative effects on carcass traits.

Gutierrez et al. (2009) fed Suffolk lambs 3 dietary levels of DDGS (0, 15, or 30%, DM basis). Feed intake was similar among DDGS levels, but body weight gain was reduced when lambs

were fed the 30% DDGS diet (0.221 kg/d) compared with feeding the 0 and 15% DDGS diets (0.284 and 0.285 kg/d, respectively), suggesting that a much lower DDGS feeding level (15%) be used for lambs compared to the feeding recommendations by Schauer et al. (2008).

McKeown et al. (2010) showed that DDGS from corn, wheat or triticale can replace a mixture of barley grain and canola meal at 20% of diet dry matter without adversely affecting dry matter intake, growth rate, or carcass characteristics of growing lambs, but wheat DDGS may reduce feed:gain and triticale DDGS may improve the fatty acid profile of carcass fat. Felix et al. (2012) fed diets containing 0, 20, 40, or 60% DDGS to growing lambs and concluded that DDGS can be fed to sheep at up to 60% of the diet dry matter without affecting dry matter intake, but higher dietary inclusion rates may decrease ADG. They also observed that feeding high inclusion rates of DDGS may affect marbling score and reduce hot carcass weight. Therefore, they recommended that feeding diets containing 20% DDGS of dry matter is optimal. In contrast, Van Emon et al. (2011) showed results that indicate that DDGS can be included in the diets of finishing lambs at levels up to 50% of dry matter intake without negatively affecting growth performance, carcass quality, and metabolite concentrations.

Huls et al. (2006) conducted a study to determine the effects of replacing soybean meal and a portion of the corn with DDGS on growth performance, carcass characteristics, and the incidence of acidosis, bloat, or urinary calculi in wethers fed a high-grain finishing diet with soyhulls as the only source of dietary fiber. Diets were balanced to have similar CP (14.6%), ME (3.4 Mcal/kg), and calcium:phosphorus (2:1) and pelleted. Average daily gain, dry matter intake, gain:feed, and carcass characteristics were not different between dietary treatments, and no symptoms of acidosis, bloat, or urinary calculi were observed. These results suggest that DDGS is an acceptable substitute for soybean meal and a portion of the corn in finishing lamb diets where soybean hulls are the only source of fiber.

Sewell et al. (2009) fed various crop residues (i.e. wheat straw, corn stover, switchgrass, corn fiber and wheat chaff) that were either thermochemically processed or not, in combination with DDGS and showed that nutrient digestibility of these crop residues was improved by thermochemically processing, and these processed crop residues can be fed in combination with DDGS to partially replace corn in ruminant diets.

McEachern et al. (2009) reported results which indicate that DDGS can replace all of the cottonseed meal in lamb finishing diets without negatively growth rate, feed conversion, wool characteristics, and can potentially reduce feed cost/kg of gain. Whitney and Lupton (2010) showed that cottonseed hulls are a good roughage source for lamb finishing diets containing 40% DDG.

Conclusions

Dried distillers grains with solubles can be an excellent protein and energy supplement for ewes and growing-finishing lambs to replace a portion of the corn and soybean meal in the diet. The higher fiber content of DDGS compared to corn and soybean meal may be effective in preventing acidosis in growing-finishing lambs fed high grain diets. Sulfur content should be

monitored and managed, especially when feeding high levels of DDGS with moderate to high sulfur levels to avoid polioencephalomalacia. Differences in performance among the limited feeding studies suggest the quality of the DDGS source being fed may be important in order to achieve optimal performance. Conservatively, adding DDGS at a level of 20% of growing-finishing lamb diets and 25% of lactating ewe diets will provide good performance results, although high inclusion rates may also result in acceptable performance.

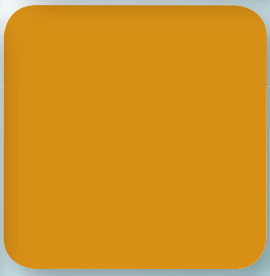
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CHAPTER 27

Use of DDGS in Horse and Companion Animal Diets



Chapter 27

Use of DDGS in Horse and Companion Animal Diets

Introduction

Very little research has been conducted related to feeding diets containing DDGS to horses and other companion animals. However, because of the increasing supply and availability of DDGS, the high quality and relatively low cost of U.S. DDGS produced today, and the low risk of mycotoxins, it is becoming a more popular ingredient for use in horse feeds and commercial pet foods.

Horses

Researchers in Germany have estimated the digestible energy in distiller's co-products range from 11.5 to 14.2 MJ/kg (2,747 to 3,392 kcal/kg) of dry matter (DLG, 1995). The relatively high oil content in DDGS allows it to be an important energy source for performance horses (DLG, 1995; Orme et al., 1997). In the first of two studies, cellulose digestibility was 32.4% when DDGS was added directly into the cecum and 27.2% in the total tract of horses when fed diets containing up to 10% DDGS (Leonard et al., 1975). In a subsequent trial, there were no differences among dietary treatments for dry matter, cellulose, or gross energy digestibility when

horses were fed diets containing corn, bluegrass hay, and DDGS at levels of 0, 9, and 18% of the diet, but protein digestibility increased with increasing dietary levels of DDGS (Leonard et al., 1975). These results suggest a significant amount of the total digestible energy in DDGS is obtained from cellulose and DDGS may contain some unidentified factors that stimulate cellulose digestion in the cecum of horses (Leonard, 1975). However, when Pagan (1991) fed pelleted diets containing 0, 5, 10,



or 20% DDGS to horses, protein and dry matter digestibility tended to decrease on the level of DDGS increased in the diet, but fat and TDN (total digestible nutrients) digestibility was not different among diets with different DDGS levels. These results suggest DDGS is a highly digestible energy source for horses. Furthermore, due to the high concentration of protein and relatively high protein digestibility in DDGS, Frape (1998) showed DDGS can be an effective partial replacement for soybean meal or dried skimmed milk powder in horse feeds. Based on these results, it appears DDGS can be used effectively in horse diets at levels up to 20% of the diet.

Although horses can utilize the nutrients in DDGS quite well, palatability is one of the potential issues that could limit its use. Equine are very sensitive to dietary inclusion of novel feed ingredients. Pagan (1991) conducted a series of feed preference and digestibility trials to determine the suitability of using DDGS as a feed ingredient for horses. In the feed preference trials, horses were fed pelleted diets containing 0%, 5%, 10%, or 20% DDGS in two tests over six consecutive days. Horses showed no preference differences between diets containing 0%, 5%, or 10% DDGS, and horses more frequently preferred the 20% DDGS diet compared with pellets containing lower levels of DDGS. These results suggest DDGS can be used effectively in pelleted horse feeds at levels up to 10% of the diet, without any negative effects on palatability, and increasing the DDGS dietary inclusion level to 20% may actually increase feed preference.

Hill (2002) evaluated eating behavior and feed intake responses of horses fed various proportions of wheat distiller's grains and concentrate at ratios of 1:0, 0.75:0.25, 0.50:0.50, and 0:1. When wheat distiller's grains were offered at a rate of 0.75 of dietary dry matter, and not soaked prior to feeding, there was a significant reduction in the rate of feed ingestion and the number of chews per kg of dry matter. If the concentrate was soaked before feeding, there was an increase in the number of feeding bouts when 0.25 of the concentrate was replaced with wheat distiller's grains. However, feed consumption processes were not affected until 0.5 of the concentrate dry matter was replaced with wheat distiller's grains. Based upon these results, Hill (2002) concluded that wheat distiller's grains can be used as a substitute for other energy and protein ingredients in horse rations, but the dietary inclusion rate depends on the method of feed presentation to the horse. Soaking of the concentrate before feeding reduced the level of the distiller's co-product that could be incorporated into the ration to meet the desired amount of dry matter intake.

Very little information is known about the effects of feeding DDGS diets on horse performance. In a recent study by Bonoma et al. (2008), weanling horses were fed completely pelleted diets consisting of 50% alfalfa and 50% concentrate containing either corn and soybean meal or 30% of the concentrate replaced with DDGS. Growth rate and feed conversion were not different between the two dietary treatments. However, feeding the DDGS diet resulted in reduced dry matter, protein, acid detergent fiber, and neutral detergent fiber digestibility compared to feeding the corn-soybean meal concentrate. Therefore, for weanling horses, no more than 30% of the concentrate or 15% of the total diet should be replaced with DDGS when alfalfa is used as the forage source and comprising 50% of the diet. If a forage source that is lower in quality than alfalfa is used, it may be advisable to use less DDGS as a partial substitute for corn and soybean meal in concentrates fed to weanling horses.

Rabbits

Very little research has been conducted to evaluate the feeding value of DDGS for rabbits. One study was conducted in Spain where researchers compared the nutrient digestibility of wheat bran, corn gluten feed, and DDGS in New Zealand White x Californian crossbred rabbits (Villamide et al., 1989). The basal diet contained a low amount of energy (2200 kcal/kg dry matter) and a high energy to protein ratio (25 kcal DE/g digestible protein). Although the fiber content of the diets was similar, energy and acid detergent fiber digestibility was highest for rabbits fed the DDGS diet (74.0% and 58.3%, respectively) compared to rabbits fed diets containing wheat bran (59.4% and 9.6%, respectively) and corn gluten feed (65.0% and 27.7%, respectively). Furthermore, rabbits fed the DDGS diet had the highest level of protein digestibility (70.1%) compared to rabbits fed the wheat bran (66.6%) and corn gluten feed (61.4%) diets. These results suggest DDGS is a suitable ingredient for rabbit diets and it provides more digestible energy, ADF, and protein than wheat bran and corn gluten feed.



Dogs and Cats

While there are no published scientific reports on incorporating DDGS into cat foods, there have been a few studies conducted showing DDGS can be effectively used in dry, extruded dog foods. Studies were conducted at the University of Illinois (Allen et al., 1981) to evaluate nutrient digestibility of diets containing DDGS for both adult and immature Pointer dogs. Supplementation of diets with low levels (4 to 8%) of DDGS had no effect on the apparent digestibility of dry matter and starch by adult dogs. Adding moderate levels (16.1%) of DDGS to the diet decreased dry matter digestibility, but had no effect on starch and energy digestibility. Feeding diets containing high levels (26.1%) of DDGS decreased dry matter and energy digestibility, but had no effect on crude protein digestibility in adult dogs. Growing puppies fed diets containing a moderate amount (14.1%) of DDGS had lower dry matter and energy digestibility, but digested more acid detergent fiber compared to puppies fed diets containing no DDGS. Nitrogen intake and fecal nitrogen were reduced when DDGS was supplemented in the diet, but there was no effect on urinary nitrogen, total nitrogen excretion, absorbed nitrogen, or nitrogen retention.

Research conducted by Corbin (1984) has shown DDGS can be added at rates up to 10% of the diet for growing puppies to achieve good food intake and body growth (**Figure 1**). Including DDGS in diets for older, more mature dogs can be advantageous for controlling weight gain due to its high fiber content. Weigel et al. (1997) suggested diets for mature dogs could include up to 25% DDGS depending on age and activity level to achieve good intestinal health.

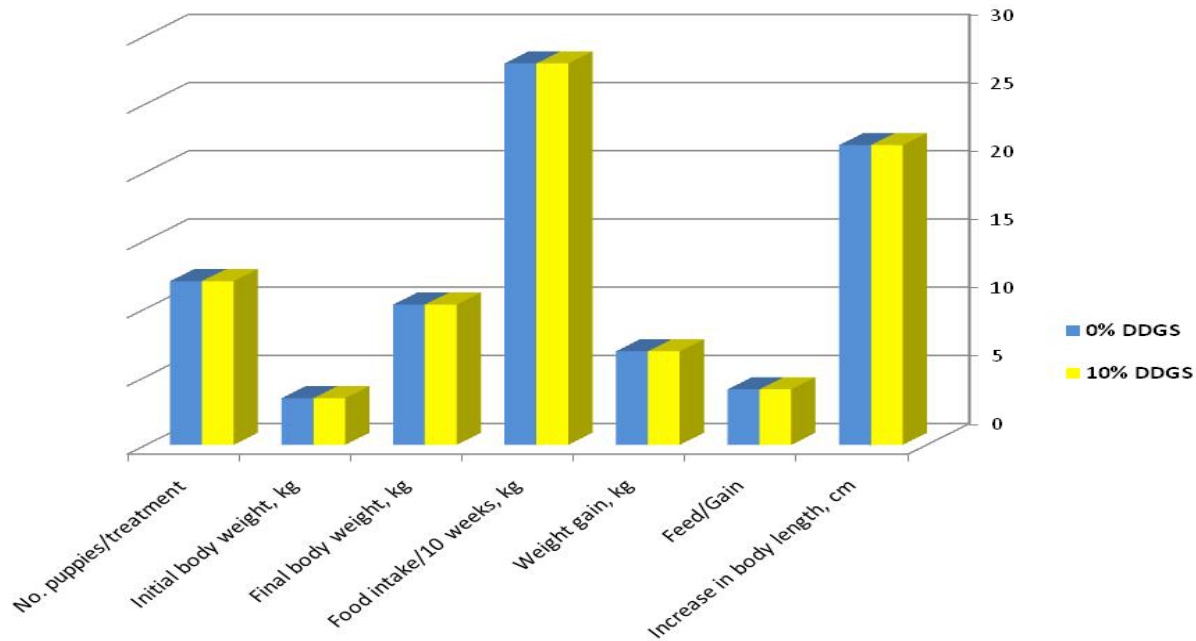


Figure 1. Effects of feeding a diet containing 10% DDGS to growing puppies on food intake, weight gain, and body length.

Conclusions

Based upon the limited research information available, it appears DDGS is a very suitable ingredient for use in horse, rabbit, and dog diets. Current feeding recommendations are shown in **Table 1**.

Table 1. Recommended maximum dietary inclusion rates for DDGS in diets for horses, rabbits, and dogs.

Species	Maximum DDGS Inclusion Rate
Horses (mature)	Up to 20% of the diet
Horses (weanling)	Up to 15% of the diet depending on forage quality
Rabbits	Up to 20% of the diet
Growing Puppies	Up to 10% of the diet
Adult Dogs	Up to 25% of the diet depending on age and activity level

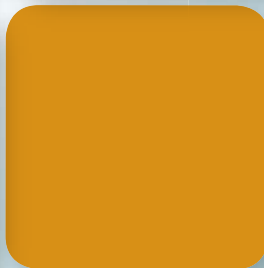
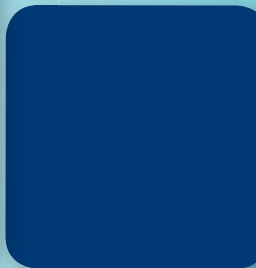
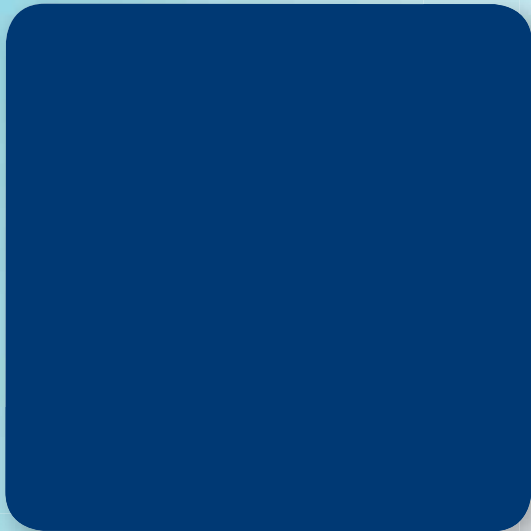
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CHAPTER 28

Impact of Diet Formulation Methods and Tools on Assessing Value of DDGS



Chapter 28

Impact of Diet Formulation Methods and Tools on Assessing Value of DDGS

Introduction

Nutrient variability

One of the challenges of obtaining the best economic and nutritional value from U.S. DDGS is to know actual nutrient content and digestibility of the DDGS source being used. **Table 1** shows an example summary of averages and ranges in nutrient content and digestibility for swine among DDGS sources. Refer to **Chapter 4 “Nutrient Composition and Digestibility of DDGS: Variability and *In Vitro* Measurement”** section of this handbook for specific recommendations on nutrient content and digestibility for various animal species.

Table 1. Nutrient composition and digestibility of DDGS samples from various ethanol plants in the Midwest U.S.¹

Nutrient	Average	Minimum	Maximum
Dry matter, %	89.22	86.22	92.4
Crude protein, %	30.8	27.3	33.9
Crude fat, %	11.2	3.5	13.5
Crude fiber, %	7.41	5.37	10.58
ME, kcal/kg	3,855	3,504	4,087
Calcium, %	0.05	0.02	0.51
Phosphorus, %	0.61	0.51	0.74
Digestible P, %	0.36	0.28	0.47
Lysine, %	0.97	0.61	1.19
SID lysine, %	0.65	0.33	0.77
Methionine, %	0.63	0.54	0.76
SID methionine, %	0.47	0.40	0.66
Threonine, %	1.15	1.01	1.32
SID threonine, %	0.87	0.68	0.96
Tryptophan %	0.24	0.18	0.34
SID tryptophan, %	0.17	0.10	0.21

¹Adapted from www.ddgs.umn.edu, Urriola (2005), and Stein and Shurson (2009).

Knowing the nutrient content and digestibility of the specific source of DDGS being fed is the single most important factor for assessing economic value and obtaining optimal animal performance. Overestimating nutrient content of DDGS, or any other feed ingredient, can result in reduced growth performance when added to complete feeds and fed to animals. This is more likely to occur when DDGS is used at high dietary inclusion rates compared to low inclusion rates. In contrast, underestimating nutrient content of DDGS can result in feeding excessive

nutrients above the animal's requirement, underestimating economic value, and increasing nutrient excretion in manure.

Decision tools to evaluate the economic value for use of DDGS in livestock and poultry diets

Several DDGS value calculator tools have been developed to determine DDGS feeding value for livestock and poultry. These tools are extremely useful for determining the actual economic value of DDGS in specific livestock and poultry diets and should be used when evaluating whether the current price for DDGS is economical relative to its nutrient contributions and price relative to other competing ingredients. The most recent and comprehensive DDGS evaluation tool was developed by researchers at Iowa State University (Dahlke and Lawrence, 2008) and is useful for a wide variety of diets and food animal species: <http://www.matric.iastate.edu/DGCalculator> SESAME, www.sesamesoft.com developed by researchers at Ohio State (Drs. Normand St-Pierre, Branislav Cobanov and Dragan Glamocic, 2007), is a comprehensive tool to help livestock and poultry producers make better feed-purchasing choices. Researchers at the University of Nebraska (C. Buckner, G. Erickson, T. Klopfenstein, D. Mark, and V. Bremer, 2006) developed a corn co-product cost calculator for beef cattle [Cattle Coproduct Optimizer Decision Evaluator](#), and 3 DDGS evaluation tools have been developed specifically for swine:

[University of Illinois DDGS Calculator](#) developed by Drs. Beob G. Kim and Hans H. Stein (Dec. 2007).

[DDGS Cost Calculator for Swine](#) - developed by Dr. Bob Thaler, South Dakota State University Extension Swine Specialist (Sep. 2002).

[DDGS Value Calculator](#) - developed by Dr. Dean Koehler, Vita Plus Corporation, Madison, WI (Sep. 2002).

Diet formulation methods

Further complicating the issue of variability in DDGS nutrient content and digestibility, variability, diet formulation methods can vary among nutritionists. Furthermore, several different diet formulation approaches vary among ruminant, swine, poultry, and fish nutritionists. Over the years, formulation methods have improved from formulating monogastric diets on a crude protein basis to a standardized ileal digestible basis and from digestible energy to net energy systems. These advances in formulation technique have greatly increased our ability to meet the animal's true nutrient requirements.

Diet formulation method affects animal performance and DDGS value and usage. Energy, protein (amino acids), and phosphorus are the 3 most expensive nutrients provided in animal feeds. As a result, diets are formulated to minimize the amounts of these nutrients in the diet to minimize cost, but yet provide adequate levels to insure that animal health and performance is not compromised.

It is well accepted that digestible energy (DE) is a more accurate measure of the utilizable energy in a feed than gross energy. Likewise, metabolizable energy (ME) is a more accurate measure than DE, and net energy (NE) is a better measure than ME. However, depending on

the accuracy and availability of DE, ME, or NE values for feed ingredients, level of technological understanding of nutritionists, and knowledge and acceptance of energy requirements using any of these energy systems, diet formulations can vary substantially. Unfortunately, NE values for DDGS are not well defined, but ME and DE values have been well established, but are variable.

Crude protein is really a measure of the nitrogen content of a feed or feed ingredient and does not adequately reflect the amino acid content. While crude protein is an acceptable measure when formulating ruminant diets, it is unacceptable to achieve accuracy in meeting the amino



acid needs of pigs, poultry, and fish. This is because the microorganisms in the rumen can convert various forms of nitrogen into the required amounts of microbial protein, with the proper amino acid content, to meet the amino acid needs of ruminants. The digestive systems of monogastric animals do not have these capabilities, and therefore, require specific amounts of digestible amino acids in their daily diet. For monogastrics, formulating diets on a total amino acid basis is more accurate than using crude protein, but greater accuracy is achieved

when swine and poultry diets are formulated on a digestible amino acid basis. In addition, it is important to monitor and adjust methionine, threonine, tryptophan, and arginine (poultry) concentrations relative to lysine to insure proper amino acid balance in DDGS diets. It is also important to insure that the proper proportion of energy is provided relative to amino acid levels (e.g. kcal/g lysine). Using a digestible amino acid diet formulation system avoids overfeeding protein and amino acids, minimizes diet cost and nitrogen excretion in the manure.

Similarly, monogastric diets containing DDGS should be formulated on a digestible or available phosphorus basis instead of a total phosphorus basis. By accounting for the relatively high level of available phosphorus in DDGS, the amount of inorganic phosphate supplementation, diet cost, and phosphorus excretion in manure can be substantially reduced. Using a digestible or available phosphorus formulation approach in DDGS diets allows full utilization of the high digestible/available phosphorus content found in DDGS.

To illustrate the impact of diet formulation method on DDGS use based on nutrient variability among sources and formulation method, several examples of swine diets have been formulated for comparison. These relative comparisons also have relevance for other livestock and poultry species using nutrient profiles and formulation methods specific those species, but it is beyond the scope of this paper to give all possible combinations of formulations for various production phases for multiple livestock and poultry species.

Impact of Variation in DDGS Nutrient Content and Digestibility on Dietary DDGS Use in Swine Diets

DDGS metabolizable energy (ME) values

Two extreme values for ME were selected from previously reported data (Pedersen et al., 2007, and Anderson et al., 2009). The maximum ME value for one DDGS source was 4,334 kcal/kg DM while the minimum ME value for a DDGS source was 3,414 kcal/kg DM. Diets were formulated on a standardized true ileal digestible (SID) amino acid basis. The SID levels were based on *in vivo* studies that directly determined the SID amino acid values for specific sources of DDGS. Diets were formulated to contain identical concentrations of ME (**Table 2**). The SID amino acid digestibility coefficients were estimated to be 63%, 82%, 71%, and 69% for lysine, methionine, threonine, and tryptophan, respectively. Desired nutrient levels were based on (NRC, 1998) requirements for a 45 kg pig with 325 g/d of lean tissue gain. Choice white grease was added to the low ME diet at the expense of corn to meet the energy requirement (**Table 2**).

Table 2. Comparison of swine grower diet formulations using high ME (4,334 kcal/kg DM) and low ME (3,414 kcal/kg DM) DDGS sources on diet composition.

Ingredient, kg	High ME DDGS	Low ME DDGS
Corn grain	607.0	569.1
Soybean meal	172.5	172.5
High ME DDGS, 4,336 kcal/kg	200.0	
Low ME DDGS, 3,414 kcal/kg		200.0
Choice white grease		37.9
Limestone	10.0	10.0
Dicalcium phosphate	4.0	4.0
Salt	3.0	3.0
Vitamin/Trace mineral premix	2.0	2.0
L-lysine	1.5	1.5
TOTAL	1000.0	1000.0

Nutrient	High ME DDGS	Low ME DDGS
Dry matter, %	87.39	84.03
Crude protein, %	19.54	19.22
ME, kcal/kg	3526	3526
Lysine, %	0.83	0.83
Methonine, %	0.30	0.30
Threonine, %	0.59	0.58
Tryptophan, %	0.16	0.16
Calcium, %	0.57	0.57
Total phosphorus, %	0.52	0.51
Available phosphorus, %	0.25	0.25
Ca:P	1.10	1.12

Since the two sources of DDGS greatly vary in ME content, 3.79% choice white grease (pork fat) was added to the low ME DDGS diet to maintain the same level of dietary ME content as the high ME DDGS diet. Without supplementing the diet with choice white grease, the low ME DDGS diet would not meet the pigs' energy requirements. Various supplemental fat sources could be used to provide these deficient calories, but regardless of fat source, the addition of supplemental fat to low ME diets can dramatically increase the total diet cost. These results show that it is important to know the source of DDGS being used and have accurate estimates of the ME, and preferably, the NE content of DDGS and other ingredients to maximize their energy value in diet formulations and minimize diet cost.

Variability in total and digestible lysine concentrations among DDGS sources

As previously described, total and digestible amino acid concentrations also vary among DDGS sources. To show the importance of knowing digestible amino values of the DDGS sources being fed, 3 different diets were formulated to contain 10% DDGS. Sources of DDGS were selected for use in growing swine diet formulations based on their SID lysine values (**Table 3**) obtained from previously published data reported by Urriola (2005). Total lysine content ranged from 0.76% to 1.02% and SID lysine ranged from 0.47% to 0.67%.

Table 3. Total and standardized ileal digestibility (SID) values for lysine, methionine, threonine, and tryptophan among 3 DDGS sources.

Nutrient	Low SID Lysine	Average SID Lysine	High SID Lysine
ME, kcal/kg	3,834	3,893	3,838
Crude protein, %	28.00	29.10	31.90
Lysine, %	0.76	0.85	1.02
Methionine, %	0.50	0.52	0.58
Threonine, %	1.05	1.05	1.15
Tryptophan, %	0.23	0.23	0.28
SID lysine, %	0.47	0.60	0.67
SID methionine, %	0.43	0.50	0.53
SID threonine, %	0.79	0.80	0.87
SID tryptophan, %	0.17	0.20	0.20

Diets were formulated to provide 10% (a low dietary inclusion rate) of each of these 3 DDGS sources to maintain a 0.66% SID dietary lysine level (**Table 4**). Accuracy of SID amino acid values becomes increasingly important as dietary inclusion rates of DDGS increase because DDGS contributes a greater amount of amino acid to the diet relative to the pig's requirement. These results show that while maintaining DDGS at a constant dietary inclusion rate (10%) under this diet formulation scenario, the amount of corn increases and the amount of soybean meal decreases when high SID lysine DDGS is used instead of low SID lysine DDGS, while maintaining diet nutrient content constant. Depending on the relative cost differences between corn, soybean meal, and DDGS, adding high SID lysine DDGS sources to swine diets generally reduces cost/5one of complete feed.

Table 4. Diet formulation of swine grower diets using low, average, and high standardized ileal digestibility (SID) lysine values for DDGS.

Ingredient, kg	Low SID Lys. DDGS	Average SID Lys. DDGS	High SID Lys. DDGS
Corn	708.1	713.2	715.9
Soybean meal, 47%	172.7	167.5	164.8
DDGS	100.0	100.0	100.0
Dicalcium phosphate	3.0	3.1	3.2
Limestone	9.7	9.7	9.7
Salt	3.0	3.0	3.0
Vitamin/Trace mineral premix	2.0	2.0	2.0
L-lysine HCL, kg	1.5	1.5	1.5
TOTAL	1000	1000	1000
Nutrient Composition			
Crude protein, %	17.03	16.94	17.11
ME, kcal/kg	3,416	3,422	3,416
Calcium, %	0.50	0.50	0.50
Phosphorus, %	0.45	0.45	0.45
Ca:P	1.11	1.11	1.11
Salt, %	0.36	0.36	0.36
Crude fat, %	4.34	4.26	4.24
Lysine, %	0.90	0.90	0.91
SID lysine, %	0.66	0.66	0.66
Methonine, %	0.29	0.29	0.29
SID methonine, %	0.26	0.26	0.26
Threonine, %	0.63	0.62	0.63
SID threonine, %	0.53	0.52	0.52
Tryptophan, %	0.18	0.17	0.18
SID tryptophan, %	0.15	0.15	0.15

Formulation Methods

Crude protein basis

Several decades ago, most swine diets in the U.S. were formulated on a crude protein basis because total and digestible amino acid requirements were not well established for different stages of production, and total and digestible amino acid content of feed ingredients was not determined. Once knowledge of specific amino acid requirements was well defined, nutritionists began formulating diets on a total amino acid basis. However, amino acid digestibility varies among sources and to account for this, diets currently are formulated in a digestible amino acid basis to provide the highest nutritional and economic value of swine diets as well as achieve optimal performance.

In order to show the potential problems that can occur when formulating swine diets containing DDGS on a crude protein basis, 3 diets were formulated to contain 0, 10, and 20% DDGS to

meet the crude protein requirement (16%) of a 50 kg pig (**Table 5**). When formulating the diet to maintain a consistent crude protein level of 16%, a 10% inclusion rate of DDGS will meet all of the pigs' nutrient requirements, including amino acids. However, when the amount of DDGS is increased to 20%, it is impossible to meet the total lysine requirement of 0.75% for a 50 kg pig even though 0.15% of L-lysine HCl is added. If this diet was fed to pigs, growth rate and feed conversion would be reduced compared to feeding the 0 and 10% DDGS diets using this diet formulation approach.

Table 5. Ingredient and nutrient composition of a 16% crude protein swine grower diet containing 0, 10, and 20% DDGS.

Ingredient, kg	0% DDGS	10% DDGS	20% DDGS
Corn	783.5	733.8	684.2
Soybean meal, 47%	196.7	147.1	97.4
DDGS	0.0	100.0	200.0
Dicalcium phosphate	5.1	3.6	2.0
Limestone	8.2	9.0	9.9
Salt	3.0	3.0	3.0
L-lysine HCl	1.5	1.5	1.5
Vitamin/Trace mineral premix	2.0	2.0	2.0
TOTAL	1000.0	1000.0	1000.0
Nutrient Composition			
Crude protein, %	16.0	16.0	16.0
ME, kcal/kg	3,372	3,316	3,261
Lysine, %	0.92	0.82	0.72
Methionine, %	0.26	0.27	0.28
Threonine, %	0.59	0.58	0.57
Tryptophan, %	0.18	0.16	0.15
Calcium, %	0.50	0.50	0.50
Phosphorus, %	0.45	0.45	0.45
Ca:P	1.11	1.11	1.11
Salt, %	0.37	0.41	0.44
Crude fat, %	3.65	4.14	4.64

Total amino acid basis

To demonstrate the problems that can occur when formulating diets on a total amino acid basis for swine, 4 example DDGS diets (0, 10%, 20% and 205 with added synthetic amino acids) were formulated on a total amino acid basis (**Table 6**). Diets were formulated using nutrients required for a 50 kg growing pig.

Although NRC requirements for total lysine, methionine, threonine, and tryptophan were met (in some cases exceeded) in each of the diets, digestibility of the amino acids was not considered. As a result, the SID amino acid requirements for lysine and tryptophan were not met in either the 10% or 20% DDGS diets (**Table 6**). However, when the 20% DDGS diet was supplemented with synthetic L-tryptophan and more soybean meal (adjusted 20% DDGS), both the SID lysine and SID tryptophan requirements are met.

Table 6. Ingredient and nutrient composition of a swine grower diet containing 0, 10, and 20% DDGS and formulated on a total lysine basis.

Ingredient, kg	0% DDGS	10% DDGS	20% DDGS	Adjusted 20% DDGS
Corn	796.5	757.5	635.4	610.9
Soybean meal, 47%	183.4	123.0	147.1	170.3
DDGS	0.0	100.0	200.0	200.0
Dicalcium phosphate	5.4	4.1	0.9	0.9
Limestone	8.1	9.0	10.0	9.9
Salt	3.0	3.0	3.0	3.0
Vitamin/Trace mineral premix	2.0	2.0	2.0	2.0
L-lysine HCl	1.5	1.5	1.5	1.5
L-tryptophan	0.0	0.0	0.0	1.5
TOTAL	1000.0	1000.0	1000.0	1000.0
Nutrient Composition				
Crude protein, %	15.5	15.1	18.0	19.0
ME, kcal/kg	3,372	3,316	3,262	3,281
Lysine, %	0.88	0.75	0.85	0.92
Methionine, %	0.26	0.26	0.31	0.32
Threonine, %	0.57	0.54	0.64	0.83
Tryptophan, %	0.17	0.15	0.18	0.20
Calcium, %	0.50	0.50	0.50	0.50
Phosphorus, %	0.45	0.45	0.45	0.46
Ca:P	1.11	1.11	1.11	1.09
Salt, %	0.37	0.41	0.44	0.44
Crude fat, %	3.66	4.16	4.60	4.57
SID lysine, %	0.66	0.52	0.60	0.66
SID methionine, %	0.23	0.23	0.26	0.27
SID threonine, %	0.49	0.44	0.51	0.54
SID tryptophan, %	0.15	0.11	0.12	0.13

True ileal digestibility basis

Currently, most swine diets in the U.S. are formulated on a SID amino acid basis. This formulation method provides high accuracy in meeting the nutrient needs of pigs and allows nutritionists to use high dietary inclusion rates (>10%) of DDGS, if amino acid digestibility values are known for the source being fed, without compromising pig performance. As shown in **Table 7**, diets formulated on a SID basis containing up to 30% DDGS, all meet the SID lysine level of 0.66% for a 50 kg pig, and meet all other nutrient requirements including SID methionine, threonine, and tryptophan. Note that no additional synthetic amino acids were used in these diets beyond a constant inclusion rate of 0.15% L-lysine HCl. These results show that in order to insure excellent pig performance, even when adding DDGS up to 30% of the diet, diets must be formulated on a SID amino acid basis to insure that digestible amino acid requirements are met.

Table 7. Ingredient and nutrient composition of a swine grower diet containing 0, 10, 20, and 30% DDGS and formulated on a standardized ileal digestible (SID) lysine basis.

Ingredient, kg	0% DDGS	10% DDGS	20% DDGS	30% DDGS
Corn	795.9	746.3	672.1	586.4
Soybean meal, 47%	184.0	134.4	109.8	96.6
DDGS	0.0	100.0	200.0	300.0
Dicalcium phosphate	5.4	3.9	1.7	0.0
Limestone	8.2	9.0	9.9	10.5
Salt	3.0	3.0	3.0	3.0
Vitamin/Trace mineral premix	2.0	2.0	2.0	2.0
L-lysine HCl	1.5	1.5	1.5	1.5
TOTAL	1000.0	1000.0	1000.0	1000.0
Nutrient Composition				
Crude protein, %	15.48	17.17	18.86	20.55
ME, kcal/kg	3371	3317	3262	3205
Calcium, %	0.50	0.50	0.50	0.50
Phosphorus, %	0.45	0.45	0.45	0.49
Ca:P	1.11	1.11	1.11	1.02
Salt, %	0.37	0.41	0.44	0.48
Crude fat, %	3.66	4.54	4.58	5.04
Lysine, %	0.88	0.90	0.92	0.94
SID lysine, %	0.66	0.66	0.66	0.66
Methonine, %	0.26	0.29	0.32	0.35
SID methonine, %	0.23	0.25	0.27	0.29
Threonine, %	0.57	0.63	0.68	0.74
SID threonine, %	0.48	0.51	0.54	0.57
Tryptophan, %	0.17	0.18	0.2	0.21
SID tryptophan, %	0.15	0.14	0.13	0.12

Supplemental synthetic amino acids and reduction in soybean meal use

The addition of synthetic (crystalline) amino acids to the diet has several advantages. It reduces excess nitrogen (protein), by reducing the amount of soybean meal or other high protein ingredients in the diet, while meeting the amino acid requirements of pigs and supporting excellent performance. It also minimizes nitrogen excretion and ammonia emissions from manure, and can significantly reduce total diet cost, especially when soybean meal is expensive. With increased commercial availability of crystalline lysine, methionine, threonine, and tryptophan at reasonable prices, a significant amount of soybean meal can be removed from the diet, while meeting the amino acid requirements for the first four limiting amino acids (lysine methionine, threonine, and tryptophan), as long as they are formulated on a SID amino acid basis.

The level of soybean meal used in the 30% DDGS diet containing reduced soybean meal in **Table 8**, was determined by adding enough soybean meal to the diet to prevent the next (fifth) limiting amino acid (isoleucine) from becoming deficient. Diets were formulated to meet or exceed all NRC (1998) recommendations for 45 kg pigs, and on a SID amino acid basis.

One of the challenges of feeding diets containing high amounts (>20%) of DDGS is the excessive amount of crude protein (nitrogen) it provides, due to its relatively poor crude protein:lysine ratio. If the crude protein level is too high, it can reduce growth performance because of the energetic cost of eliminating excess nitrogen from the pig's body. By adding synthetic amino acid to DDGS diets, the amount of excess protein is reduced. In fact, by reducing soybean meal use to only 2% of the diet and adding enough synthetic amino acids to meet the pig's requirement, crude protein level was below a typical corn-soybean meal diet (**Table 8**).



Table 8. Ingredient and nutrient composition of a diet containing 30% DDGS, high amounts of synthetic amino acids, and reduced soybean meal.

Ingredient, kg	Reduced Soybean Meal, 30% DDGS, and Synthetic Amino Acids	
	Control	
Corn	738.5	653.1
Soybean meal	238.8	20.0
DDGS	0.0	300.0
Limestone	8.2	12.0
Dicalcium phosphate	8.0	2.6
Salt	3.0	3.0
Premix	2.0	2.0
L-Lysine	1.5	5.9
L-Threonine	0.0	0.7
DL-Methionine	0.0	0.0
L-Tryptophan	0.0	0.7
TOTAL	1000.0	1000.0
Nutrient Composition		
Crude protein, %	17.6	16.3
ME, kcal/kg	3,333	3,459
SID lysine, %	0.92	0.84
SID methonine, %	0.26	0.26
SID threonine, %	0.56	0.52
SID tryptophan, %	0.18	0.17
SID isoleucine. %	0.61	0.46
Calcium, %	0.60	0.58
Total phosphorus, %	0.52	0.48
Available phosphorus, %	0.21	0.26
Ca:P	1.15	1.20

Conclusions

In order to achieve the best economic and nutritional value from DDGS, the source, nutrient content, and digestibility must be known. Depending on the nutrient composition of the DDGS source being used, and the diet formulation methods chosen, the relative economic and nutritional value of DDGS can vary substantially. Using accurate energy, amino acid, and phosphorus digestibility values for DDGS can reduce excessive feeding of nutrients, avoid nutrient deficiencies, and reduce diet costs while supporting optimal animal performance.

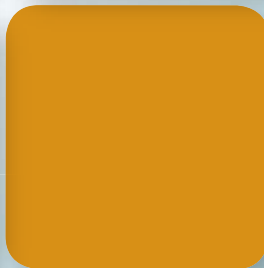
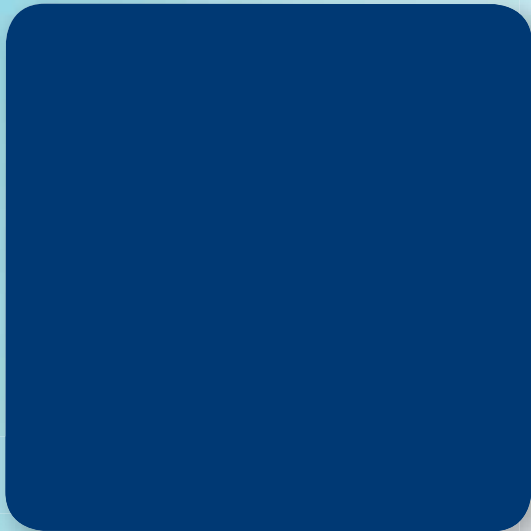
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CHAPTER 29

Factors that Affect DDGS Pricing and Transportation Logistics



Chapter 29

Factors that Affect DDGS Pricing and Transportation Logistics

Introduction

One of the biggest factors for determining whether DDGS is an economical animal feed ingredient in the international market are the price and transportation logistics to import DDGS. This section of the *U.S. Grains Council Users Handbook* describes the current factors, challenges, and pricing mechanism for determining the destination cost of importing U.S. DDGS. Historically, the primary users of distiller's grains were the dairy and beef industries in the U.S. (**Figure 1**). However, beginning in 2003-2004, with new research information available on the benefits of using DDGS in swine and poultry diets, usage of DDGS in the swine industry began to increase dramatically, and to a lesser extent in the poultry industry. Today, the U.S. swine and poultry industries consume >25% of the domestic DDGS market and this growing trend is likely to continue, especially with high feed prices and reduced availability of corn for animal feeds.

Composition of Domestic Usage (One Thousand Short Tons DDGS Equivalent)

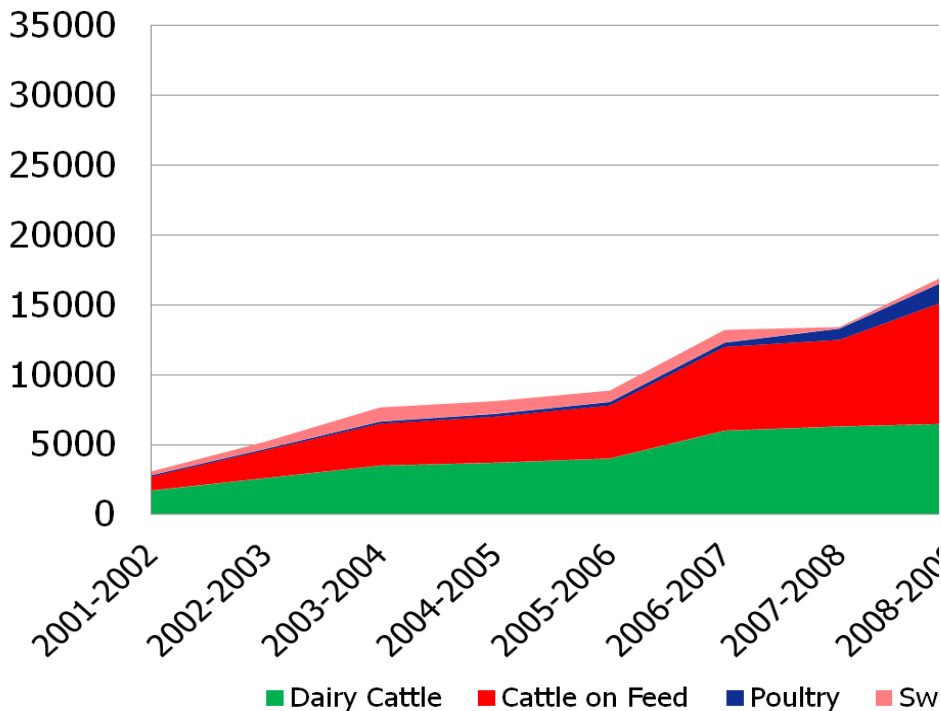
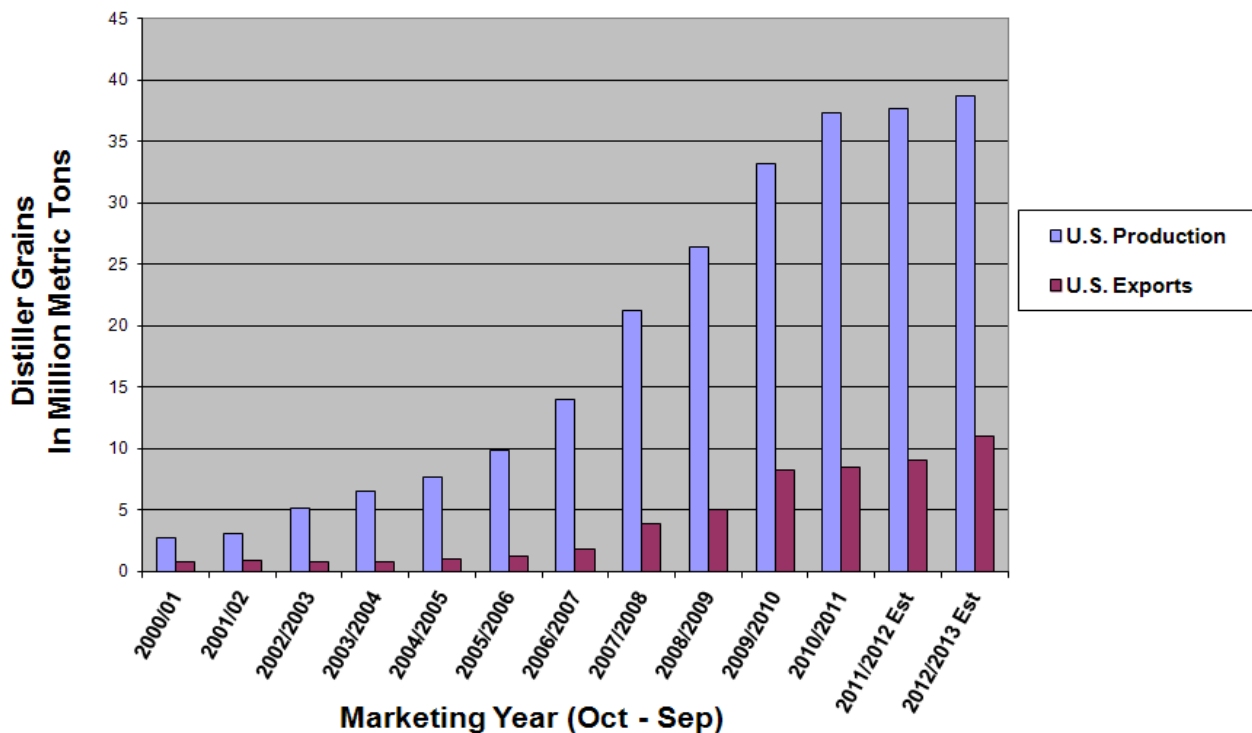


Figure 1. Historical consumption of distiller's grains with soluble in the livestock and poultry industries (2000 to 2011 for the October to September Crop Year).

Source: Steve Markham, CHS Inc.

As shown in **Figure 2**, rapid growth of the U.S. ethanol industry has resulted in dramatic increases in DDGS production, as well as increases in the percentage of DDGS being exported. As the livestock and poultry markets achieve maximal market penetration for DDGS use, an increasing proportion of DDGS production will be exported. The amount of increase in DDGS exports will be highly dependent on the price relationship of competing ingredients in the international market as well as transportation costs.

Figure 2. Estimates of historical and future trends in U.S. DDGS production and exports



(2000 to 2013).

Source: Steve Markham, CHS Inc.

Factors Affecting DDGS Price

A number of factors can affect DDGS pricing. First and foremost, it should be noted that the highest demand for DDGS is in the U.S., where approximately 78% (22% is exported) of the distiller's grains produced today are consumed by livestock and poultry. However, the amount of DDGS exported to other countries is increasing every year. Many producers and marketers of DDGS are beginning to consider the export markets as a very important component in overall DDGS demand.

DDGS is a very unique mid-protein, high-energy feed ingredient. It partially replaces corn, soybean meal, and phosphorus supplements in animal feeds. The price of DDGS is affected by

several factors including: the market price of corn and soybean meal, availability of supply for export, seasonality of domestic DDGS consumption, fluctuating transportation costs, and import tariffs imposed by many countries. Although many feed ingredient traders consider DDGS to be a “protein meal”, and consequently compare it to soybean meal, it actually is more similar in nutritional and economic value to corn. In fact, DDGS price follows the corn market more closely than the soybean meal market. **Figure 3** shows historical corn and DDGS prices FOB at the Gulf of Mexico. It is important to recognize that DDGS price tends to follow corn price more closely than soybean meal price. Overall trends in both the corn and soybean meal markets affect the DDGS price, but daily volatility in the corn or soybean meal market on the Chicago Board of Trade does not always translate into daily volatility in the DDGS market. If corn and/or soybean meal prices are generally high relative to DDGS price, DDGS will often replace a larger proportion of corn and soybean meal in animal feeds (i.e. higher dietary DDGS inclusion rates).

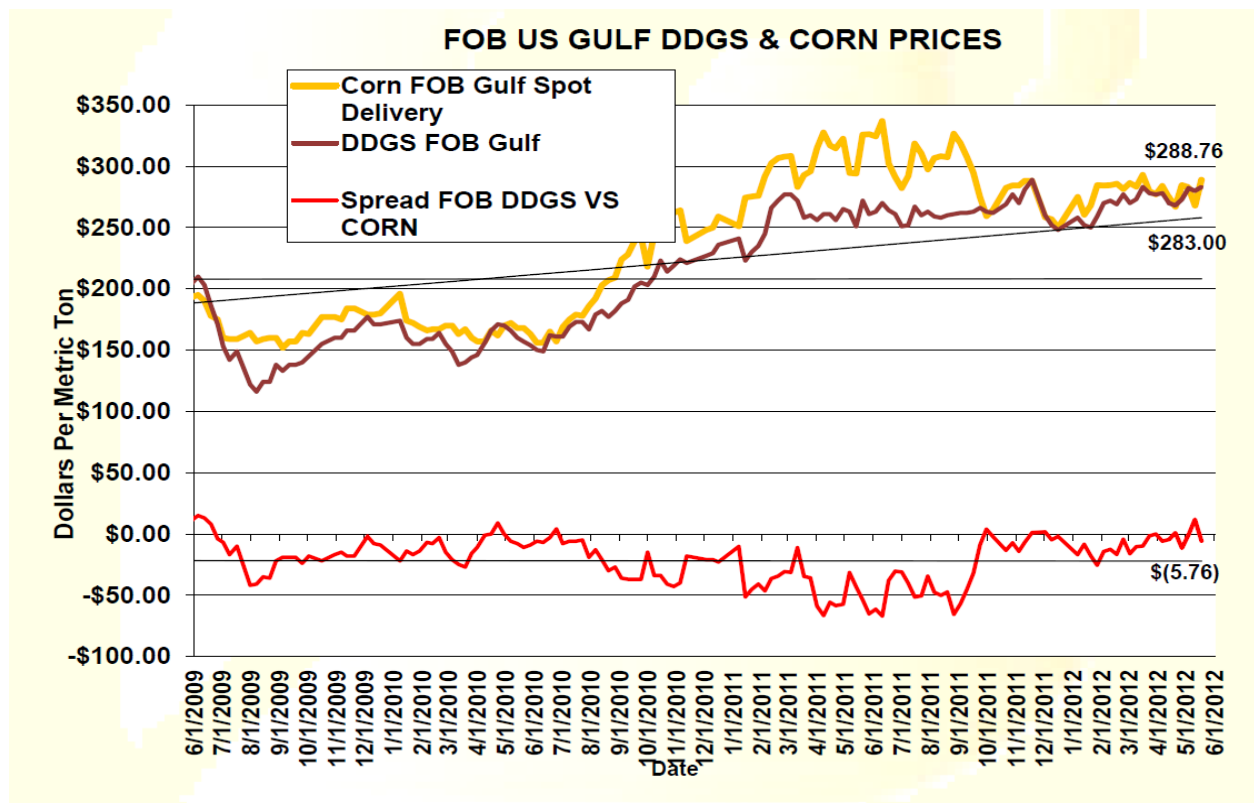


Figure 3. DDGS prices relative to corn and soybean meal from June, 2009 to June, 2012.

Source: Steve Markham, CHS Inc.

The price of DDGS is influenced by season of the year. Most of the domestic DDGS use is in cattle feeds. When cattle are moved to pastures for grazing during the summer months (May through October; **Figure 4**), the number of cattle on feed decreases causing the demand for distiller’s grains to decrease dramatically. This results in an increased supply available for the export market and usually results in lower DDGS prices compared to other months of the year.

Lower elevation costs coupled with traditionally lower barge freight during the summer months also adds to a more competitive DDGS value during this time period.

During seasonal price increases in the DDGS market, corn and soybean meal will compete favorably with DDGS and DDGS will not be used in least cost diet formulations. Strong demand in the early months of the year, coupled with historically short supplies at the same time, has typically caused higher DDGS prices in January through May. However, even though this has been a historical trend, it is not a certainty that DDGS will always be priced higher during this time of year. Due to the rapid growth of the U.S. ethanol industry, more and more DDGS is being supplied to the market each month, causing both buyers and sellers to not expect the typical supply shortages normally seen in the late winter and spring. However, as the U.S. swine and poultry industries continue to use a greater share of total DDGS production, and since they are not associated with the grazing season like cattle, the seasonality effects on DDGS price will likely become less dramatic in the future.

**Cattle on Feed U.S.
From USDA (in Thousands)**

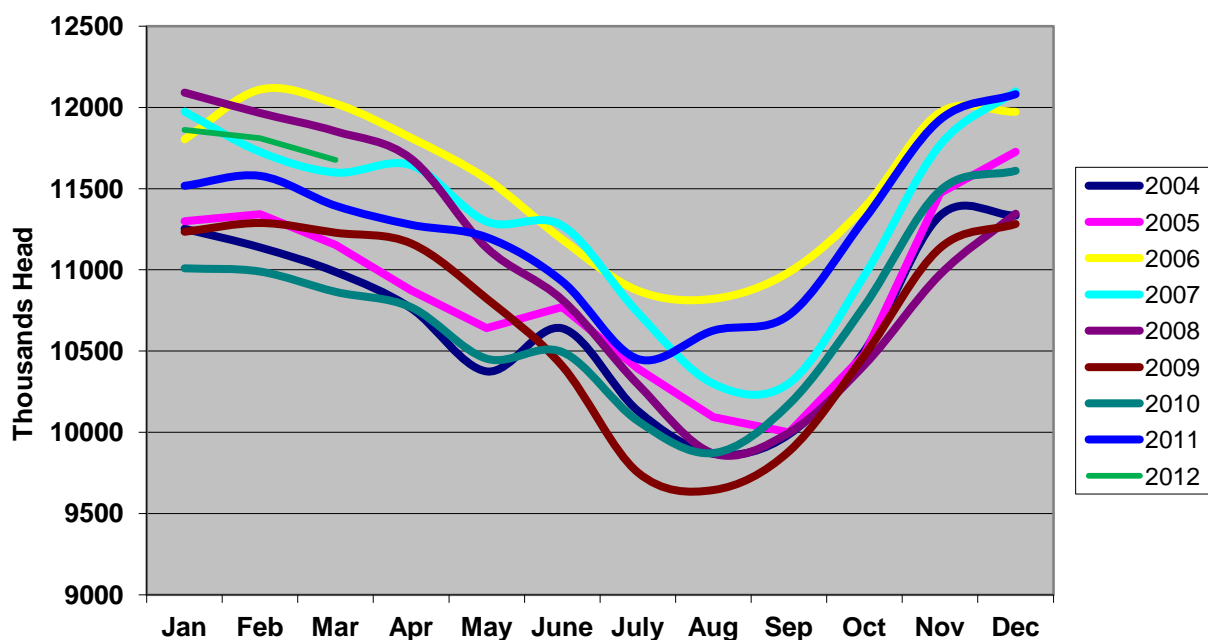


Figure 4. The seasonality of U.S. cattle on pasture vs. feedlots consuming high grain diets.

Transporting DDGS

Barges and ocean vessels

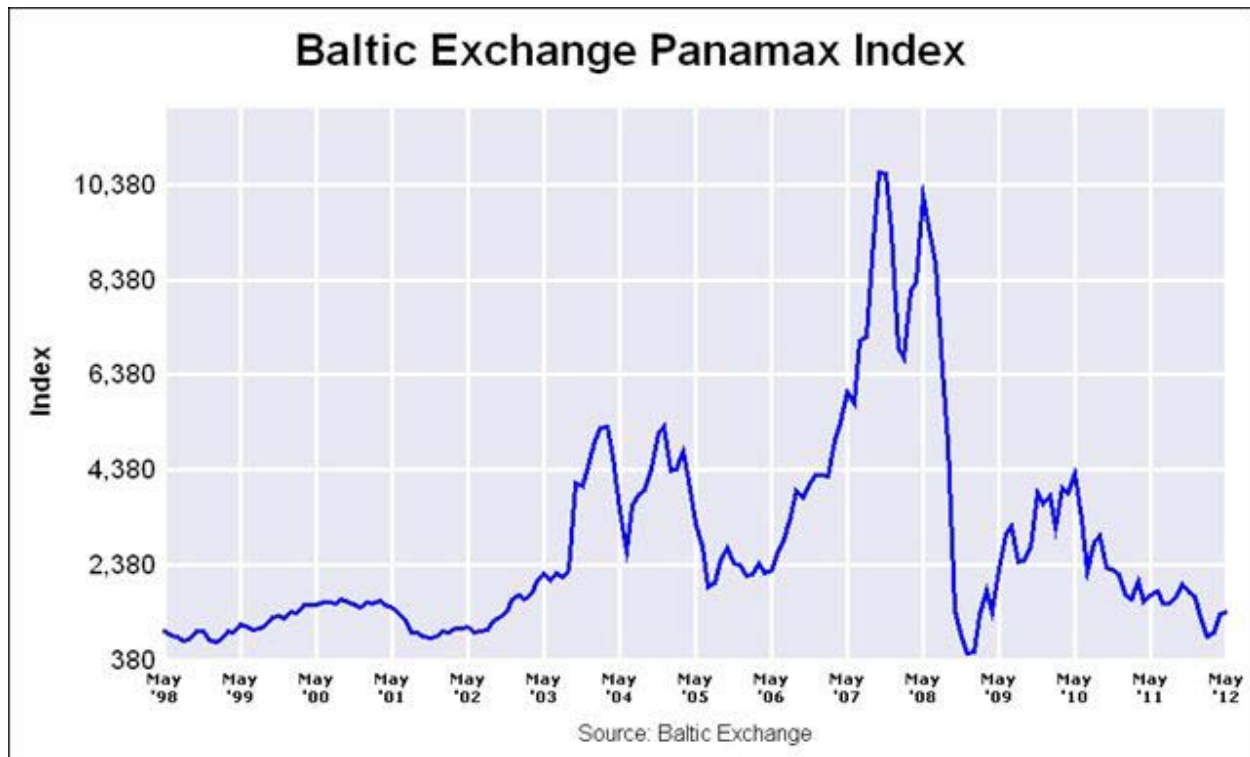
Ocean freight rates, based on the Baltic Exchange Panamax Index, have varied dramatically over the past 10 years (**Figure 5**). Ocean charter vessels were costing over \$94,000 per day in September, 2007 and then dropped as low as \$3,350 per day in December, 2008, a little more

than one year later. The high volatility in charter vessel freight has a major impact on the cost of obtaining DDGS for international customers. Current freight rates have increased substantially from the low point in December, 2008, but are much more reasonable than the highest freight cost that occurred during the summer and early fall of 2007.



Photo Courtesy of Steve Markham, CHS Inc.

One of the most cost effective freight options available is to ship DDGS on the river system via barges, and then load DDGS onto ocean vessels. Barge freight trades as a percent of tariff. Percentage rates fluctuate. Longer trips (e.g. Minneapolis, Minnesota to New Orleans, Louisiana) will have a higher tariff and probably a higher percentage rate. The U.S. has 5,000 miles of navigable waterways for barges and tug boats. Different tariffs and percentage rates are traded for each navigable river in the U.S.



Barges traded to New Orleans are usually offered as CIF NOLA (Cost, Insurance, and Freight to New Orleans). In general, DDGS is loaded onto barges in the interior U.S. and shipped to the Port of New Orleans and surrounding areas where it is transferred into holds on ocean going vessels. This transfer is usually done via mid-stream loaders. Both the barges and vessels are pulled up alongside the midstream loader where the transfer is made. Vessel sizes vary, but the most common vessel types are Handysize, Handymax, and Panamax vessels. The Handysize will hold 20 to 30 thousand metric tonnes of cargo, whereas the Handymax holds 35 to 49 thousand metric tonnes, and the Panamax holds 50 to 75 thousand metric tonnes of cargo. One Panamax vessel will hold the DDGS equivalent of approximately the amount contained in 37 barges or 555 rail cars. Ocean freight trades like a commodity and the rates change on a daily basis.

These rates depend on a number of factors including, but not limited to:

- market conditions
- type of vessel needed
- port drafts
- port charges
- load terms
- discharge terms
-

Factors affecting the overall ocean freight market include:

- supply and demand issues
- cost of vessel construction and operation
- new vessel construction vs. vessel retirements
- seasonal demand (e.g. grain harvest in North and South America)
- China's demand for all raw materials
- length of voyage
- turnaround time
- market psychology or expectations

Freight chartering options include:

- Voyage Charters – point A to point B shipments
 - o less risky for cost calculations
- Time Charters – give more flexibility because the vessel is chartered for a specified amount of time rather than by the voyage
 - o this option gives potentially higher risk and potentially higher reward. Once the cargo arrives to destination port it is unloaded via clam buckets which scoop the product out of the vessel, or it is unloaded pneumatically.

Containers

The United States is currently the world's largest container importer, which puts it in a very unique situation. Containers filled with electronics, textiles, auto parts, etc., arrive in the U.S., primarily from Asia, and they need to be shipped back to that region in order to be re-loaded with the same types of consumer goods for another shipment to the U.S. Steamship lines prefer to generate some revenue on the backhaul to Asia, rather than sending empty containers back to Asia which do not generate any revenue for them. This backhaul is where DDGS, along with other agricultural products, have found their niche in this freight market. The largest surpluses of empty containers in the interior U.S. are found in Chicago, Illinois and Kansas City, Missouri, followed by Memphis, Tennessee. The typical container export process is as follows:

1. DDGS is shipped from the ethanol plant to a facility dedicated to container loading. These facilities are typically located close to large container collection yards where the empty containers are stored.
2. In some cases, ethanol plants load containers with DDGS on site, thereby circumventing the costs associated with a third-party container loader.
3. Once containers are loaded with DDGS, they are shipped by trucks to the container collection yard and placed onto a rail chassis.
4. From there, containers are shipped by rail to a U.S. port to later be loaded onto a container vessel. Long Beach, California handles more containers than any other U.S. port. Typical transit time from Chicago to Long Beach is 7 to 10 days. Typical transit time from Long Beach to Asian ports is 16 to 18 days.

Shipping via containers is an excellent option for the discriminating buyer who desires purchasing DDGS from a limited number of sources or ethanol plants.



Photo Courtesy of Steve Markham, CHS Inc.

Rail

Hopper rail cars are used to export DDGS to Mexico and Canada. Rail shipments of DDGS to Mexico are growing exponentially every year, and the number of rail car shipments to Canada is also increasing. Rail exports are considered to be the easiest to manage considering the number of steps involved and the time in transit. Rail cars are loaded at the ethanol plant, billed with the railroad, and shipped to the final destination. Cars must be inspected and cleaned once they arrive at the border. Once inspected and cleaned, they cross the border and make their way to the final destination. The principal railroads serving the U.S. are Union Pacific (UP) and Burlington Northern Santa Fe (BNSF). Mexico's main rail lines are Ferromex (FXE) and Kansas City Southern de Mexico (KCSM), formerly TFM. Canada's principal rail lines are the Canadian National Railway (CN) and Canadian Pacific Railway (CPR).

Challenges of Exporting DDGS: Perspectives from DDGS Exporters

Loading cost and efficiency

It requires twice as much time to load a boat with DDGS as it does with corn. Since elevation margins are costly, this is one of the major cost contributors to DDGS transportation costs. For exporters that do not have control of elevators, events when vessels do not arrive on schedule can cause them to default on the loading. To avoid this situation, DDGS exporters must have the right boat at the right time from the right owner with the barges, rail cars, or boats waiting to load it. Timing is critical to minimize cost.



Photo Courtesy of Steve Markham, CHS Inc.

Containers

Very few containers return empty today as they did a few years ago. As a result, availability has been a challenge in the world economy, and has led to a real problem with on-time delivery. As a general rule, use of bulk vessels is less expensive, more dependable, and usually easier to control DDGS quality, especially when a sample is obtained and tested before loading.

Many of the containers today are loaded directly at the ethanol plant. Even plants that do an excellent job at producing high quality DDGS can, occasionally, produce a less than desirable DDGS co-product on a given day, and that co-product can be loaded in a container without the marketer knowing it.

Containers being delivered to the right ship for a timely delivery can also sometimes be a problem, as well as the possibility of freight rates changing at any time even after a container is loaded. Seasonality and variability in the container market occasionally causes disruption in the supply chain, including cancelled bookings and restricted availability in key origin markets.

Suggestions for Success in Importing DDGS

It is essential that DDGS importers know, and have a relationship with their supplier. Specifically, importers should understand the exporting company's logistical and transportation capabilities. If a DDGS exporter does not own export elevators, access to these elevators can be a problem. Currently, U.S. DDGS exporters have limited freight and elevation capacity because fewer elevators are available and record supplies of grain and grain co-products are being produced.

Freight spreads change. Exporters that have facilities and capabilities via multiple transit ways (Great Lakes, major rivers, Gulf of Mexico, Pacific Northwest) have a better ability to serve the export market around the globe. Purchasing DDGS at the lowest freight costs will require working with companies that have multiple transportation and loading options and flexibility.

Suppliers who market for specific ethanol plants, have control over the DDGS sources and can more easily control the quality of DDGS. Buyers who purchase through brokers or other suppliers that do not have direct marketing agreements with ethanol plants cannot easily control the quality of DDGS. It is also possible for DDGS marketers that control the supply sources, to send DDGS samples at the time of origination, to reputable commercial laboratories for testing, and send results directly to the customer before a vessel or hold is loaded. It is important to identify and agree on a third party, reputable commercial laboratory for sample analysis to avoid potential problems upon arrival at the destination.

Mycotoxin testing can be conducted on origin samples or the supplier can provide the procedures and limits to be used at the ethanol plant where the DDGS was produced for testing corn used for DDGS production. Color scores can also be determined for the DDGS customer using Hunter or Minolta color score measurements. Protein and fat guarantees should always be agreed upon before consummating a trade.





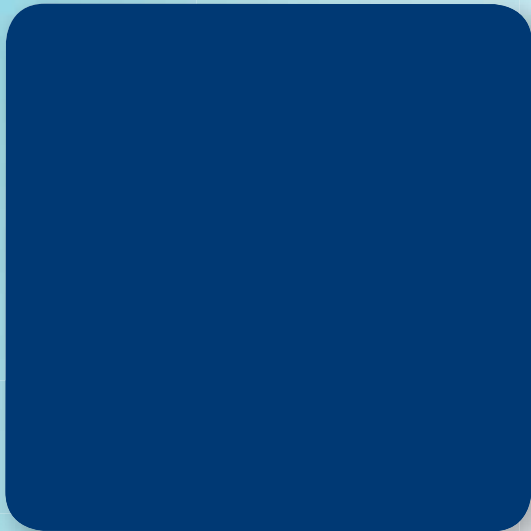
Photos Courtesy of Steve Markham, CHS Inc.



DDGS Unloading
Photos Courtesy of Steve Markham, CHS Inc.

CHAPTER 30

Summary of U.S. Grains Council Sponsored International Feeding Trials



Chapter 30

Summary of U.S. Grains Council Sponsored International Feeding Trials

Australia

Cattle

Effect of DDGS inclusion on pelletizing characteristics and milk production of dairy cows

A commercial dairy trial was conducted to measure the effect of varying levels of corn DDGS on pellet quality (pellet durability index (PDI), color, odor and bulk density), milling (tonnes per hour, steam and feed rate, and amps), and on-farm animal performance (palatability and change in milk production). DDGS from corn was sourced from the US Grain Council and shipped to Australia. Energy (14.5MJME/kgDM) and protein (30%, dry matter basis) specifications of DDGS were as provided by USGC. These specifications were used in 'balancing' the ration. Four farmers received various concentrations of the DDGS feed rations, ranging from 5% to 20% inclusion. The choice of ration was maintained as per the current ration purchased by the farmer which were Summer Special (16% Protein and 12.5 MJ ME/kg on a dry matter basis) and Rovers Ration (20% Protein and 12.3 MJ ME/kg on a dry matter basis). Feeding rates were as follows:

Control			Treatment 0
Farm A	6kg/head/day	5% inclusion DDG-S	Treatment 1
Farm B	6kg/head/day	10% inclusion DDG-S	Treatment 2
Farm C	7kg/head/day	10% inclusion DDG-S	Treatment 3
Farm D	10/kg/head/day	20% inclusion DDG-S	Treatment 4

Rations were formulated to same energy and protein as the previous rations supplied. There were no statistical analyses performed on the results of this trial. All results are numerical and based on raw data. The results on milling parameters are shown in Table 1. Compared to control treatment, there appeared to be no effect of DDGS inclusion on milling parameters.

Table 1. Effect of DDGS on pelleting parameters

Ration	Treatment	Steam	Feed	PDI	Amps	Bulk	Tonnes/hr
Control	0	70	3.5	96	150	59	17.8
Summer Special	1	69	3.7	96	150	58	18.5
	2	71	3.6	94.7	148	58	17.6
	3	72	3.4	97	150	60.8	16.9
Rovers ration	4	65	3.2	96.4	155	60	17.3

Milk production results are shown in Table 2. For cows fed the Summer Special ration, milk production did not seem to change following DDGS inclusion in the ration. This trend appears to be same with the 5%, 10% and 20% dietary inclusion of DDGS. Note that the rations were formulated to be the same energy & protein and no significant change were expected. With Rovers ration (20% inclusion), it appears that milk production decreased after the original ration was re-introduced into the diet. The farmer commented that he believed that the change was a result of decreased palatability of the traditional DDGS previously used, but highlighting the good increase in palatability of the US DDGS. All other parameters did not change (i.e. milk fat and protein).

Table 2. Effect of dry distiller's grain with soluble on milk production parameters

Ration	Treatment	No. of cows	No. of days	Liters during/post	Fat (%)	Protein (%)
Summer Special						
	1	125	5	26.8/27	3.6	3.1
	2	320	8	27.1/26.7	3.9	3.1
	3	183	9	23.9/22.7	3.4	3.0
Rovers ration						
	4	390	12	34/31.8	4.2	3.1

In conclusion, these preliminary trials suggest that DDGS can be included in dairy rations in the Northern Victorian Dairy region of Australia. It may be possible to include DDGS up to 20% without any adverse effect on milk production of dairy cows or in the pelleting process. DDGS inclusions did not seem to have a major impact on pelleting other than the issue with the steam conditioning of the higher 20% DDGS inclusion. While anecdotal, it is believed that the physical ability of the pelleting process to handle US DDGS is at a maximum of 20% DDGS inclusion. Further trials are required to confirm this. DDGS is a tangible alternative for CopRice Feeds, and will become a great option if economical against current raw material protein and energy sources.

Indonesia

Cattle

Evaluation of DDGS for feeding cattle under commercial conditions. PT Lembu. Jantan Perkasa

A feeding trial was conducted to measure the effect of DDGS inclusion on the performance of finishing cattle in Indonesian feedlots (May - September 2007). Two dietary treatments were used in this trial, a control diet (0% DDGS) and treatment diet (20% DDGS) in a concentrate made from locally available ingredients (cassava waste, wheat pollard, copra meal, palm kernel meal) and elephant grass given at 2.4 kg fresh daily. The diets were formulated to have similar protein (13%) and TDN (72%). Each diet was fed to newly arriving cattle (Brahman cross from

Australia) in pens containing 25 cattle and replicated 3 times (a total of 150 cattle used in the 105 day trial). Measurements of body weight and feed consumption were taken after 49 and 105 days of feeding. Daily gain of cattle fed 20% DDGS was 1.19 kg and was not statistically different from daily gain of cattle fed the control diet (1.30 kg). Average concentrate intake between 50-105 days was 8.66 kg and 8.23 kg for DDGS and control diets respectively. Dry matter and protein digestibility, measured by internal marker, of diets containing DDGS was 68.5% and 65.7% respectively and slightly lower than the control treatment at 76.7% and 79.1%, respectively. Carcass percentage of cattle fed DDGS was 52.7 % while those fed the control diet was 50.3%. The pH of feces from cattle fed DDGS was 5.6 compared to 7.3 from those on the control diet. The cost of the feed containing DDGS (Rp 868) was lower than the control feed (Rp 942). In conclusion, DDGS can be economically fed to finishing cattle at a 20% inclusion rate without negative effects on growth performance and carcass characteristics.

DDGS use as a substitute and a supplement to concentrate in dairy nutrition results in significant improvement in milk production, Central Research Institute for Animal Science
Jl. Pajajaran Bogor

An experiment was undertaken in 2009 to improve milk production by supplementing local feeds with U.S. corn DDGS (*Dried Distiller's Grains with Solubles*). The results indicated that milk production increased by 10% on a farm in Cinagara, West Java and by 30% in a farm in Grati, East Java. Domestic milk production can only supply 30% of Indonesia's total milk requirement. About 70 percent of the total milk requirement is imported from overseas. One of the main problems facing the dairy industry in Indonesia is low quality of dairy feed. DDGS is a co-product of corn ethanol production containing valuable energy and protein levels amid reasonable price. In 2009, Indonesia is estimated to import about 200,000 metric tons of DDGS mainly used for poultry diets. In this research project, DDGS was used as a supplement and a substitute for the dairy concentrate. The experiment was conducted in two locations: 1) a farm in Cinagara, Sukabumi District, West Java, in which 1 kg DDGS was given as a substitute for the concentrate and performance was compared to non-DDGS supplemented animals, and 2) a farm in Grati, Pasuruan District, East Java, in which 1 kg DDGS was given as a supplement on top the concentrate given by the farmer and performance was compared to non-DDGS supplemented animals. Twenty dairy cows were used in each location and divided randomly into two comparable groups. The results show that milk production increased by 10% in Cinagara, West Java and by 30% in Grati, East Java. The higher milk production with the inclusion of DDGS was mainly due to the high protein content in DDGS (30%). Economically, the supplementation with 1 kg of DDGS benefited the dairy farmers due to the income from increased milk production was higher than the cost of including DDGS in the concentrate ration. Results from this project indicate that the milk production and farmer income can increase significantly if DDGS are used in dairy feeds. Results of this project should be disseminated to other dairy farmers in Indonesia.

Japan

Broilers

Report of the results of a DDGS feeding trial in broilers. Kimura, N. Access at:
[http://www.ddgs.umn.edu/international-research/2007-Japan%20DDGS Trial in Broilers-ENG.pdf](http://www.ddgs.umn.edu/international-research/2007-Japan%20DDGS%20Trial%20in%20Broilers-ENG.pdf)

This study was conducted to assess the effects of corn DDGS produced in the U.S. on meat production and quality, such as accumulation of peritoneal fat, composition of fatty acids, meat color, and fecal phosphorus concentration. A total of 63 broilers were allotted to the following 3 groups (21 animals per group) and were fattened for 4 weeks: 1) control group, fed a commercial feed; 2) fed a diet containing 10% DDGS; 3) fed a diet containing 20% DDGS. The higher the inclusion of DDGS in the diet, the higher the growth rate found in the early fattening period. The feed intake was similar across groups. The production of cut meat tended to be higher in the DDGS fed groups. Also, the higher the content of DDGS in the diet, the lower weights of liver and peritoneal adipose tissue, and a smaller amount of fat accumulated in the liver. Meat from the DDGS fed groups was observed to be rich in linoleic acid, which was probably due to the higher content of linoleic acid and unsaturated fatty acid in DDGS.

Laying hens

Basic studies on the effect on layer hens of DDGS produced in USA

Access at:

<http://www.ddgs.umn.edu/articles-poultry/2005-Kimura-%20Layer%20hens%20trial%20report%20summary.pdf>

U.S. studies have shown that dietary inclusion rates of 10% DDGS is suitable for hens. However, there are only a few studies in Japan. This study was conducted to evaluate the impact of feeding USA-made DDGS to White Leghorn Julia strain hens (the most commonly reared layer breed in Japan) on egg quality and fat metabolism. DDGS was added to a commercial feed used in Japan, where there is a demand for eggs with stronger yolk color than in the U.S. Dietary treatment consisted of 1) control diet with commercial layer feed; 2) feed containing 10% DDGS; 3) feed containing 20% DDGS; 4) feed containing 10% CS (a 1:1 mixture of crushed corn and soybean cake which is similar to DDGS in protein and ME content); and 5) feed containing 20% CS.

The body weight decreased in all treatment groups throughout the treatment period. This decrease was greater in hens fed higher percentages of DDGS or CS. The weight of individual eggs did not differ among the control and treatment groups, but egg production showed a decreasing trend in the 20% DDGS group, which reduced the total weight of eggs produced in the DDGS group. Eggshell strength and Haugh Unit (HU) was not affected by dietary treatments. Egg yolk color was significantly affected by dietary treatments. The color was reduced immediately after switching to the experimental feeds, but recovered rapidly in the DDGS groups, which reached the level of the control group in about 10 days. In the CS groups, however, the color did not recover and was lighter almost proportionately to the amount of CS in the diet. This suggested that feeding diets containing 10 or 20% DDGS had almost the same yolk color as feeding control diet with paprika to enhance yolk color. The plasma triglyceride

concentration decreased after feeding diets with DDGS, suggesting a decrease in lipid synthesis in the liver. DDGS groups had a higher liver and ovary weight, whereas the weight of their abdominal adipose tissues tended to be low. In 20% DDGS group, fat content was highest in the ovary (follicles) and abdominal adipose tissue. In conclusion, this study suggested that DDGS can be used in the feed of layer hens in Japan without affecting egg quality. DDGS may also improve egg yolk color, which leads to the savings of a yolk coloring agent.

Effects of feeding corn DDGS on ammonia and hydrogen sulfide emissions from manure of laying hens Access at: http://www.ddgs.umn.edu/international-research/2011-Maki_IIDA-Effects_of_feeding_corn_DDGS_on_ammonia.pdf

One hundred twenty white leghorns (Julia strain, aged 251 days) with stable egg production were used in an experiment to determine the effects of feeding corn DDGS to laying hens on ammonia and hydrogen sulfide emissions from manure. The control diet contained no DDGS, as well as 10%, 20% and 30% DDGS diets that replaced corn and soybean meal, were all formulated to provide similar level of crude protein, metabolizable energy, phosphorous, calcium, methionine, lysine, tryptophan and threonine. Experimental diets were fed ad libitum to three replicates of 10 hens each for 4 weeks.

Egg production performance was investigated during the experiment period and yolk color evaluation was also conducted at the end of the experiment using the eggs produced by one of the replicates of each dietary treatment group. All of the manure was collected from replicates on days 6-7, 13-24 and 27-28 after the start of the experiment and stored in buckets. Ammonia and hydrogen sulfide concentrations were measured in the empty space in the each bucket at 12, 24 and 48 hours later, followed by pH measurement of the manure. Manure water content was also measured using the manure produced on days 5, 12 and 26 after the start of the experiment and nitrogen and dry matter excretion rates were calculated for each dietary treatment. There was no difference in body weight gains during the period from the day of group assignment to the final day of the experiment between the control diet group and the 10% and 20% DDGS diet groups. Body weight gain of the 30% DDGS group was significantly lower than that of the control diet group. Except for one of the laying hens fed 10% DDGS diet that stopped laying eggs and was culled, all of the hens in the experiment were healthy and no abnormal health conditions were observed. There were no differences in egg production rate, average egg weight, or daily egg production between the control diet group and the 10% DDGS group. Hens fed 20% and 30% DDGS diets showed a tendency to decrease in egg production rate, average egg weight and daily egg production at week 2 after the start of the experiment, and thereafter, compared to those fed the control diet. This tendency was more pronounced in the group fed the 30% DDGS diet. There was no significant difference in feed intake in any weeks during the experimental period between the group fed the control diet and the other three dietary treatment groups. Although the weekly feed conversion rate of the DDGS diet groups tended to slightly decrease compared to the control diet group, there was no significant difference in the feed conversion rate throughout the experiment period between the control diet and the other three dietary treatments. Egg yolk color significantly increased as dietary level of DDGS increased. Adding DDGS to diets had no effect on the concentration of ammonia from manure at any time point. The dietary DDGS inclusion level did not affect the concentration of hydrogen sulfide at weeks 1 and 2 after the start of the experiment, however, the concentration

of ammonia from the DDGS diet groups tended to decrease at week 4. This tendency was apparent in the treatment groups fed the 20 and 30% DDGS diets. Manure pH significantly decreased as dietary level of DDGS increased. There was no difference in manure water content among treatment groups at week 1, but there was a trend for decreased in manure water content at weeks 2 and 4, almost directly correlating with the increase in dietary level of DDGS. Nitrogen and dry matter excretion rates showed negligible differences between hens fed the control diet and the 10% DDGS diet, but excretion rates of hens fed the 20% and 30% DDGS diets tended to be higher than those fed the control diet.

Fish

Report on the feeding trial and usage of DDGS in aquaculture fish diets Access at: [http://www.ddgs.umn.edu/international-research/2010-Japan-Report on feeding trial and usage of ddgs in aquaculture\(ENG\)2.pdf](http://www.ddgs.umn.edu/international-research/2010-Japan-Report%20on%20feeding%20trial%20and%20usage%20of%20ddgs%20in%20aquaculture(ENG)2.pdf)

An experiment was conducted to determine if there are any differences in the quality of fish meat between fish fed diets containing lower cost ingredients compared to diets containing fish meal. High protein (49%) DDG was used in this study to replace a portion of fish meal. Feed cost was reduced by 10% by partially replacing fish meal with 20% HP DDG as a result of the greatest improvement in feed conversion compared to control diets. Replacing 12% of fish meal with corn gluten meal improved feed conversion by 4%, which had less effect on reducing feed cost (3.7%). There was no yellowing of muscle, but rather fish meat was whiter in groups fed corn co-products. No difference in palatability was observed among dietary treatments.

Swine

Effect of feeding corn distiller's dried grains with solubles (DDGS) on the growth and other parameters of swine. Suga, K., Y. Hashimoto, M. Hanazumi, and C. Yonemochi.

Access at:

[http://www.ddgs.umn.edu/international-research/2006-Keisei%20Suga%20et%20al-%20Feeding%20DDGS%20to%20swine%20\(Japanese%20trial\).pdf](http://www.ddgs.umn.edu/international-research/2006-Keisei%20Suga%20et%20al-%20Feeding%20DDGS%20to%20swine%20(Japanese%20trial).pdf)

This study was conducted to investigate the effect of adding DDGS to the diets of finishing pigs in Japan on growth performance, carcass quality, and other parameters. Fifty LWD pigs (25 barrows and 25 gilts) about 3 months of age were used in this study. Ten pigs were allotted to 1 of the 5 dietary treatments, and barrows and gilts were reared separately in groups. Pigs in the control group were fed a commercial diet without DDGS from a body weight of 30 kg up to marketing. Pigs in Treatment 2, 3, and 4 were fed different levels (10, 15, and 20%, respectively) of DDGS from 30 kg to 70 kg BW followed by the same feed as controls from 70 kg up to marketing. Pigs in Treatment 5 were fed 10% DDGS feed throughout, from 30 kg to marketing. Body weight of each animal was measured weekly. Feed intake of each pen was measured bi-weekly. Pigs were harvested when individual BW achieved 110 kg. Carcass weight, dressing %, backfat thickness were measured. The L*, a*, b* values of the carcass were determined, and carcass meat was graded. There were no significant differences on average daily gain, feed intake, and feed conversion ratio among dietary treatments. Carcass weight, dressing %, backfat thickness, and carcass quality score did not differ among

treatments. Among barrows, the b^* value of meat color in the 20% DDGS group was significantly higher than that of the 10% DDGS group, and a^* value was significantly higher when comparing 10% DDGS group with the control group. However, there were no definite trends in relation to the percentage of DDGS added in the feed and its period of feeding. These results showed that adding up to 20% DDGS in the feed of finishing pigs did not impact growth performance and carcass characteristics, suggesting that DDGS could be used in finishing pigs' diets in Japan.

Dairy cows

Effects of corn distiller's dried grains with solubles (DDGS) under hot summer conditions in lactating dairy cows. Tanaka, M.

Access at:

http://www.ddgs.umn.edu/international-research/2008-Japan-%20Study_report-DDGS_dairy_summer.pdf

In Japan, the use of DDGS as a feedstuff for livestock animals is increasing dramatically. However, only limited information has been obtained about the properties of DDGS from feeding trials. In lactating dairy cows, in particular, the effects of DDGS on the physical condition and properties of raw milk are poorly understood. In order to obtain information on the use of DDGS in dairy cattle under high temperature conditions, a TMR supplemented with DDGS was fed to lactating dairy cows during the hot summer months, and its effect on DM intake (an indicator of palatability), blood parameters, milk yield, and fatty acid composition in raw milk was assessed.

Three Holstein cows were used in each of the DDGS group (20% DDGS) and the control group (0% DDGS). All animals were kept under the same conditions throughout the study period. Figure 1 shows the treatment and sampling schedule.

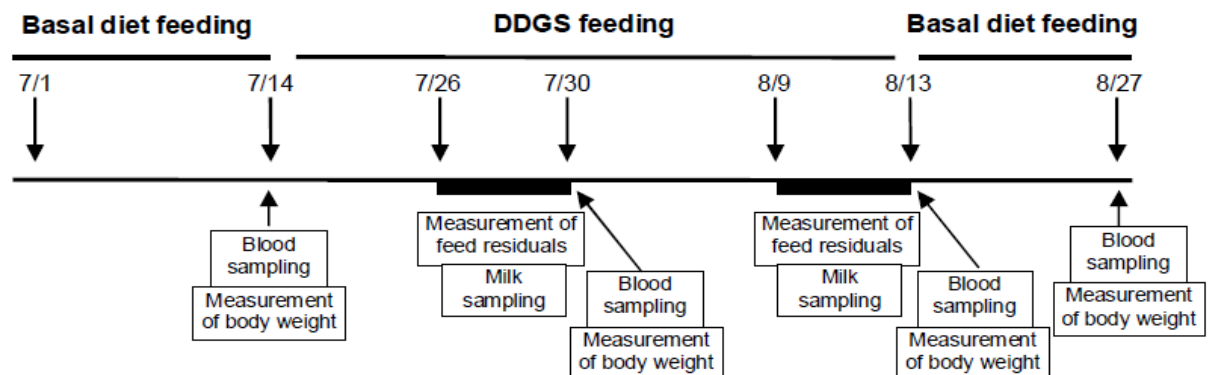


Figure 1. Overview of the DDGS feeding trial.

Before and after the DDGS feeding period, cows received *ad libitum* a TMR as the basal diet. The body weight of each cow was measured after morning milking on d 17 and 31 of the DDGS feeding period, and on d 14 of the post-DDGS period. Feed intake from d 13 to 27 and from d 27 to 31 of DDGS feeding period was measured. Milk samples were collected at every milking time (morning and evening) throughout the study period. Blood samples were collected prior to

morning milking on d 17 and 31 of DDGS feeding period, and on d 14 of the post-DDGS feeding period. The rectal temperature of each cow was measured every morning immediately after milking.

During the DDGS feeding period, the daily mean ambient temperature (29.1°C) was higher than the normal range (23°C), and thus the rectal temperatures of the cows in both groups were above the normal range, but no significant difference was observed between two groups. There was no significant difference in feed intake, body weight between the DDGS and control group. The blood cell counts, hemoglobin and hematocrit of lactating dairy cows were not significantly affected by DDGS under the high temperature conditions. The plasma levels of total protein, albumin and sulfhydryl (SH) groups in the DDGS group were higher ($P < 0.05$) than those in the control group, although they were within normal ranges, suggesting DDGS feeding may have affected the nutritional condition or oxidative stress level in lactating dairy cows. There was no significant difference in milk yield between the two groups. In the DDGS group, the percentage of milk protein was significantly lower, while the percentage of lactose was significantly higher than those in the control group. There was no significant difference in fatty acid composition of raw milk between the two groups. In conclusion, when lactating dairy cows were fed 20% DDGS in the diet, there were only marginally negative impacts, if at all, on milk composition, and cow's conditions were unaffected. Therefore, if it is cost-effective, DDGS is a possible option as a feedstuff in dairy cows and can be included at rates up to 20% in the diet.

Report on experimental feeding of dairy cattle with distiller's dried grains with solubles (DDGS)

Access at:

[http://www.ddgs.umn.edu/international-research/Japanese%20\(DDGS%20part%201-2004\).pdf](http://www.ddgs.umn.edu/international-research/Japanese%20(DDGS%20part%201-2004).pdf)

This study was conducted to evaluate the usefulness of DDGS as a feedstuff in existing dairy farms in Japan before its large-scale adoption as a feed in the country. Three dairy farms of the Nasu region, which is the leading dairy farm region of the country, were chosen to conduct this study. All cattle were assigned to either DDGS group (12-15% DDGS) or control group (without DDGS). The study was conducted for about 3 months. During the first and third month, all animals were fed a control diet. During the second month, animals were fed their assigned diets (DDGS or control diet). The number of cattle used in this study were 34, 39 and 87 respectively in farms A, B and C. The milk yield and milk components (milk fat, milk protein and non-fat solid contents) were determined each month. The milk yield and milk components showed no significant difference at the time of switchover between non-DDGS and DDGS feeds and did not differ among the different periods at each farm location, indicating that including DDGS in the diet did not affect milk yield and milk composition of dairy cattle, and DDGS could be used as a feed ingredient for dairy cattle in Japan.

Other

Report on storage experiments with distiller's dried grains with solubles (DDGS)

Access at:

[http://www.ddgs.umn.edu/international-research/Japanese%20\(DDGS%20part%202-2004\).pdf](http://www.ddgs.umn.edu/international-research/Japanese%20(DDGS%20part%202-2004).pdf)

In order to detect quality changes in DDGS, and autoxidation of lipids at high temperature, the authors of this study conducted high temperature storage tests and high temperature and high humidity exposure tests on DDGS samples imported from the U.S. DDGS was stored at high temperatures (40°C and 60°C) for 8 weeks, and at high temperature and high humidity (40°C, relative humidity 75-100%) for 4 weeks to simulate the passage of DDGS through high temperature regions during long transportation. The qualitative changes in lipids, and changes in odor and color were examined. All control samples were stored in a feed store at 23 consistently.

High temperatures increased off odor in the samples, suggesting that high temperature storage can lower the commercial value of DDGS because of off odor development. The color of DDGS changed during high temperature storage. At 60°C, the color of DDGS samples turned darker and became brown in appearance. This change could be observed after just one week of storage. At 40°C, however, there was little change in external appearance even after 8 weeks of storage. In both high temperature storage and high temperature plus high humidity storage, acid value and peroxide value of lipids in DDGS samples remained low and did not change relative to storage time. In conclusion, under high temperature (60), the color and odor of DDGS changes, but there are no degenerative changes of lipids. DDGS has a high lipid content of 10-13%. The results of this study suggest that the lipids do not easily degrade, and therefore the nutritional value of DDGS does not change much under normal conditions of storage.

Report on experiments on variation in nutrient composition and digestibility of distiller's dried grains with solubles (DDGS)

Access at:

[http://www.ddgs.umn.edu/international-research/Japanese%20\(DDGS%20part%203-2004\).pdf](http://www.ddgs.umn.edu/international-research/Japanese%20(DDGS%20part%203-2004).pdf)

This study was conducted to evaluate the relationships between the external appearance of DDGS and its nutrient composition and digestibility. A total of 22 DDGS samples were analyzed for total energy, water-soluble matter, water soluble protein, color values, apparent color depth, and dry matter digestibility. The variation in nutrient composition and the digestibility indices were also analyzed. The correlation between color and nutrient composition and digestibility indices was studied to estimate the nutritional value of DDGS from its external appearance. There was a small variability (coefficient of variation less than 10%) observed in analyzed parameters except for water-soluble matter (coefficient of variation about 23%). Samples with high luminosity measured by the color difference meter had a high fat content and high total energy, and low contents of water-soluble matter and water-soluble nitrogen. DDGS with high apparent color depth (dark in color) had low total energy and high water-soluble matter content.

Korea

Broilers

Nutritive and economic values of corn distiller's dried grains with solubles in broiler diets.
Bong Duk Lee

This study was conducted to evaluate the nutritive and economic values of high quality DDGS in commercial broiler diets. Day-old 3200 unsexed Cobb-500 broiler chicks were randomly allotted to 16 pens with 200 chicks per pen. There were four diet treatments (0, 5, 10, and 15% DDGS), and four replicates per treatment. All birds were fed a commercial pre-starter diet until d 7, and then they were fed their respective starter diets and grower diets from d 8 to 21 and from d 22 to 29, respectively. One bird from each pen was sacrificed for carcass measurements. Muscles from breast and thigh, and shanks from both sides were sampled for texture and color analysis. Thigh meat samples were collected for fatty acid composition analysis. No significant difference was found in growth performances among the four treatments. As the DDGS level increased, the degree of unsaturated fatty acids in meat increased significantly ($P < 0.05$). The color scores of breast and thigh muscles were not influenced by DDGS, however, the yellowness of shank increased significantly by the addition of DDGS. Although not significant, the hardness of breast and thigh meats tended to decrease by the addition of DDGS. These results suggest that the use of DDGS in broiler diets up to 15% does not have negative effects on growth performance and meat qualities.

Laying hens

Nutritive and economic values of corn distiller's dried grains with solubles in laying hen diets.
Bong Duk Lee

A layer feeding trial was conducted for 10 weeks to investigate the effects of the addition of corn distiller's dried grains with solubles (DDGS) to layer diets on laying performance, egg qualities, and yolk fatty acid composition. A total of 900 Hyline Brown layers, 24 weeks of age, were randomly allotted to 20 replicate laying cages, 45 birds per replicate. There were four diet treatments (0, 10, 15, and 20% DDGS), and 5 replicates per treatment. The use of DDGS up to 20% level in layer diets did not have any influence on feed intake, laying rate, total egg mass, mean egg weight, and feed conversion ratio. DDGS did not impact weight, breaking strength, and color of eggshell. The yolk color was significantly increased by DDGS supplementation. As the DDGS level increased, the oleic acid content decreased, and the linoleic acid increased ($P < 0.05$). The degree of saturation of yolk fatty acids was not affected by dietary DDGS. In conclusion, the use DDGS up to 20% level in layer diets could replace corn and soybean meal without any negative effect on laying performance, and possibly decrease the feed cost.

Swine

Nutritive and economic values of corn distiller's dried grains with solubles in swine diets.
Young, C.J., C.K. Byung, K.K. Jong, and H.L. Won.

Access at:

[http://www.grains.org/images/stories/technical_publications/2008-2009%20DDGS%20feeding%20trials%20\(2\).pdf](http://www.grains.org/images/stories/technical_publications/2008-2009%20DDGS%20feeding%20trials%20(2).pdf)

To evaluate the nutritive and economic values of U.S. corn ethanol DDGS in Korean commercial hog diets, a total of 396 head of three breed crossed (YLD) pigs were utilized in a feeding trial. The experiment was conducted in three phases, nursery (15-30 kg), grower (30-70 kg), and finisher (70-105 kg) simultaneously. Each experimental phase consisted of 3 treatments: control, DDGS 10%, and DDGS 15% for nursery phase (**Table 1**), and control,

DDGS 15%, and DDGS 20% for grower/finisher phases (**Table 2, 3**). The corn ethanol DDGS used in this study was imported from the U.S.

Table 1. Nursery pigs (15-30 kg).

	Control (DDGS 0%)		Treatment 1 (DDGS 10%)		Treatment 2 (DDGS 15%)	
# of pens(replications)	2	2	2	2	2	2
# of pigs per pen	10	10	10	10	10	10
Total # of pigs per treatment	40		40		40	

Table 2. Grower pigs (30-70 kg).

	Control (DDGS 0%)		Treatment 1 (DDGS 15%)		Treatment 2 (DDGS 20%)	
# of pens (replications)	1	1	1	1	1	1
# of pigs per pen	20	20	20	20	20	20
Total # of pigs per treatment	40		40		40	

Table 3. Finisher pigs (70-105 kg).

	Control (DDGS 0%)		Treatment 1 (DDGS 15%)		Treatment 2 (DDGS 20%)	
# of pens (replications)	1	1	1	1	1	1
# of pigs per pen	26	26	26	26	26	26
Total # of pigs per treatment	52		52		52	

Body weight for individual pigs on initial and final days of the experiment was recorded to calculate average daily gain (ADG). Feed intake of each pen was measured to determine the average daily feed intake (ADFI). When finisher pigs reached marketing weight, 10 pigs were randomly selected from each treatment to evaluate carcass and pork quality traits, including carcass weight, backfat thickness, loin eye muscle area, lean %, carcass pH 24, and meat color (L^* , a^* , b^*) of longiss muscle. Carcass weight and back fat thickness were measured by Korean carcass grading system. Loin eye are of 5th lib was measured. Lean percent (5% fat) was estimated by equation of NSIF. There were no significant differences among treatments for ADG, ADFI, and G:F of nursery, grower, or finish phase, respectively. Back fat thickness was similar among treatments. However, there was a significant difference ($P < 0.05$) between sexes for back fat thickness (average of gilts was 20.1 mm, barrows was 26.6 mm). There were no significant differences for loin pH after 24 hours, NPPC color, drip loss after 72 hours, or marbling score.

Economic values of including U.S. corn ethanol DDGS in swine diet were also evaluated. In general, as DDGS substitution rates increase, inclusion rates of corn, soybean meal, and crude protein are reduced, whereas those of synthetic lysine and lime stone increase. Addition of

DDGS by 15% to nursery, grower, and finisher diets resulted in increased total ingredients cost by 1.1, 0.6, and 0.1%, respectively. The minimal biological and cost impacts under current unstable feed grains and other ingredients supply conditions, indicates U.S. corn DDGS could be immediately utilized in Korean swine diets.

Mexico

Swine

Effects of feeding grow-finish pigs conventional swine diets used in Jalisco, Mexico compared to diets containing 10% Norgold DDGS on growth performance

Access at:

<http://www.ddgs.umn.edu/articles-swine/2003-Mexico%20feed%20trials.pdf>

This study was conducted in Jalisco, Mexico (Ramiro Martin) to compare growth rate, feed intake and feed conversion of pigs fed conventional diets used in Mexico with diets containing 10% Norgold DDGS during grower (30 to 60 kg body weight) and finisher (60 to 100 kg) phases. A total of 800 pigs and a total of 600 pigs were assigned to either the control or DDGS diet during the grower and finisher phase, respectively. Pen was the experimental unit with 12 replications during the grower phase and 9 replications during the finisher phase. Pigs were fed experimental diets for 49 days during the grower phase and for 50 days during the finishing phase. During the grower period, pigs fed the DDGS diet grew faster than those fed control diet ($P < 0.0002$). There was no significant difference in feed intake ($P < 0.12$) and feed conversion ($P < 0.13$) between the two dietary treatments. During the finisher period, pigs fed the DDGS diet showed similar ADG as those fed the control diet. Average daily feed intake of pigs fed the DDGS diet was higher ($P < 0.01$) than those fed the control diet, but feed conversion was not significantly different ($P > 0.79$) between the treatments. In conclusion, this study showed that grow-finish pigs fed 10% Norgold DDGS diet had higher ADG during the grower phase, and higher ADFI during the finisher phase compared to those fed the standard diet used in Jalisco, Mexico. Feed conversion was similar between pigs fed the control and the DDGS diets. These results suggest that Norgold DDGS can be added to grow-finish swine diets in Mexico to provide at least equal, and perhaps improved growth performance compared to current commercial swine diets.

Distiller's dried grains with solubles – swine feeding trial

This study was conducted to evaluate the effects of feeding diets containing DDGS on pig growth performance in Mexico. Growing finishing pigs were allotted to one of two dietary treatments containing either 0 or 10% DDGS. Pigs were maintained on a feeding plan of 18 d for Phase I diet, followed by 34 d for Phase II diet, followed by 55 d for Phase III diet. Pigs were weighed initially, and at the end of each phase. Average daily gain was similar between DDGS and control treatment. Feed efficiency varied by feeding period. DDGS treatment pigs appeared more efficient during the 18 day and 34 day feeding periods, and the control treatment appeared more efficient during the 54 day feeding period. These results suggest that including 10% DDGS in the grower finisher diets of swine does not have negative effects on growth performance.

Others (DDGS demo trials with unknown country):

Access at

[http://www.grains.org/images/stories/technical_publications/2008-2009%20DDGS%20feeding%20trials%20\(2\).pdf](http://www.grains.org/images/stories/technical_publications/2008-2009%20DDGS%20feeding%20trials%20(2).pdf)

Chemical composition of DDGS shipments (RCFF Trials)

In order to evaluate the variation in chemical composition of DDGS, five representative samples of DDGS from 5 shipments were chemically analyzed. Ranges of chemical composition of these 5 shipments are shown below:

Chemical composition of DDGS shipments:

Item/Sample	Moisture	DM	CP	CF	Fat	Ash
1	12.0	88.0	27.0	7.4	7.2	4.9
2	8.36	91.6	26.4	9.2	8.3	4.5
3	8.4	91.6	24.2	8.2	9.9	5.0
4	10.5	89.5	27.0	6.8	8.3	4.6
5	11.5	88.5	26.1	9.5	7.2	4.6
Average	9.74	90.26	25.94	8.22	8.57	4.72
Range	8.4 to 12.0	88.0 to 91.6	24.2 to 27.0	7.4 to 9.5	7.2 to 9.9	4.5 to 5.0
Variability, %	44.0	4.0	11.5	28.3	37.5	11.0

Broilers Demo Trials

- Trials with RCFF

1848 Cobb broilers were fed DDGS in 4 treatments with 3 replicates per treatment. The specific treatment description is shown below:

Treatment	Starter	Grower	Finisher
1	0% DDGS	0% DDGS	0% DDGS
2	2.5% DDGS	5.0% DDGS	7.5% DDGS
3	5.0% DDGS	7.5% DDGS	10.0% DDGS
4	7.5% DDGS	10.0% DDGS	12.5% DDGS

The results showed that chicks given Treatment 3, which was 5.0, 7.5, and 10% DDGS in the starter, grower and finisher, respectively, performed as good as those of the control rations in terms of mortality, feed intake, daily gains, feed conversion. Feed cost for the chicks given Treatment 3 were 1.2, 3.7, and 3.5% less than those given the control diet for starter, grower, and finisher, respectively.

- Trials with Misr El Arabia Co.

Six broiler farms with a total of 1,804,934 Cub, Ross, Hubbard, Isa and Avian broilers were given Mash diets containing 5% DDGS in starter, grower and finisher rations for 36 days. Performance of broilers given the 5% DDGS in place of soy 44% and corn was similar in terms of mortality, motility, feed intake, body weight and feed conversion, and was even improved (in feed conversion and feed cost saving 2%) to that of broilers fed diets without DDGS.

Trials with Dairy Buffalo/Cattle Badr Farm

Seventy dairy buffalos were used in this trial. They were given diets containing 15% DDGS in place of 10% cotton seed meal and 5% wheat bran. Performance of the dairy buffalo given 15% DDGS was similar to those given the control diets in terms of milk production. There was 3% feed cost saving for the diets containing DDGS.

Taiwan

Broilers

Effects of feeding diets containing U.S. corn distiller's dried grains with solubles on growth performance and carcass quality of domestic colored broiler chickens in Taiwan. Lu, J.J., and Y.K. Chen.

Access at:

<http://www.ddgs.umn.edu/articles-poultry/2005-Lu-%20DDGS%20domestic%20color%20chicken%20final%20report-082405.pdf>

Domestic colored chickens are popular in Asia. There are specific market characteristics for consumer acceptance of chickens, including body maturity, red comb with suitable size, glittering feathers, yellow skin, and tender meat. To achieve the color requirements of comb and skin, artificial pigments are regularly added in the commercial poultry feeds, and thus increase the cost of feed. Xanthophylls are the yellow to orange pigments found in corn, which are more concentrated in corn DDGS. Therefore, the addition of DDGS as a source of xanthophylls pigment in poultry feed is an attractive feature for using DDGS in Taiwan. The objective of this study was to determine the effect of different dietary inclusion rates of DDGS on growth performance, skin color, and carcass quality of domestic colored chickens in Taiwan.

Six hundred and twenty four day-old commercial domestic colored chickens were used in this feeding trial. Six dietary treatments were used in a three-phase commercial feeding program: Phase 1 (0 to 4 weeks of age), Phase 2 (5 to 12 weeks of age), and Phase 3 (13 to 16 weeks of age). 26 chickens (13 male and 13 female) were allotted to one of the six treatments with four replications per treatment, and were fed their respective dietary treatments from 0 to 16 weeks of age. Dietary treatments were as follows:

- 1) Control diet: corn-soybean meal
- 2) Control diet + full amount of artificial pigments during phase 2 and 3 without DDGS
- 3) 10% DDGS diet
- 4) 20% DDGS diet
- 5) 20% DDGS + 50% of the amount of artificial pigments during phase 2 and 3
- 6) Control diet for phase 1 and 20% DDGS diet during phase 2 and 3.

All chickens were weighed individually bi-weekly and feed intake of each pen was recorded. Eight chickens (4 male and 4 female) were randomly selected from each replication and slaughtered at 12, 14, and 16 weeks of age, respectively. Live weight, carcass weight, dressing percentage, amount and color of abdominal fat pad, and liver weight were measured. One half of the breast and thigh muscle were sampled and ground for Hunter's meat color measurements using L*, a*, and b*. The other half of breast and thigh muscle were steam-cooked at 100°C for

10 minutes for shear force measurements. Blood samples were collected at harvest for total protein (TP), albumin (ALB), triglyceride (TG), total cholesterol (CHOL), and creatinine (CREA) analysis to determine the effects of DDGS on chicken protein and lipid metabolism.

Adding 20% corn DDGS to domestic colored chicken diets had no negative effect on weight gain, feed efficiency, meat quality, protein metabolism and fat metabolism. The color of abdominal fat pad was significantly influenced by the dietary treatments (Table 1). The diets with either the full amount of artificial pigments, or 20% DDGS plus half amount of artificial pigments significantly improved ($P < 0.05$) the abdominal fat pad color at 12, 14, 16 weeks of age, respectively. 10% DDGS and 20% DDGS treatments did not impact abdominal fat pad color at 12 or 16 wks of age, but improved the color score at 14 wks of age. Treatment 6, which switched from the control diet to the 20% DDGS diet during Phase 2, did not show improvement in abdominal fat pad color up to 16 wks of age. Feeding diets containing the full amount of artificial pigments and 20% DDGS plus $\frac{1}{2}$ of the recommended level of artificial pigments resulted in chickens with a bright yellow skin color. These results suggest that although the xanthophylls in DDGS cannot completely replace the artificial pigments to meet the color requirement for the Taiwan market, 20% DDGS plus half of the amount of artificial pigments can achieve the desired carcass quality and color of the abdominal fat pad and skin. Considering the additional savings by adding DDGS in the diet, DDGS could be a good alternative feedstuff for efficient domestic colored chicken production.

Table 1. Effects of feeding diets containing artificial pigment and DDGS on abdominal fat pad color of Taiwan domestic native chickens.

Measure	Age	Treatment						MSE
		Control	Control + AP ¹	10% DDGS	20% DDGS	20% DDGS + $\frac{1}{2}$ AP ¹	Control Phase 1, 20% DDGS Phase 2&3	
Abdominal fat pad color score	12 Wks	1.0 ^d	4.4 ^b	1.1 ^d	1.5 ^{cd}	5.3 ^a	2.0 ^c	0.5
	14 Wks	2.0 ^e	4.2 ^b	2.7 ^d	3.5 ^c	5.0 ^a	2.0 ^e	0.4
	16Wks	2.5 ^d	6.5 ^a	3.0 ^d	4.2 ^c	5.0 ^b	2.5 ^d	0.4

^{a, b, c, d} Means within the same row without the same superscript are significantly different ($P < 0.05$).

¹AP = artificial pigment.

Growth performance of broiler chickens fed diets containing 0 or 10% DDGS during winter conditions in Taiwan. G.C. Shurson

This study was conducted to evaluate growth performance and livability of broilers fed diets containing 10% DDGS under commercial production conditions in Taiwan during the winter months. A total of 320 broilers were randomly assigned to one of the two dietary treatments containing either 0 or 10% DDGS, and remained on their respective dietary treatments during the starter (d 0 to 14), grower (d 14 to 29), and finisher (d 29 to 38) phases of the 38 d trial. There was no significant difference ($P > 0.05$) for average daily gain between two dietary treatments. Average feed intake and feed/gain were unaffected by dietary treatment in the starter, grower, finisher phases, and overall. Livability was numerically higher for broilers fed the 10% DDGS diet. These results suggest that excellent growth performance can be obtained

when adding 10% DDGS to starter, grower, and finisher broiler diets, which are equal to typical commercial broiler diets in the Taiwan broiler industry.

Laying hens

Effects of corn distiller's dried grains with solubles on the productive performance and egg quality of laying hens. Bor-Ling Shih, A-Li Hsu, Y.K. Chen

This study was conducted to evaluate the effects of DDGS on productive performance and egg quality of laying hens in Taiwan. A total of 240 Hy-Line egg-type layers were used in this study. They were randomly assigned to one of the four dietary treatments with 3 replicates per treatment and 20 hens per replicate from 23 to 42 weeks of age. The four treatments were as follows: 1) control diet without DDGS; 2) 6% DDGS in the diet; 3) 12% DDGS in the diet; 4) 18% DDGS in the diet. Egg production, body weight, feed intake were recorded. Egg and eggshell quality, including eggshell breaking strength, shell weight and thickness, were measured within 24h of the eggs being laid. Egg yolk color was measured using lightness (L*), redness (a*), and yellowness (b*). Blood samples were collected from 12 randomly selected hens per replicate, and were used for total protein, uric acid, calcium, inorganic phosphate, cholesterol and triglyceride analysis. Six eggs from each treatment were also selected for cholesterol and fatty acids composition analysis. Results from this study suggested that including 6 to 12% DDGS in the diet of laying hens did not influence feed intake, feed efficiency, egg production rate, and egg mass. Yolk color was improved by including more than 12% DDGS in the diets, indicating the xanthophylls in DDGS are well utilized by laying hens. Plasma calcium and phosphate contents were increased and shell break strength was improved when 12% DDGS was used in the diet of laying hens. In conclusion, 12% DDGS dietary inclusion resulted in the best productive performance and egg quality in laying hens. Thus, DDGS can be efficiently used in the diet of laying hens to improve the productive performance, eggshell, and yolk characteristics.

Laying ducks

Effects of corn distiller's dried grains with solubles on the productive performance and egg quality of brown duck layers. J.F. Huang, M.Y. Chen, H.F. Lee, S.H. Wang, Y.H. Hu, and Y.K. Chen

This study was conducted to investigate the effects of DDGS on productive performance and egg quality in Brown duck layers. A total of 240 Brown Tsaiya ducks were used in this study. They were randomly assigned to one of the four dietary treatments with 3 replicates per treatment and 20 ducks per replicate from 14 to 50 weeks of age. The four treatments were as follows: 1) Control diet without DDGS; 2) 6% DDGS in the diet; 3) 12% DDGS in the diet; 4) 18% DDGS in the diet. Egg production from the first egg, feed intake, feed efficiency, egg weight, eggshell strength, and egg yolk color were recorded. At the age of 20, 30, 40 and 50 week, six eggs per replicate were randomly selected, and egg yolks were used for cholesterol and fatty acid content analysis. Results from this study suggested that adding DDGS at rates up to 18% in the diets of laying ducks did not significantly influence feed intake, feed efficiency, and quality of eggshell. Higher inclusion rates of DDGS (18%) increased egg production rate. Egg weight tended to be higher when 12 or 18% DDGS was added in the diet. Yolk color was linearly improved by the increased amount of DDGS, indicating that xanthophylls in DDGS can

be well utilized by laying ducks. When 12 or 18% DDGS was included in the diet, fat percentage of yolk and linoleic acid content of yolk was increased. In conclusion, DDGS can be efficiently used in the diets of duck layers to improve yolk characteristics without influencing the productive performance.

Swine

Growth performance of nursery and grower pigs fed diets containing 0 or 10% DDGS during winter conditions in Taiwan. G.C. Shurson

This study was conducted to evaluate growth performance and livability of nursery and grower pigs fed diets containing 10% DDGS under commercial production conditions in Taiwan during the winter. Two nursery trials used a total of 232 pigs weaned at 17 to 18 days. At weaning, all pigs were fed a common creep feed diet for two weeks, and then pigs were randomly assigned to one of two phase II dietary treatments containing either 0 or 10% DDGS. Another grower trial was conducted using a total of 264 pigs with an initial body weight of 23 kg. Pigs were randomly assigned to either 0 or 10% DDGS diets. For the nursery trials, feeding a Phase II nursery diet containing 10% DDGS had no significant effect on ADG, ADFI, and G/F compared to the control diet in Trial 1 ($P > 0.41$). In Trial 2, however, pigs fed the 10% DDGS diet grew significantly faster ($P < 0.03$) and consumed significantly more feed ($P < 0.002$) compared to those fed the control diet, but G/F was unaffected by dietary treatments. Livability was not affected by dietary treatments. For the grower trial, there were no differences in ADG, ADFI, and G/F ($P > 0.42$) between pigs fed the 0 and 10% DDGS diets. These results suggest that pig performance is at least similar, and may even be improved, when 10% DDGS is added to the nursery and grower diets compared to feeding a typical commercial diet in Taiwan during the winter.

Effects of feeding diets containing 0, 2.5% and 5% DDGS to nursery pigs and diets containing 0 and 7.5% DDGS to growing pigs on growth performance during summer conditions in Taiwan. Clare Pei-Ying Feng and Jerry Shurson

This study was conducted to evaluate growth performance and livability of nursery pigs fed diets containing 0, 2.5 and 5% high quality DDGS, and growing pigs fed diets containing 0 or 7.5% DDGS diets under commercial production conditions in Taiwan during the summer. A total of 324 nursery pigs at 3 weeks of age were used in this study. At weaning, all pigs were fed a common creep feed diet (Phase 1) for two weeks, and then they were randomly assigned to one of the three Phase II dietary treatments containing 0, 2.5, or 5.0% DDGS. All pigs were weighed initially and at the end of the 25 day experimental feeding periods. One grower trial was conducted using 96 pigs with the initial BW of 26.8 kg. Pigs were allotted to 4 pens with 2 pens per treatment. Pens were randomly assigned to one of two dietary treatments containing either 0 or 7.5% DDGS. All pigs were weighed initially and at the end of the 42 day experimental feeding period. For the nursery trials, feeding a Phase II nursery diet containing 2.5 or 5.0% DDGS had no significant effect on ADG, ADFI, and G/F compared to the control diet. For the grower trial, there were no differences in ADG, ADFI, and G/F between pigs fed the 0 and 7.5% DDGS diets. Livability was not affected by dietary treatment in both nursery and grower trials. These results suggest that pig performance is similar when 2.5 or 5.0% DDGS is

added to Phase II nursery diets, and 7.5% DDGS is added to grower diets, compared to feeding a typical commercial diet without DDGS in Taiwan.

Fish

The evaluation of dietary DDGS levels for Milkfish (*Chanos chanos*) and hybrid Tilapia (*O. aurea x O. nilotica*)

The objective of these two feeding trials was to estimate the maximal amount of the distiller's dried grains with solubles (DDGS) that could be included in the diets of milkfish and hybrid tilapia. Five isonitrogenic and isoenergetic dietary DDGS levels ranging from 0 to 40% of tested diets were fed to the two fish groups with 3 replicates per treatment in both trials. In the tilapia groups, fish received dietary DDGS level up to 20% exhibited similar growth performance compared with fish with the control diet, but those with 20% DDGS diet showed higher growth rate and better FCR than those with 30 and 40% DDGS in the diet. In the milkfish groups, there were no significant differences in growth performance of milkfish receiving various levels of DDGS in the diets. These results suggest that DDGS could be included up to 20% in the diet of tilapia fish without sacrificing growth performance. The maximum DDGS level in the milkfish diet could be 40% though it required further confirmation.

Thailand

Broilers

Effect of DDGS at different inclusion rates on growth performance and carcass measurements of broilers.

Access at

[http://www.grains.org/images/stories/technical_publications/2008-2009%20DDGS%20feeding%20trials%20\(2\).pdf](http://www.grains.org/images/stories/technical_publications/2008-2009%20DDGS%20feeding%20trials%20(2).pdf)

In the U.S., DDGS is now widely used in ruminant feeding, but there remains research to be done on its use in non-ruminant feeds, in particular, broiler and egg layers. In order to better understand how broiler birds respond to DDGS under practical environment, a trial was conducted at the Bangkok Animal Research Center (BARC), Samut Prakan, Thailand, using 960 newly hatched Ross 308 male broilers to compare their growth performance when fed diets containing various levels of DDGS. Broilers were randomly allocated to five treatments with twelve replications. Each replication had 16 birds and these were raised in a pen as a unit. Dietary treatments consisted of four inclusion levels DDGS, namely, 3, 6, 9, and 12% with 0% inclusion level as control. All feeds were corn-soybean meal based (from Soon Soon Oilmills Malaysia), wheat pollard and crude palm oil plus varying levels of DDGS. Starter feeds were fed from 0 to 21 days, and grower feeds from 22 to 42 days. Birds were weighed at the end of 21 days and 42 days. Two birds from each treatment group were sacrificed for carcass evaluation at the end of the trial.

There was little difference in body weight gain (BWG), feed intake (FI) and feed conversion ratio (FCR) for birds up to 21 days. However, at the end of 42nd days, FCR for groups using more than 6% DDGS was significantly ($P < 0.05$) higher than those fed feeds using less than 6%

DDGS, which indicated that during the growing phase, there was no advantage to including DDGS above 6% because growth performance would be negatively affected. For the overall experimental period, BWG was not different among the treatment groups. Final FI was significantly higher ($P < 0.05$) for the treatment group with 12% DDGS, but FI of the control and the 3, 6, and 9% treatments was similar. Feed conversion ratio (FCR) was significantly higher ($P < 0.05$) for 12% and 9% DDGS groups compared to the control group, while the differences in FCR between the 3, 6, and 9% DDGS groups and the control, 3, and 6% DDGS groups were not significant. There was no significant difference in mortality and culling rate during starter, grower, or overall phase. These results confirmed that DDGS can be used in broiler diets up to a maximum of 10% with no deleterious effect on growth performance. Considering FI and FCR, the maximum usage rate could be between 6 to 9%. Higher than 9%, broiler birds would need additional feed to sustain the fast rate of growth leading to poorer FCR. Eviscerated carcass weight, viscera weight, and total fat pad weight was similar among treatment groups, indicating that the impact of DDGS on carcass quality is minimal, and its use should be judged purely on meeting the growth performance objectives.

Vietnam

Swine

Effect of feeding dried distiller's grains and solubles with different protein levels on growing pigs. Chung Kim

A feeding trial on Dried Distiller's Grains and Solubles (DDGS) has been conducted to compare the value of DDGS with different protein contents for feeding growing pigs. A total of 270 pigs in three dietary treatments were used in this trial comprised of a control diet without DDGS, and diets with the inclusion of DDGS with protein content 26% and 40% at 20%. Three diets having similar digestible amino acids and energy were formulated using ingredients (corn, cassava, soybean meal, peanut meal and rice bran) in pelleted form to meet the requirements of growing pigs. Each ration was fed to growing pigs placed in a concrete pen containing 30 growing pigs at initial weight 35 kg and replicated 3 times. The feeding trial was performed for 81 days to reach marketable weight, which was approximately 90 kg. Feed containing DDGS was readily consumed by pigs and there was no indication of refusal or toxicity related with DDGS. Body weight of pigs after feeding for 81 days was not different between dietary treatments. Daily gain of pigs fed control, DDGS 26% and DDGS 40% were 0.675 kg, 0.672 kg and 0.640 kg respectively. Average daily feed consumptions were similar among the treatments (around 2 kg/day) and therefore the feed per gain ratio was not different by feeding DDGS with different protein contents. Backfat thickness was not different among the dietary treatments. At end of feeding, a digestibility trial was conducted using Acid Insoluble Ash as internal marker. Dry matter, protein and phosphorus digestibility of the diet with DDGS 26% was 91%, 91% and 96%, respectively and was higher than the diet with DDGS 40% with value 83%, 85% and 92.5%, respectively. Income over feed cost of the pig fed DDGS 26% is higher than that of the pig fed DDGS 40% and the control diet without DDGS. In conclusion, DDGS can be successfully and economically fed to growing pigs at a 20% level and DDGS with 26% protein had better dry matter, protein and phosphorus digestibility than those of DDGS with 40% protein.

Fish

Use of DDGS for feeding red tilapia under Vietnam condition. LE Hung VY

Access at

[http://www.grains.org/images/stories/technical_publications/2008-2009%20DDGS%20feeding%20trials%20\(2\).pdf](http://www.grains.org/images/stories/technical_publications/2008-2009%20DDGS%20feeding%20trials%20(2).pdf)

Red tilapia is one of major fish grown in Vietnam and is considered a popular species for human consumption. It has been shown that dried distiller's grains with solubles (DDGS) is economically feasible for animal feed especially in dairy cattle, swine and poultry. However, information on the use of DDGS for feeding fish is limited. This study was conducted to evaluate the impact of feeding increasing levels of DDGS on the performance of Tilapia fish reared under commercial conditions in Vietnam. At least 6000 fingerling of common carp and tilapia with initial weight 190 g were raised for 4 months up to around 800-900 g in floating cages placed in a reservoir. Four dietary treatments containing DDGS at 0, 5, 10 and 15% were included in similar dietary energy (2500 kcal/kg) and protein level (30%) of feed composed mainly with soybean meal, corn, rice bran and fish oil. Results of feeding for 4 months showed that increasing levels of DDGS in Tilapia diets increased growth rate and improved feed efficiency. The best growth rates were obtained in the 10 and 15% DDGS in combination with soybean meal ($P < 0.05$). The lowest growth rate was presented in the 0% DDGS feed. The lowest feed conversion ratio (FCR) during entire culture period was 2.1 in the 15% DDGS feed treatment. The use of DDGS at 15% inclusion level also improved survivability of the fish compared to treatment without DDGS (97.3% vs. 94%). Fish meat evaluation at the end of trial showed no different in chemical composition. In conclusion, DDGS can be included up to 15% in Tilapia diet and may improve the growth performance.

Feeding trial of DDGS for Common Carp. Le Khan Hung

A feeding trial on common carp was conducted at the Hoa Binh reservoir, Hoa Binh Province, Vietnam to measure the optimum inclusion of Dried Distiller Grain Solubles (DDGS) in the feed. The trial was performed using common carp fish with initial weight 26-51g raised for more than 3 months up to around 200 g in floating cages placed in a reservoir. Four dietary treatments containing DDGS at 0%, 5%, 10% and 15% were formulated in similar dietary energy (2.9 Mcal/kg) and protein level (26%) feed, composed mainly with soybean meal, wheat by products, rice bran, fish meal, meat and bone meal and fish oil. Results of feeding for 3 months showed that increasing the level of DDGS in the diet did not affect growth rate and feed consumption of the fish. There was an indication that fish fed 10% and 15% DDGS grew at a faster rate (40 g/month) than the fish fed lower levels (0% and 5%) of DDGS (28 g/month). Fish survivability rate was around 99.3-99.5% and there was no difference due to the dietary treatment. Fish meat evaluation at end of trial indicated no different in moisture, protein and fat content and meat color was similar among the dietary treatment. In conclusion, DDGS can be included in common carp diets up to 15% and not affect the growth performance and meat quality of the fish.



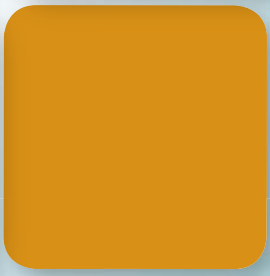
Summary

The effects of adding U.S. made DDGS as a feed ingredient in domestic livestock feed have been evaluated by many countries. In Japan, where there is a demand for eggs with stronger yolk color than in the U.S., including up to 20% DDGS in the diet of domestic laying hens did not affect egg quality, but could improve egg yolk color which leads to a saves in yolk coloring agent. Positive results were also observed when feeding broilers with up to 20% DDGS in the diet. The higher the content of DDGS in the diet, the better growth rate and higher meat production was found. In dairy cattle, 20% DDGS could be added in the diet without affecting the cow's condition, milk yield and milk composition. In swine, there were no significant differences in growth performance and carcass characteristics in finishing pigs when 20% DDGS was added to the diet, indicating that 20% DDGS could be used swine finishing diets in Japan. In Korea, similarly, 20% DDGS could be added to swine diets without affecting growth performance, carcass characteristics and meat quality. In the poultry research conducted in Korea, feeding birds up to 15% DDGS in broiler diets and up to 20% DDGS in layer hens diets had no negative effects on animals growth performance and laying performance. One study conducted in Mexico reported a higher ADG and ADFI, and similar feed efficiency in growing-finishing pigs fed 10% DDGS in the diet compared with those fed a control diet. These suggested that DDGS can be added to grow-finish swine diets in Mexico to provide at least equal, and probably improved growth performance compared with current commercial swine diets. In Taiwan, where consumers prefer domestic colored chickens with yellow skin, adding 20% DDGS plus only half of the amount of artificial pigments can achieve the desired growth performance, carcass quality and color of the skin, suggesting DDGS could be a good alternative feedstuff for domestic colored chicken production. In addition, 12% DDGS can be added to the diets of laying hens in Taiwan to improve productive performance, eggshell, and yolk characteristics. Similar results were also reported by another study where the authors observed improved yolk characteristics and unaffected productive performance when feeding laying ducks with diets containing up to 18% DDGS. In swine, pig performance is at least similar, and may even be improved, when 10% DDGS is added to the nursery and grower diets compared to feeding a typical commercial diet in Taiwan. In fish species, DDGS can be included up to 20% in the diet of domestic tilapia fish without sacrificing growth performance, while the inclusion level may be up to 40% for milkfish diets in Taiwan. In Thailand, researchers found DDGS could be used in broiler diets up to a maximum of 9% with no deleterious effect on

growth rate, feed intake and feed efficiency, but carcass quality was not affected by dietary DDGS. In Vietnam, DDGS can be included up to 15% in the feed of Tilapia, which is one of the most popular fish for consumption in Vietnam, and may improve the growth performance and survivability. For swine, DDGS can be successfully and economically fed to growing pigs at a 20% level. In Indonesia, 20% DDGS can be added to the diets of finishing cattle without negative effects on growth performance and carcass characteristics. These results from different countries suggested that U.S. made DDGS could be added to the feed of many domestic species including swine, dairy cattle, broiler chickens, laying hens, laying ducks and fish with minimal or no negative effects on economic traits.

CHAPTER 31

Frequently Asked Questions about DDGS



Frequently Asked Questions About DDGS

What is the average protein content of high quality DDGS?

In a University of Minnesota DDGS sampling survey evaluating 32 different DDGS sources, the average crude protein content was 27.6% on an as fed basis, with a range from 25.6-29.4%. Recently, a few ethanol plants are using new processes to produce ethanol and higher protein DDGS which may contain as much as 40-50% crude protein.

Is there DDGS available that has crude protein levels of 40% or more?

No. Only a few ethanol plants still make high protein DDGS, but this small amount of production is not conducive to meet potential demands in the international market.

Why are U.S. ethanol plants extracting oil from DDGS?

The current market price and demand for crude corn oil is very attractive as another revenue source for ethanol plants and the availability and relatively low cost of adding oil extraction equipment to existing ethanol plants makes this process very profitable.

How does reduced-oil DDGS affect its feeding value?

Removal of some of the oil in DDGS reduces its energy value but slightly increases its protein content. Research is underway to determine the impact of oil removal from DDGS on energy value for various livestock and poultry species. Refer to the Chapters in this Handbook for the most current information available.

Are there antibiotic residues in DDGS?

Recent research conducted at the University of Minnesota indicates that many DDGS samples contain very small amounts of one or more antibiotic residues. However, due to the processing conditions used to produce ethanol and DDGS in ethanol plants, these antibiotic residues do not have biological activity. Therefore, even though antibiotics are used in ethanol production, DDGS is safe to feed to animals based on current U.S. FDA regulations.

Can any DDGS replace soybean meal on a one-to-one basis in a layer/broiler/swine/ruminant diet? Why or why not?

No. Each individual feed ingredient is a package of nutrients in various quantities and proportions. The three most expensive nutrients in livestock and poultry feeds are energy, amino acids and phosphorus. Depending on relative ingredient prices, DDGS *partially replaces* some of the energy, amino acid and phosphorous sources in commercial livestock

and poultry diets. In typical corn/soybean rations DDGS can partially replace corn and soybean meal. But where a greater variety of energy and protein sources are available, DDGS may replace other ingredients without reducing the soybean meal in the ration.

The trade-off between soybean meal and DDGS in swine and poultry rations is complex:

- The energy value of DDGS is equal to, or greater than, dehulled soybean meal in livestock and poultry diets.
- The protein content of DDGS typically averages about 27% whereas soybean meal contains 44-48% crude protein.
- The amino acids most likely to be limiting in corn-soybean meal based swine and poultry diets are lysine, methionine, threonine and tryptophan. Soybean meal is substantially higher in these essential amino acids – and they are more digestible – than in DDGS.
- Soybean meal contains about the same concentration of phosphorus as DDGS, but the majority of the phosphorus in DDGS is in a chemical form that is easily digested and utilized by swine and poultry compared to the indigestible form of phosphorus (phytic acid) found in soybean meal. This nutritional advantage for DDGS allows nutritionists to significantly reduce the amount of inorganic phosphorus supplementation needed in the diet, diet cost and phosphorus concentrations in manure, while supporting optimum swine and poultry performance.

Does DDGS need to be treated with propionic acid or mold inhibitors in order to extend its shelf life?

Preservatives and mold inhibitors are commonly added to **wet distiller's grains** (~50% moisture) to prevent spoilage and extend shelf life. However, since the moisture content of **DDGS** is usually between 10-12%, there is minimal risk of spoilage during transit and storage unless water leaks into transit vessels or storage facilities. No research studies have been conducted to demonstrate that preservatives and mold inhibitors are necessary to prevent spoilage and extend shelf life of DDGS.

In a U.S. Grains Council field trial, DDGS was shipped from an ethanol plant in South Dakota in a 40 ft. container to Taiwan. Upon arrival in Taiwan, DDGS was put into 50 kg bags and stored in a covered steel pole barn for 10 weeks during the course of the dairy feeding trial on a commercial dairy farm located about 20 km south of the Tropic of Cancer. Environmental temperatures averaged 90+ degrees F and humidity was in excess of 90% during this storage period. Samples of DDGS were collected upon arrival at the farm and again after the 10 week storage period. There was no change in peroxide value (measure of oxidative rancidity of oil) during this trial.

How do you value DDGS in relation to cost?

The best method of determining DDGS value in various types of livestock and poultry diets is to obtain a complete nutrient profile and the digestibility coefficients of the source being considered, the price at which it can be purchased and offering it as an ingredient to compete with the nutrient profiles and prices of other ingredients being used in a least cost diet

Alternatively, value can be calculated by knowing the protein (amino acid), fat and phosphorus content per ton of DDGS and using the cost and concentrations of these nutrients in competing ingredients commonly used (e.g. soybean meal, choice white grease and dicalcium phosphate). However, this approach does not account for digestibility of nutrients which may be lower or higher in DDGS compared to other nutrient sources.

What should be written in the certificate of analyses of DDGS?

Typically, DDGS is traded on a protein, fat or “pro-fat” combination for nutrient guarantees. However, more DDGS customers are asking for additional guarantees depending upon the intended feeding application. Additional guarantees are negotiated between the buyer and seller. It is extremely important to agree on the laboratory and testing method that will be used for any nutrient analysis being guaranteed or checked because the testing procedure can have a significant influence on whether or not a guarantee is met.

Are aflatoxins present in DDGS?

Most of the corn used to produce DDGS is grown in the upper Midwest of the United States where there is minimal risk of aflatoxin production except under unusual growing conditions (high temperature and high humidity). When these growing conditions occur, they are usually in relatively small, isolated regions. On average, growing conditions conducive to aflatoxin production in the upper Midwest occur 1 out of 10 years. If aflatoxin is detected in a given area, most ethanol plants receiving corn from that area will use a “black light” to screen incoming corn and many will set maximum allowable levels to avoid concentrating aflatoxin in DDGS. If corn containing aflatoxin or other mycotoxins is used to produce ethanol and DDGS, those mycotoxins are concentrated by three-fold compared to the initial level found in the corn.

How do you manage the caking of DDGS in containers?

Research studies have been conducted to determine the factors that cause flowability problems and potential solutions to reduce these problems. It appears that several factors contribute to whether or not DDGS “sets up” in a container including: fine particle size, warm temperature when loading, moisture content, proportion of solubles added to the grains

fraction before drying and the number of times it has been handled and unloaded during transit.

Does DDGS improve egg yolk and poultry skin pigmentation when it is added to the diet?

Yes. Several studies have been conducted in the past few years showing that egg yolk and poultry skin pigmentation improves when DDGS is added to the diet. Currently, there are limited data on xanthophyll content of DDGS but initial sampling indicates it can range from very little (dark colored DDGS) to approximately 40-50 parts per million (ppm) (light golden colored DDGS). Although the level of xanthophyll is significantly less than found in corn gluten meal (180 to 200 ppm), it still contributes a significant amount of pigment to poultry diets and as a result, less synthetic pigment must be added to the diet to achieve the desired level of pigmentation. This can represent a significant savings in diet cost.

Does DDGS contain alcohol?

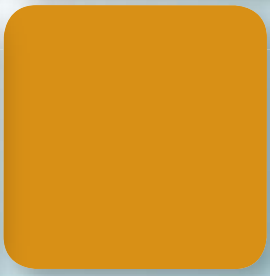
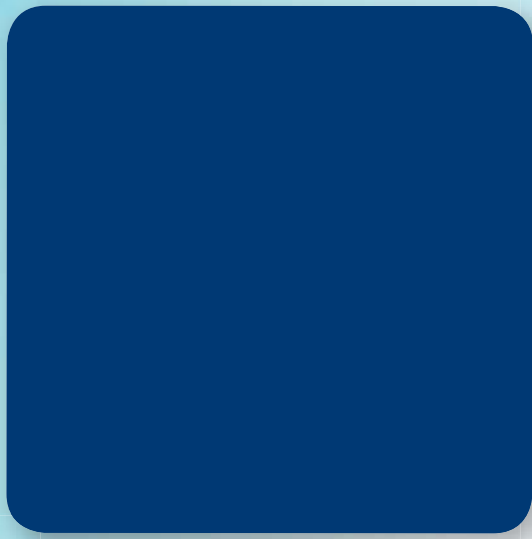
No. The distillation process used in ethanol plants is very complete and, because alcohol is very volatile (evaporates easily), any alcohol remaining is lost during the drying process used to produce DDGS.

How can I qualify a DDGS supplier?

Due to the variability in processes used by ethanol plants to produce ethanol and DDGS, there can be significant variation in nutrient content and digestibility among sources. This variation in nutrient content and digestibility makes it unwise for nutritionists to formulate diets using “typical” nutrient values. Therefore, many DDGS users have chosen to contact direct marketers of DDGS, request nutrient information and samples from specific ethanol plants of interest, develop a “preferred supplier” list of ethanol plants that meet their quality criteria, and purchase and use only DDGS from those sources.

CHAPTER 32

U.S. Suppliers of Distiller's
Dried Grains with Solubles



Chapter 32

U.S. Suppliers of Distiller's Dried Grains with Solubles

Abengoa Bioenergy Trading U.S.

Contact: Thomas Rossmanith

Tel: (636) 728-4500

Email: Thomas.Rossmanith@bioenergy.abengoa.com

Abengoa Bioenergy Trading U.S., LLC was formed to manage the critical functions of grain procurement, ethanol and DDGS co-product marketing, and hedging and risk management for all commodities, including energy needs. The concentration of these functions into one specialized entity for all U.S. operations is critical to achieve the company's goals of consistency, efficiency, and identification of one common brand throughout U.S. Abengoa Bioenergy operations. Currently, Abengoa Trading markets co-products for the six Abengoa owned U.S. ethanol plants. Abengoa's plants are located strategically in the western cattle feeding markets and along the Mississippi River system.

Abengoa Bioenergy Trading U.S. marketed approximately 500,000 short tons of DDGS through the Gulf of Mexico in 2010. Abengoa's unique ability to put this much volume into the market place from identical production facilities leads to the consistency that has been missing from the marketplace in the past. Abengoa also has the ability to pellet co-products without sacrificing the specifications, which leads to increased efficiencies in freight and handling costs for their customers that can benefit from full vessel shipments of DDGS from NOLA.

Agribase International, Inc.

Contact: Terry English

Tel: (217) 370-5654

Email: terry.english@agribaseinc.com

Agribase International, Inc. is a U.S. feed ingredients exporting company based in Schaumburg, IL. Their core business deals in DDGS, soybeans, whey powder, and other ingredients. Terry English, formerly the USGC delegate for the Illinois Department of Agriculture, has been named the delegate to the Council on behalf of Agribase.

AgMotion

Contact: Tim Carlson
Tel: (612) 486-3880
Email: trade@agmotion.com
www.agmotion.com

AgMotion, Inc. is a principal trading and exporting company that specializes in DDGS among other major U.S. commodities. The company also operates as US Commodities. Please see their website and contact them directly for more information.

Agniel Commodities, LLC

Contact: Lucien Agniel
Tel: (401) 248-2086
Fax: (401) 248-2087
Email: info@agnielcommodities.com
www.agnielcommodities.com

Brokers for wheat, corn, soybeans, soybean meal, DDGS, corn gluten meal, cotton seed, soy hull pellets

AG Processing, Inc (AGP)

Contact: Craig Pietig
Tel: (402) 492-3322
Email: cpietig@agp.com

Historically, AGP has been a wet distiller's grains marketer, but is now marketing DDGS from two ethanol plants in Iowa and Nebraska. Their export capabilities include barge, rail car and container shipments. AGP owns an export facility located in the Port of Grays Harbor in the state of Washington.

Archer Daniels Midland Company (ADM)

Contact: Ryan J. Brocklesby
Tel: (217) 451-8162
Email: ryan.brocklesby@adm.com (vessels)

Contact: Tony Ielase
Tel: (217) 451-4776
Email: containers@adm.com (containers)

Contact: Aaron Taft
Tel: (217) 451-5061
Email: aaron.taft@adm.com (truck and rail)
www.adm.com

Every day, the 29,000 people of Archer Daniels Midland Company (NYSE: ADM) work to

connect the harvest to the home, turning crops into renewable products that serve the vital needs of a growing world. ADM trades, transports, stores, and processes corn, oilseeds, wheat, and cocoa into products for food, animal feed, chemical, and energy uses. They are committed to the responsible, sustainable development of agriculture throughout the world. ADM is a producer and exporter of DDGS with production facilities in North Dakota, Iowa, Nebraska and Illinois. ADM has four gulf export elevators as well as two floating rigs to load DDGS or combination commodity vessels. ADM has three exclusive container loading facilities and also utilizes two additional public container loading facilities. Export capabilities include vessel, barge, rail car and container shipments.

Attebury Grain, LLC

Contact: Keith Hunt

Tel: (806) 335-1639

Fax: (806) 335-1165

Email: khunt@attebury.com

www.atteburygrain.com

Brokers for DDGS, corn and soybeans

Big River Resources

Contact: Raymond Defenbaugh

Tel: (319) 753-1100

Email: ray.defenbaugh@bigriverresources.com

www.bigriverresources.com

Big River Resources West Burlington, LLC is an ethanol plant in West Burlington, Iowa. Initial annual production of this 40 million gallon ethanol plant started April 12, 2004, and capacity doubled from 40 to 92 million gallons per year in December 2007.

Bunge North America

Contact: David Barham

Tel: (314) 292-2927

Email: david.barham@bunge.com (vessel)

Contact: Julio Salinas

Tel: (314) 292-2988

Email: julio.salinas@bunge.com (vessel)

Contact: Richard Moneymaker

Tel: (314) 292-2923

Email: richard.moneymaker@bunge.com (rail)

Contact: Elisa Uribe

Tel: (314) 292-2422

Email: elisa.uribe@bunge.com (rail)

Contact: Kristan Barta
Tel: (712) 366-8830
Email: kristan.barta@bunge.com (trucks)

Contact: Jim Macfarlane
Tel: (314) 292-2115
Email: jim.macfarlane@bunge.com (containers)

Bunge North America has marketing agreements and is a minority investor in two ethanol facilities that began production in 2008. With a 200 year history in agribusiness, Bunge can provide not only critical contacts in the North American animal nutrition markets, but with their global reach they are able to provide access to developing export markets as well. Bunge's export capabilities include vessel, rail car, and container shipments. Bunge owns an export facility located in Destrehan, LA. Please contact them directly for more information.

C&D (USA) Inc.

Contact: Jerry Wang
Tel: (630) 928-1180
Email: jwang@chinacnd.com
www.chinacnd.com

C&D (USA) Inc. is a wholly-owned subsidiary company of Xiamen C&D Inc., a top 100 ranking, public company in China. Xiamen C&D is one of the biggest importers of grain, oilseeds and feedstuffs in China. After C&D USA opened in Chicago, Ill. in 2008, it quickly set up a suppliers' and logistics network of agricultural commodities in the United States and became one of the largest exporters of U.S. DDGS to China. C&D USA is currently working to develop its buyers' network in Southeast Asia.

Cargill, Inc.

Contact: Daniel Humboldt
Tel: (952) 742-2326
Email: daniel_humboldt@cargill.com

Contact: Mark Jirik
Tel: (952) 742-6068
Email: mark_jirik@cargill.com

Cargill has marketing agreements with dry-grind ethanol facilities. They are also investors in those facilities. Cargill takes market positions from other DDGS marketers in the United States. Cargill sells a combination 36% protein-fat DDGS. Export capabilities include vessel, barge, container, rail cars and truck shipments. Cargill markets approximately 1 million metric tons of co-products per year.

Cenex Harvest States (CHS)

Contact: Clayton Haupt

Tel: (651) 355-6804

Email: clayton.haupt@chsinc.com (vessel)

Contact: Scott Thiel

Tel: (800) 769-1066

Email: scott.thiel@chsinc.com (container)

Contact: Sean Broderick (For prices FOB ethanol plants and delivered points in the U.S. Canada and Mexico)

Tel: (800) 769-1066

Email: sean.broderick@chsinc.com

www.chsinc.com

CHS is a diversified energy, grains and food company committed to providing the essential resources that enrich lives around the world. A Fortune 100 company, CHS is owned by farmers, ranchers and cooperatives, along with thousands of preferred stockholders, across the United States. CHS supplies energy, crop nutrients, livestock feed, grain, food and food ingredients, along with business solutions, including insurance, financial and risk management services. The company operates petroleum refineries/pipelines and manufactures, markets and distributes Cenex® brand refined fuels, lubricants, propane and renewable energy products. CHS is the largest agricultural cooperative in the U.S. CHS is also the largest marketer of DDGS with estimated tons marketed in excess of 5 million for 2010. CHS currently has exclusive marketing agreements with 28 U.S. ethanol plants. CHS has container loading capabilities at several locations and owns and operates bulk export capacity in the U.S. Gulf, on the West Coast, and off of the Great Lakes. With offices around the world, CHS is positioned to serve your DDGS needs.

Consolidated Grain and Barge Company (CGB)

Contact: Mitchell McGee

Tel: (985) 867-3554

Email: mitchell.mcgee@cgb.com

www.cgb.com

CGB is a full service agriculture commodity trading and logistics company that specializes in the trading and exporting of golden DDGS. They focus their service on shipping only those DDGS with a consistent quality, utilizing strong relationships with various origin plants. Their logistical capabilities include truck, rail car, container, barge, and vessel shipments. CGB owns several container and barge loading facilities throughout the Midwest and use third party loaders when necessary. In addition, they can load and unload barges at multiple locations in the Gulf of Mexico, and load DDGS or combination commodity vessels. Currently, CGB services numerous export markets and can streamline the supply chain for quality golden DDGS from origin to destination. Please contact them directly and visit their website for additional information.

DeLong Co., Inc.

Contact: Brian Arnold

Tel: (608) 676-3039

Email: barnold@delongcompany.com

www.delongcompany.com

As one of the Midwest's largest suppliers of food grade corn and soybeans, the DeLong Co. has more than a quarter-century of experience supplying food grade white and yellow corn to domestic and international markets, including Europe, Asia, Mexico and Canada. With annual sales exceeding \$800 million, the company is active in grain, fertilizer and agricultural chemicals, seed, feed and pet foods, and transportation. The company also operates 45 trans-loading facilities in the Midwest, where products from farmer producers and elevators in Wisconsin, Illinois, Indiana and Ohio are trans-loaded into containers for shipment.

Flint Hills Resources LLC

Contact: Ryan Sauer

Tel: (515) 817-2987

Email: ryan.sauer@fhr.com

Flint Hills Resources is an independent refining and chemicals company. It strives to create value for its customers and society - through the way its facilities operate, its efficient use of resources, the products it produces and markets, and its involvement in its communities. The company, based in Wichita, Kansas, has expanded its operations through capital projects and acquisitions worth more than \$6.2 billion since 2002.

The following Flint Hills plants are members of the U.S. Grains Council:

Flint Hills Resources Fairbank LLC is a 115 million-gallon-per-year plant that began operation in 2006 as the second ethanol production facility in the Hawkeye Renewables system. The facility consumes about 41 million bushels of corn annually and produces about 980 tons of DDGS per day.

Flint Hills Resources Iowa Falls LLC is a 100 million-gallon-per-year ethanol plant that was expanded to its current capacity in 2006. The plant uses 36 million bushels of corn per year and produces about 860 tons of DDGS each day. The plant was the first plant in the Hawkeye Renewables system and was originally constructed as a 50 million-gallon-per-year plant. It began operations in November of 2004.

Flint Hills Resources Menlo LLC is a 115 million-gallon-per-year ethanol plant that was completed in September, 2008. The plant uses 41 million bushels of corn per year and produces about 370,000 tons of DDGS each year. The plant was the third plant in the Hawkeye Energy Holdings system.

Flint Hills Resources Shell Rock LLC is a 115 million-gallon-per-year ethanol plant that was completed in October, 2008. The plant uses 41 million bushels of corn per year and produces about 370,000 tons of DDGS each year. The plant was the fourth plant in the Hawkeye Energy Holdings system.

Fornazor International Inc.

Contact: John Fornazor, Jr.

Tel: (201) 664-4000

Fax: (201) 664-3222

Email: jf@fornazor.com

www.fornazor.com

Brokers of corn, sorghum, barley, and corn co-products (gluten feed, gluten meal, and distillers grains)

Fornazor International is a US trading company and feed manufacturer that has exported commodities globally since 1979. Fornazor exports and trades grains, vegetable proteins, marine proteins, and animal proteins primarily to Asian and the Middle Eastern markets. Fornazor owns and operates their own loading facilities on the east coast and also has a forage export facility in Kansas where they produce alfalfa pellets as well. Fornazor has a blend facility where they create their own custom feed formulations as well as other finished feeds.

Gavilon

Contact: Tomas Elvir

Tel: (402) 889-4348

Email: tomas.elvir@gavilon.com

www.gavilon.com

Gavilon sources and distributes grain inputs including corn, wheat, soybeans, sorghum, milo and DDGS throughout North American, the Caribbean, Central America, South America, Europe and Asia. Gavilon Grain, with roots that go back well over 130 years as Peavey Grain, achieves quick, efficient handling while protecting quality with 64 high-volume capacity grain elevators. Formerly ConAgra Trade Group, Gavilon was formed as a new independent entity through the acquisition by a group of investors led by Ospraie Special Opportunities Fund. Gavilon is now positioned to provide its customers with a more complete and robust trading, merchandising, and distribution platform than ever before. Gavilon is headquartered in Omaha, NE with 930 employees worldwide and 144 facilities on six continents.

Green Plains Renewable Energy Inc.

Contact: Brent Lorensen

Tel: (402) 315-1643

Email: brent.lorensen@gpreinc.com

www.gpreinc.com

Green Plains Renewable Energy (GPRE) was founded in 2004 and is North America's fourth largest ethanol producer. GPRE operates a total of 8 dry-grind ethanol plants in Indiana, Iowa, Michigan, Nebraska, and Tennessee with annual expected operating capacity totalling approximately 670 million gallons. GPRE's 8 plants will consume approximately 239 million bushels of corn in the ethanol production process. They also market and distribute ethanol for third party ethanol producers with annual expected operating capacity totaling approximately 360

million gallons. Today, GPRE markets and distributes over 1 billion gallons of ethanol, representing about 8% of the total U.S. supply, as well as 2.1 million tons of distillers grains. GPRE owns 51% of Blendstar, LLC, a biofuel terminal operator which operates 9 blending or terminal facilities with approximately 495 million gallons per year of total capacity in 7 states in the south central United States. GPRE also operates grain storage facilities with 31 million bushels of storage capacity and complementary agronomy and petroleum businesses at 13 facilities located in Iowa, southern Minnesota, and western Tennessee.

Golden Grain Energy

Contact: Walter Wendland

Tel: (563) 238-5555

Email: wwendland@etoh.us

Golden Grain Energy is a privately-held company dedicated to adding value to northern Iowa's corn production by turning locally-grown corn into clean-burning ethanol. The company currently produces approximately 100 million gallons of ethanol annually at a plant in Mason City, Iowa. Owned by more than 750 members, the majority of whom are northeast Iowa farmers, Golden Grain Energy is committed to being a strong partner in the local community, a key player in the regional economy and a leader in Iowa's ethanol industry. The company employs 45 individuals and purchases more than 33 million bushels of locally-grown corn annually from producers and grain dealers. In addition to ethanol, Golden Grain Energy produces both wet and dry distillers grains, providing a feed source for livestock producers. Golden Grain Energy strives to help meet the growing national demand for domestic biofuels, which are the key components of our nation's efforts to reduce reliance on foreign oil and improve air quality around the country.

Granite Falls Energy

Contact: Tracey Olson

Tel: (320) 564-3100

Email: tolson@granitefallsenergy.com

Based in Granite Falls, Minnesota, Granite Falls Energy began producing ethanol in 2005 and has a production capacity of 50 million gallons per year. The plant is a limited liability corporation comprised of over 900 investors. Granite Falls Energy has recently submitted permits to increase its production capacity to 70 million gallons per year. DDGS produced at Granite Falls Energy are marketed by CHS, though the company does market directly to the local end-users. The company recently added a corn oil extraction process to its production capacity.

Hawkeye Gold, LLC

Contact: Mike Borcharding

Tel: (515) 663-6468

Email: mborcharding@hawkgold.com

www.hawkgold.com

Hawkeye Gold is an operating subsidiary of Hawkeye Energy Holdings, a privately owned, Iowa-

based renewable energy company. The company provides professional marketing services for distillers grains producers. We have an industry leading team with many years of experience in marketing distillers grains and other commodities, and have access to a wide range of local, domestic and international markets. Our client-plants have state-of-the-art ethanol facilities that produce a premium golden color distiller grains that is highly nutritious and well suited for animal feed.

The following Hawkeye plants are members of the U.S. Grains Council: Hawkeye Renewables – Fairbanks is a 115 million-gallon-per-year plant that began operation in 2006 as the second ethanol production facility in the Hawkeye Renewables system. The facility consumes about 41 million bushels of corn annually and produces about 980 tons of DDGS per day. Hawkeye Renewables – Iowa Falls is a 100 million-gallon-per-year ethanol plant that was expanded to its current capacity in 2006. The plant uses 36 million bushels of corn per year and produces about 860 tons of DDGS each day. The plant was the first plant in the Hawkeye Renewables system and was originally constructed as a 50 million-gallon-per-year plant. It began operations in November of 2004. Hawkeye Menlo LLC is a 115 million-gallon-per-year ethanol plant that was completed in September, 2008. The plant uses 41 million bushels of corn per year and produces about 370,000 tons of DDGS each year. The plant was the third plant in the Hawkeye Energy Holdings system. Hawkeye Shell Rock LLC is a 115 million-gallon-per-year ethanol plant that was completed in October, 2008. The plant uses 41 million bushels of corn per year and produces about 370,000 tons of DDGS each year. The plant was the fourth plant in the Hawkeye Energy Holdings system.

Homeland Energy Solutions

Contact: Walter Wendland

Tel: (563) 238-5555

Email: wwendland@etoh.us

www.homelandenergysolutions.com

Homeland Energy Solutions, LLC operates an ethanol production plant which produces 100 million gallons of ethanol annually from 37 million bushels of corn using a 2.8:1 conversion ratio. Based in Lawler, IA, the facility serves corn producers in an 11 county area in northeastern Iowa. The purchase of the 37 million bushels of corn will increase the demand for corn and increase its market value. Based on existing industry experience, a projected value increase is expected between \$.05 and \$.08 per bushel. This amounts to an increased income of approximately \$1.85 million to \$2.96 million annually to regional participating producers. The facility also produces significant quantities of distillers' grains that are used in livestock production.

International Feed

Contact: Bernie Kaiser

Tel: (763) 479-8185

Email: berniek@internationalfeed.com

www.internationalfeed.com

International Feed has over a decade of experience in the production, supply, and export of feed ingredients. The company has practical experience in the handling and storage of feed ingredients, and offers expert advice on the nutritional value of protein meals. International Feed has excellent relationships with numerous container lines, which enable them to offer low-priced freight and fast transit times. The exporting and importing of animal feed ingredients is a more detailed process that requires many documents and certificates. International Feed has vast experience in the handling and negotiating of export documents.

J.D. Heiskell & Co.

Contact: Mark Neher

Tel: (515) 663-6483

Email: mneher@heiskell.com

www.heiskell.com

J.D. Heiskell & Company is a professionally managed, family-owned company with a rich 123 year history. As the fourth largest feed manufacturer in the US (by volume), they understand and are committed to supplying the same high quality grain and feed ingredients that they use themselves. Export capabilities include rail car and container shipment, with an extensive list of freight providers to ensure competitive rates, as well as a staff to manage all export documents and certificates. By exporting grains and feed ingredients from various container transloading facilities spread across the US, they are able to seamlessly adapt to changing markets and originate from the most economical location. J.D. Heiskell had annual sales over \$3 billion during the last fiscal year. Their culture is driven by relentless pursuit of the highest standards of integrity, accountability, professionalism, excellence and innovation. Customer satisfaction and employee growth opportunities are the benchmarks by which they measure their success.

Kimshe International Grain & Feed LLC

Contact: Sherif Gendi

Tel: (732) 444-1129

Email: sgendi@kimshellc.com

www.kimshellc.com

Based in Holmdel, NJ, Kimshe International Grain specializes in the procurement of grain from several different locations in the midwest, east coast and west coast of the USA. While its focus is mostly on procurement of grain, they also have a department that can assist with all logistics from transportation to documentation and grain testing services. Kimshe was formed by a group of specialists who combined have over 60 years of experience in grain purchasing and logistics.

Land O' Lakes Purina Feed, LLC (LOLPF)

Contact: Darian Carpenter

Tel: (425) 653-4237

Email: DACarpenter@landolakes.com

Contact: John Hany

Tel: (651) 375-5652

Email: jahany@landolakes.com
www.ddgsnutrition.com

Land O' Lakes Purina Feed (LOLPF) DDGS Marketing has exclusive marketing agreements with ethanol plants for the marketing of distillers grain co-products. LOLPF has a highly recognized and respected history of success in the livestock feeding business. Being recognized as the "Industry Leader" in the animal nutrition business, they bring a unique marketing opportunity for their partners in the ethanol business. Combining the expertise of their animal nutrition business with their highly qualified feed ingredient merchandising staff brings value to the company's clients. They have over 80 highly technical feed mills located across the U.S. LOLPF also has feed plants in Ontario, Canada and a partnership in Taiwan. LOLPF has a 'state-of-the-art' animal nutrition research facility in Missouri. This facility is located just Southwest of St. Louis, Missouri, spans over 1200 acres, and is used to conduct feeding trials on multiple species of livestock. There are 11 research scientists at this facility that produce research results that allow them to back up our feeding recommendations. The Land O' Lakes Purina Feed DDGS Marketing team has experience and expertise in all forms of logistics (truck, rail car, containers, barge and vessels). Our export experience has included the St. Lawrence River, Gulf of Mexico, Southwest Pacific Coast, and in the near future, the Pacific Northwest out of Portland/Seattle.

Lansing Trade Group

Contact: Steven J. Speck
Tel: (419) 897-3182
Email: sspeck@lansingtradegroup.com
www.lansingtradegroup.com

Lansing Trade Group is a trading company focused on the movement of physical commodities. The company trades whole grains, feed ingredients, biofuels, freight, and many other commodities, including DDGS and corn gluten feed, within North America and internationally. It controls over 12 million bushels of elevator space through ownership or lease arrangements across the U.S. as well as various other strategically located storage and handling facilities for other commodities traded. Originally formed in Michigan in 1931, Lansing Trade Group is now headquartered in Overland Park, Kansas and has 10 U.S. offices as well as international offices in Geneva, Switzerland; Sao Paulo, Brazil and Buenos Aires, Argentina. The company provides customers with market opinion, price discovery, marketing support, timely distribution, and works hard to ensure that customers will get the quality of product they purchased.

Lincolnland Agri-Energy LLC

Contact: Eric Mosbey
Tel: (618) 553-3802
Email: ejmosbey@lincolnlandagrienergy.com
www.lincolnlandagrienergy.com

Lincolnland Agri-Energy, LLC was formed by local people to add value to the agricultural community. Located in Palestine, IL, ethanol and DDGS production operations began in 2004 after almost 5 years of planning and has operated successfully since that time. The company strives to be a leader in dry-grind ethanol operation and to be excellent neighbors and

environmental stewards. We are here to serve farmers, shareholders, and employees.

Little Sioux Corn Processors

Contact: Steve Roe

Tel: (712) 376-2800

Email: Steve.roe@littlesiouxcornprocessors.com

Little Sioux Corn Processors is a corn-to-ethanol processing facility located in, Marcus, Iowa. The company currently has a nameplate capacity of 92 million gallons of ethanol. It began operation in 2003 and was expanded to its current capacity in 2007. Little Sioux Corn Processors produces DDGS as well as "Modified" Wet Distillers Grains with Solubles (approximately 55% moisture).

Louis Dreyfus Commodities Inc.

Contact: Jose Martinez

Tel: (816) 218-2304

Email: jose_martinez@ldcommodities.com

www.louisdreyfus.com

Louis Dreyfus Commodities Inc. commenced production of ethanol and DDGS in October of 2007. They are also a full service commodity export and trading company and are involved in all major commodities. Their DDGS trading includes exports as well as U.S. domestic truck and rail.

Marquis Grain Inc.

Contact: Marcus Throneburg

Tel: (815) 925-9590

Fax: (815) 925-9504

Email: marcustroneburg@marquisgrain.com

www.marquisenergy.com

Products: DDGS

Marquis Grain Inc. supplies golden dried distiller's grains to markets throughout the world. These markets can be reached by rail, container, and bulk vessel, thanks to the location of the Marquis Energy biofuel facilities. Marquis Grain is the proud supplier of Marquis Gold 60. Thanks to a low-heat drying system at Marquis Energy's Hennepin facility, this uniquely bright product is the real gold standard when it comes to DDGS production. For samples, analysis, or pricing information, please contact them any time. They look forward to reaching new markets and building mutually beneficial business relationships.

Marinex Grains, Inc.

Contact: Kevin Yoon

Tel: (714) 990-2222

Email: kevin.yoon@marinexgrains.com

www.marinexgrains.com

Marinex Grains Inc. (MGI) has various transloading facilities to provide state-of-the-art container shipment services to their grain clients, and the capability to export bulk from the U.S. Gulf of Mexico. MGI serves and distributes corn, wheat, soybeans, sorghum, barley, milo, soybean meal, corn gluten meal, DDGS, and other special purpose co-products. The staff of knowledgeable employees and experts provide unique service experiences, superior quality, and competitive pricing. Currently, MGI is planning to establish a transloading facility in the west coast to provide more competitive and flexible services to their valuable clients.

McCaulay Dalton & Company USA LLC

Contact: Graeme B. Foote

Tel: +61-2-9410-0409

Email: graeme@mccaulaydalton.com.au

www.mccaulaydalton.com.au

McCaulay Dalton & Company was formed in 2000 based on the philosophy that business needs to be approached by forming long-term relationships. Over the course of the company's life span, McCaulay Dalton has evolved from an Australian agricultural marketing consultant to an international commodity broker and has again reinvented itself to include MCCD Freight Services, offering clients ocean freight support for bulk export.

Mirasco Inc.

Contact: Daa Ghaly

Tel: (770) 956-1945

Email: daaa.ghaly@mirasco.com

www.mirasco.com

Based in Atlanta, Georgia, Mirasco Inc. is a major global exporter and distributor of feed ingredients and raw materials, including corn, barley, sorghum, DDGS and corn gluten meal and feed. Mirasco organizes logistics, finance, and risk management to achieve the maximum results for their importers and suppliers. Through global offices located in the US, Uruguay, Brazil, Russia and Egypt, Mirasco is capable of serving its customers worldwide, including importers, distributors and processors. Mirasco's ultimate aim is to build a strong export business for US grains and co-products to several markets including Asia and the Middle East.

Northwest Grains International, LLC

Contact: Gary Mao

Tel: (952) 746-2888

Email: gmao@nwgrains.com

www.nwgrains.com

Northwest Grains International is a company dedicated to the marketing and distribution of

commodity products. Our committed relationship with a professional network of partners enables us to supply our customers efficiently. They export commodity products to Pacific Rim countries which makes Northwest Grains International the leading provider of commodity products to industries worldwide. They pride themselves with outstanding attention to detail. Northwest Grains International employs a selected group of experienced professionals. This staff is well acquainted and involved in every aspect of each transaction, from manufacturing to logistics, and promises quality service and complete satisfaction. Their goal is to provide our customers with trustworthy service, extensive communication, and deliver continuous innovative solutions. They focus their attention in creating complete respect to our different cultural and geographical clientele, always finding a positive response to any problem during the work in progress.

Pasternak, Baum & Co., Inc.

Contact: Michael Johnson

Tel: (914) 630-8145

Email: mjohnson@pasternakbaum.com

www.pasternakbaum.com

Importers and exporters on 6 continents have engaged the services of Pasternak, Baum and Co. for more than 70 years. As brokers and merchant consultants, Pasternak has been known by the community of agricultural commodity traders around the globe since the 1920's. As an independent third party intermediary between buyer and seller, Pasternak provides competitive prices and each client is also offered a total solution through a variety of support services. These services include procurement of freight, financing, insurance and logistics management. This full service brokering allows Pasternak to facilitate transactions of commodities for buyers and sellers around the world. The company brokers nearly one-third of American corn and wheat products. It employs a knowledgeable staff of brokers with an average of 22 years experience in the commodity-trading field.

Patriot Renewable Fuels

Contact: Judd Hulting

Tel: (309) 935-5700

Email: jhulting@patriotethanol.com

Patriot Renewable Fuels, LLC's mission is to produce high quality, environmentally conscious renewable fuels that will promote energy independence for our community and the nation. The company operates a 100 million gallon per year ethanol producing facility in Annawan, IL. This facility also produces 320,000 tons per year of dried distillers grains with soluble for use as a high quality livestock feed ingredient. Patriot Renewable Fuels exported its first international shipment of DDGS in April 2009.

Phibro Ethanol Performance Group

Contact: Tom Slunecka

Tel: (402) 575-5855

Email: tom.slunecka@phibrochem.com

Contact: Michael Giambalvo
Tel: (201) 329-7314
Email: Michael.giambalvo@phibrochem.com

Phibro Ethanol Performance Group (EPG) is a part of PhibroChem. The company was created to focus efforts on developing and marketing products that optimize the fermentation of alcohol during ethanol production. EPG offers LACTROL® antimicrobial, Neotrol and Ethanol Red® Dry Yeast. Together, these products provide a complete fermentation package for EPG customers. EPG and PhibroChem are divisions of Phibro Animal Health Corporation, serving customers worldwide throughout the Animal Health & Nutrition and Performance Products industries. The company has 900 employees to manufacture and market more than 550 specialty products all over the globe. Its combined annual sales are more than \$500 million.

Platinum Ethanol, LLC

Contact: Nick Bowdish
Tel: (712) 367-2727
Email: nbowdish@fageninc.com

Platinum Ethanol is a 110 million gallon per year ethanol production facility located in Arthur, Iowa. Platinum Ethanol began operations in September 2008 and is proud to purchase locally grown corn and produce renewable energy and value-added feed products. Platinum Ethanol employs nearly 50 people and operates 24 hours a day. The company takes pride in its international relationships, which provide an important end market for distiller's dried grains with solubles.

POET Nutrition

Contact: Tarri Rott (Merchandising Manager)
Tel: (605) 965-6279
Email: tarri.rott@poet.com
info@dakotagold.com
www.poet.com or www.Dakotagold.com

POET Nutrition is responsible for one of the more important achievements in biorefining, the development of the standard-setting Dakota Gold DDGS. POET Nutrition's Dakota Gold is an excellent source of livestock feed that is in demand across the globe. With years spent on developing proprietary biotechnologies and processes, POET Nutrition delivers premium distiller's grains consistent in nutrient concentrations, loaded with protein and blessed with excellent flowability and other important technical characteristics. POET's team of PhD. nutritionists and their innovative spirit, have resulted in not only capturing maximum nutrition from each corn kernel, but also creating products with ideal properties for use in multiple applications for a variety of livestock feeds. For product to be given the Dakota Gold label, it needs to meet the highest quality standards in the industry. In addition, because of their tremendous volume, they have unique access to rail, truck and ocean freight to make the delivery of Dakota Gold a simple, predictable affair for their clients all around the world. As part of POET™, they're backed by the strength and resources of one of America's largest and most innovative ethanol

companies. For more information on POET Nutrition and the Dakota Gold family of products, please visit www.dakotagold.com

Renewable Products Marketing Group (RPMG)

Contact: Jim Montbriand
Tel: (952) 465-3248
Email: jmontbriand@rpmgllc.com

Contact: Trevor Kallop
Tel: (651) 465-3252
Email: tkallop@rpmgllc.com
www.rpmgllc.com

The Renewable Products Marketing Group (RPMG) markets 1 billion gallons of ethanol annually from producer-owned ethanol production plants, allowing them to gain economies of scale in their marketing. The company also has distillers grain marketing services and markets over 1 million tons. RPMG has a staff with more than 80 years experience managing co-product marketing. The company has implemented a quality program and is developing global markets for its client plants. RPMG is poised to market any and all co-products produced by the plants utilize fractionation and additional processing technologies. RPMG was founded in 1996 and strives to provide a competitive advantage for producer-owned plants. Marketing ethanol and DDGS through a pool concept allows smaller producers to participate in all markets and utilize all contractual methods to maximize margins. Ethanol and distillers marketing, as well as a group buying program make up the core of RPMG's services. In addition, state-of-the-art logistics management, inventory management, RINs management and support services are provided. With the improvement in technology and the global demand for energy and protein, RPMG is prepared to provide the necessary services for its clients.

Rycom Trading Ltd.

Contact: Ryan Slozka
Tel: (250) 768-4321
Email: ryan.slozka@rycomtrading.com
www.rycomtrading.com

Rycom Trading Ltd. purchases, sells and distributes agricultural commodities, such as corn DDGS, canola meal, protein and energy feeds for the animal feed industry in both Canada and the United States. Rycom works closely with animal nutrition consultants and frequently tests its products to ensure customers are receiving high quality feed products. Rycom also operates a transloading facility in Sunburst, Mont. that facilitates the importing and exporting of agricultural commodities between Canada and the United States.

The Scoular Company

Contact: Jim Harding
Tel: (941) 365-0090
Email: jharding@scoular.com

Contact: Jennifer Li
Tel: (612) 252-3533
Email: JLi@scoular.com

Contact: Doug Grennan
Tel: (612) 335-8205
Email: dgrennan@scoular.com

Contact: Josh Kasprzyk
Tel: (800) 365-0524
Email: jkasprzyk@scoular.com
www.scoular.com

Scoular's export capabilities include barge, rail car and container shipments. They have their own container freight and container transloading division, TSC Container Freight, which is a Scoular subsidiary. Scoular has marketing agreements with ethanol plants for the sale of DDGS.

Touton USA Limited

Contact: Dan Freeman
Tel: (317) 324-6800
Email: d.freeman@touton.com

Formed in June 2008, Touton USA Limited is a U.S. subsidiary of a privately held French company that specializes in trading of raw materials of grain, coffee, and cocoa. The company specializes in the sale of grains and grain products, including DDGS, to markets around the world. It has a specific focus on the Asia market and container shipments. Other Touton locations include the Ivory Coast, Nigeria, Indonesia, Singapore, Australia and it also has business representation in Vietnam, Russia and China. The revenue of the Group totals \$775 million and employs 800 people. Touton USA Limited is based in Indianapolis, IN.

Trans Coastal Supply Co.

Contact: Pam Moses
Tel: (217) 421-0203
Email: pam@transcoastalsupply.com

Contact: Bob Briscoe
Tel: (217) 421-0203
Email: briscoe@pcgrain.com
www.transcoastalsupply.com

Trans Coastal Supply Company (TCSC) provides export customers with agricultural grains and products such as yellow corn, distillers dried grains with solubles (DDGS), corn gluten meal,

yellow soybeans and Hi Pro soybean meal delivered to the transloading facilities of Prairie Creek Grain Company Inc., in Elwood, IL and Agri-Load, Inc in Decatur, IL, as well as to the rail ramps and C&F final port destinations. The company also provides origination, logistics, transloading and drayage complete with product analysis and export documentation. The company's founders bring more than 20 years of experience in grain and feed ingredient trading, logistics and management, and experience in agricultural businesses ranging from drain tiling, elevator management and transloading operations.

Uriman Inc.

Contact: Ryan Kim

Email: rkim@uriman.com

Contact: Joe Onorato

Email: joe.onorato@urimangrain.com

Tel: (714) 257-2080

Fax: (714) 257-2087

Brokers for DDGS, corn, sorghum, gluten feed and meal

Valero Marketing & Supply Company

Contact: Allan Assmann (Manager, DDGS Sales)

Tel: (402) 727-5300

Email: allan.assmann@valero.com

Contact: Ted Hattori (Manager, DDGS Export Sales)

Tel: (210) 345-5304

Email: ted.hattori@valero.com

Contact: Ernest Blansfield (Director, Distillers Grain Sales)

Email: ernest.blansfield@valero.com

www.valero.com

Valero Marketing & Supply Company currently has 7 production facilities and 1 development site in 5 states. Valero has an annual production capacity of approximately 780 million gallons of ethanol and nearly 2.5 million tons of distillers grains.

Western New York Energy

Contact: Andrew Buck (Marketing Manager – Distillers Grains)

Tel: (585) 798-9693

Email: abuck@wnyenergy.com

Western New York Energy is the first ethanol plant in operation in the northeastern United States. The company was founded in 2004 and began producing ethanol and co-products in November 2007. The plant utilizes approximately 20 million bushels of corn annually to produce 55 million gallons of fuel ethanol and 160,000 tons of high quality "Dairy Distillers Grain," a unique low-fat distillers grain that is marketed to western New York feed users. They also

produce and market other co-products such as corn oil and food grade carbon dioxide.

Zeeland Farm Services

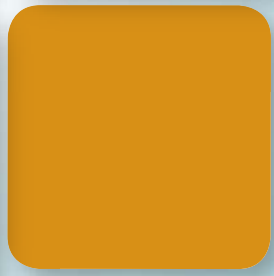
Contact: Darwin Rader (International Sales Manager)

Tel: (616) 748-1819

Email: darwinr@zfsinc.com

Zeeland Farm Services, Inc. is a family-owned and operated business with over 55 years of service to the agricultural and transportation industries. It was founded in 1950 by Robert (Bob) G. Meeuwsen as Meeuwsen Produce and Grain. In 1977, it was reorganized as Zeeland Farm Services, Inc. to provide customers with a wider variety of agricultural services. Bob sold the company to his sons Cliff, Arlen, and Robb in 1992. Over 200 employees, including 12 Meeuwsen family members, work at ZFS. They strive to provide the best possible customer service and offer quality products and services at competitive prices.

CHAPTER 33
Glossary of Terms



Chapter 33

Glossary of Terms

Absorption	(in animal nutrition) the movement of nutrients from the digestive tract into the blood or lymph system.
Acidosis	an undesirable condition that can occur in ruminant animals when fed diets high in readily fermentable carbohydrates such as starch.
Additive	an ingredient added in small quantities to the diet for the purpose of fortifying it with trace nutrients or medicines.
ADF	Acid detergent fiber. the fraction of a feedstuff that is not soluble in an acidic detergent in a laboratory procedure used to determine some components of fiber.
ADG	Average daily gain. the rate of body weight gain of an animal expressed on a daily basis.
ADICP	Acid detergent insoluble crude protein. a measure of by-pass or ruminally undegradable protein of a feed ingredient.
Adipose	fat tissue in an animal or carcass.
ADIN	Acid detergent insoluble nitrogen. a measure of the insoluble portion of nitrogen in a feed ingredient; used to calculate ADICP.
Ad libitum	(feeding) unlimited access to feed or water.
Aerobic	Living or functioning in the presence of oxygen.
Aflatoxin	a carcinogenic mycotoxin produced by molds under specific environmental conditions in growing and stored grains.
Aleurone	the protein portion of the endosperm of a seed.
Amino acids	nitrogen containing organic molecules that are the building blocks of proteins, and essential components of nutrition.
Amylase	an enzyme that can hydrolyze starch to maltose or glucose.
Anaerobic	living or functioning in the absence of oxygen.
Antibiotic	a substance produced by a microorganism that has an inhibitory effect on other microorganisms.
Anti-nutritional factors	chemical components of feed ingredients that reduce the nutritional value of a feed ingredient.
Antioxidant	a substance that prevents fats from becoming rancid through oxidation.
Apparent digestibility	the amount of a nutrient that is absorbed from the gastrointestinal tract.
Arginine	an essential amino acid.
As fed	as consumed by the animal.
Ash	the residue remaining after complete incineration at 500° to 600° C of a feed; comprised of metallic oxides.

Assay	the determination of the chemical components of a feed ingredient or complete feed.
Availability	(nutrient) – the proportion of a nutrient that is utilized by the animal.
Bacteria	single celled living organisms that multiply by simple division. Some are beneficial while others can cause illness.
Balanced diet	a combination of feed ingredients that provide the essential nutrients in the required amounts to meet the animal's needs.
Barrow	castrated male pig.
Beta-carotene	a precursor source of vitamin A found in some plants and plant products.
Biopsy	the removal and examination of tissue or other material from the living body.
Boar	intact, uncastrated male pig.
Bran	seed coat of cereal grains.
Brewer's grains	a grain co-product of the brewing industry.
Beer	(in ethanol production) – a term that refers to the fermented mash that contains ethanol.
By-pass protein	protein not broken down by microbes in the rumen and available for further digestion in the small intestine.
Calorie	a unit of energy measurement defined as the amount of heat required to raise the temperature of one gram of water from 14.5 to 15.5° C.
Carbohydrates	organic substances containing carbon, hydrogen and oxygen; many different kinds are found in plant tissues and include starch, sugar, cellulose, hemicellulose, pectins and gums.
Carcinogen	substances that can cause cancer.
Carotene	a yellow organic compound that is a precursor for vitamin A.
Cecum	a section of the gastrointestinal tract that follows the small intestine and precedes the large intestine which contains a significant amount of bacteria that break down fiber not digested in the small intestine.
Cellulose	a polymer of glucose that has a linkage between glucose molecules resistant to hydrolysis in pigs and poultry, but can be broken down by microbes in the rumen of cattle and sheep and converted into energy.
Co-product	secondary products produced in addition to principle products.
Co-products, ethanol dry-grind	The water and solids remaining after distillation of ethanol is called whole stillage , comprised primarily of water, fiber, protein and fat. This mixture is centrifuged to separate coarse solids from liquid. The coarse solids are also called wet cake and contain about 35% dry matter. Wet cake can be sold to local cattle feeders without drying, or dried to produce dried distiller's grains (DDG) . The liquid, now called as thin stillage , goes through an evaporator to remove additional moisture and the resulting co-product is called

	condensed distiller's solubles which contains approximately 30% dry matter. Condensed distiller's solubles can be sold locally to cattle feeders.
•	Or, the wet cake can be mixed with condensed distiller's solubles and dried to produce distiller's dried grains with solubles (DDGS) which has 88% dry matter.
Colon	the lower portion of the large intestine.
Complete feed	a single feed mixture which may be used as the only source of the nutrients required by an animal except water.
Condense	a process to reduce an item such as stillage to a denser form by removing moisture.
Condensed distiller's solubles	– see Co-products, ethanol dry milling.
Corn germ meal	a co-product from wet milling ethanol plants that contains about 20% crude protein, 2% fat and 9% fiber with an amino acid balance that makes it a useful feed ingredient in swine and poultry diets.
Corn steep liquor	a high energy liquid co-product produced in wet milling ethanol plants that is sometimes combined with corn gluten feed or sold separately as a liquid protein source for beef and dairy cattle.
Crude fat	the portion of a feed or feed ingredient that is soluble in ether and is often referred to as ether extract.
Crude fiber	the less digestible portion of a feed ingredient composed of cellulose, hemicellulose, lignin and other complex carbohydrates.
Crude protein	an estimate of the protein in a feed or feed ingredient, calculated by measuring the nitrogen content (proteins contain about 16% nitrogen) and multiplying by a factor of 6.25 to obtain the crude protein percentage.
Cystine	a sulfur containing amino acid that can replace up to 50% of the swine requirement for methionine.
DDGS	Distiller's dried grains with solubles. In dry-grind ethanol production, a blend of the wet cake and at least 75% condensed solubles, dried to a moisture content of ~ 10%. See Co-products, ethanol dry-grind.
Deamination	removal of the amino group from an amino acid.
Diet	a regulated selection or mixture of feed ingredients provided on a continuous basis or prescribed schedule.
Digestibility	a measure of the extent that the nutrients in a feed are digested and absorbed by an animal.
Digestible energy (DE)	gross energy of the feed minus the energy remaining in feces.
Digestion	the process occurring in the gastrointestinal tract that breaks down complex nutrients into forms that can be absorbed by an animal.
DON	Deoxynivalenol. a mycotoxin sometimes abbreviated as DON and often referred to as vomitoxin because it causes reduced feed intake and feed refusal at low concentrations in the diet and vomiting at higher dietary concentrations.
DL-methionine	a source of synthetic methionine.
Dressing percent	also known as carcass yield and is the portion of the carcass

	remaining after the removal of most internal organs, feet and in most cases, the head.
Drug	as defined by the U.S. Food and Drug Administration is a substance intended for the use in the diagnosis, cure, mitigation, treatment or prevention of disease in humans and other animals.
Dry grind	refers to an ethanol production process that involves grinding the whole corn kernel and fermenting the resultant corn meal without separating out the component parts.
Dry matter (DM)	the portion of a feed remaining after water is removed by drying in an oven.
Duodenum	the first portion of the small intestine.
Endogenous	(in nutrition) – compounds such as enzymes and hormones that are internally produced by the body.
Endosperm	part of the seed which provides food for the developing embryo.
Enzyme	a protein formed in animal or plant cells that act as biological catalysts to increase the rate of chemical reactions.
Essential amino acid	an amino acid that cannot be synthesized in the body in sufficient quantities for the body's needs and must be supplied in the diet.
Ether extract	used to measure the amount of fats and oils in feeds and feed ingredients based on their solubility in ether.
Excreta	the products of excretion from an animal's body which are primarily feces and urine.
Exogenous	(in nutrition) originating from outside of the body.
Fat soluble vitamins	vitamins A, D, E and K (menadione).
Fatty acids	components of a fat molecule that have different carbon lengths and may be unsaturated or saturated.
Feed conversion	the amount of feed required by an animal for a unit of weight gain.
Fermentation	chemical changes brought about by enzymes produced by various microorganisms.
Flowability	the ability of a mass of feed particles or grains to move by gravity out of storage or transport containers.
Fumonisin	a mycotoxin produced by specific molds that can be present in feed ingredients and reduce animal health and performance.
Fractionation	processes used in dry-grind ethanol plants to separate various components of the corn kernel to improve ethanol yield and produce a variety of co-products with different nutritional composition.
Gastric	refers to the stomach of animals.
Gastrointestinal	refers to the stomach and the rest of the intestinal tract used in digestion and absorption of nutrients.
GE	Gross energy. the total heat of combustion of a feed or feed ingredient burned in a bomb calorimeter.
Germ	the embryo of a seed.
Glycerol	a three carbon component of fat.
Ground, grinding	a mechanical process to reduce particle size by impact, shearing or attrition.

Hulls	the outer covering of seed kernels.
Hydrogenation	the chemical addition of hydrogen to any unsaturated compound (double bond), often to fatty acids.
Hydrolysis	the chemical process where a compound is split into simpler units with the uptake of water.
Ileum	the lower portion of the small intestine.
IU	International units. an arbitrary scale used to compare the biological activity of some vitamins.
Insoluble fiber	the portion of non-starch polysaccharides that is not easily fermented in the lower intestinal tract of animals
In vitro	refers to things that occur outside the animal's body in an artificial environment such as a test tube. In vivo – refers to things that occur within the animal's body.
Iodine number	the amount of iodine (in grams) that can be taken up by 100 grams of fat or fatty acids and is a measure of unsaturation.
Jejunum	the middle portion of the small intestine.
Kcal (kilocalorie)	is a unit of energy equal to 1,000 calories.
Kjeldahl	a method to determine the nitrogen content of a feed ingredient to be used in calculating and estimating crude protein.
Lesion	an unhealthy change in color, size or structure of body tissues.
Lignin	an indigestible inorganic component of fiber.
Linoleic acid	an essential fatty acid.
Lipid	fat.
Liquifaction	the process of converting solids into liquid.
Macro (major) minerals	minerals present or required in large amounts relative to the animals requirement and include (calcium, phosphorus, sodium, potassium, magnesium, sulfur and chloride).
Maillard products	a group of poorly digestible protein-carbohydrate complexes that are produced in feed ingredients that are subjected to significant amounts of heating and are characterized by darkening of color (browning), burned flavor and burned smell.
Mash	a mixture of water and corn meal prior to fermentation in a dry grind ethanol plant.
Meal	a grain or feed ingredient or diet that has been ground or otherwise reduced in particle size.
Megacalorie	Mcal. unit of energy equal to 1,000,000 calories or 1,000 kilocalories.
Metabolism	the net effect of biochemical changes in the body including building up (anabolism) and breaking down (catabolism).
ME	Metabolizable energy. gross energy minus fecal and urinary energy from feeding a complete feed or feed ingredient.
Micro (trace) minerals	minerals present or required in small amounts in feeds and feed ingredients relative to the animal's requirement and include (iron, copper, zinc, iodine, selenium and manganese).
Modified wet cake	a blend of partially dried wet distiller's grains with condensed distiller's solubles which has dry matter of approximately 50%. See

	also Co-products, ethanol dry milling.
Monogastric	refers to animals such as swine and poultry that have a single, simple stomach.
Mycotoxycosis	poisoning of an animal that occurs when consuming significant quantities of mycotoxins.
Mycotoxins	toxic substances produced by specific types of molds under specific types of climatic and environmental conditions.
NDF	Neutral detergent fiber. fiber components in plant and grain cell walls that is undigestible for monogastric animals.
NE	Net energy metabolizable energy minus the heat increment.
NFE	Nitrogen free extract. is a calculated estimate of the carbohydrate fraction of a feed ingredient by subtracting moisture, fat, fiber, protein and ash from 100%.
NPN	non-protein nitrogen — any one of a group of nitrogen containing compounds that are not true proteins that can be precipitated from a solution (e.g. ammonia and urea).
Nutrient	any chemical substance that provides nourishment to the body.
Ochratoxin	a mycotoxin produced by aspergillus mold which attacks the kidneys, reduces growth performance and may cause birth defects.
Oleic acid	an 18 carbon fatty acid that contains one double bond and is found in animal and vegetable fat.
Oxidation	the union of a substance with oxygen.
Palmitic acid	a saturated fatty acid with 16 carbons.
pH	a measure of the acidity or alkalinity of a substance; pH = 7 is neutral.
Phytic acid	alternative chemical forms of phytate or phytin and are naturally occurring bound phosphorus compounds in grains and grain co-products that have low digestibility and availability for monogastric animals.
Phytase	is a commercially available enzyme added to monogastric diets to improve digestibility of phosphorus in the phytic acid form in grains and grain co-products for monogastric animals.
ppm	parts per million – a unit of concentration for compounds found in small amounts in feeds and feed ingredients and is equal to mg/kg.
Premix	a mixture of the proper proportions of vitamins and trace minerals that when added to animal diets will meet the requirements for those nutrients.
Propionic acid	one of the volatile fatty acids commonly found in rumen contents.
Proximate analysis	a combination of analytical procedures used to describe feeds and feed ingredients.
Rancid	a term used to describe fats that have undergone partial decomposition.
Ration	a fixed portion of feed, usually expressed as the amount of a diet allowed daily.
Rumen	the second compartment of a ruminant stomach.
Ruminant	any group of hoofed mammals that have a four compartment,

Rumination	complex stomach and that chew their cud while ruminating. the process of regurgitating previously eaten feed, reswallowing the liquids and rechewing the solids (cud).
RUP	ruminally undegradable protein. sometimes referred to as by-pass protein, which is protein that is not degraded by microbes in the rumen and enters the small intestine of ruminants. Generally, undegradable protein is heat damaged protein.
Saccharification	is a process involving hydrolysis (break down) of starch using water and enzymes in ethanol production.
Saturated fat	a fat that contains no fatty acids with double bonds and is solid at room temperature.
Silage	feed resulting from storage and fermentation of wet crops under anaerobic storage conditions.
Soluble fiber	the portion of non-starch polysaccharides in a feed that is readily fermented by microbes in the lower intestinal tract of animals
Solubles	(syrup) see Co-products, ethanol dry milling. In drymill ethanol production, the liquid portion of stillage separated from the coarse grain by centrifugation and concentrated to about 30% solids by evaporation.
Starch	a white, tasteless, odorless polysaccharide carbohydrate found in large quantities in corn, sorghum, wheat and other grains that yields glucose upon hydrolysis.
Steeping	in wetmill corn processing, a process that involves soaking corn kernels under controlled conditions for temperature, time and concentration of sulfuric acid and lactic acid to soften the corn kernel before separating the germ, bran, gluten and starch in wet milling ethanol production.
Stillage	see Co-products, ethanol dry milling.
Stomach	the part of the digestive tract where chemical digestion is initiated in most animal species.
Syrup	see Co-products, ethanol dry milling.
TDF	total dietary fiber which is a measure of non-starch polysaccharides in a feed or feed ingredient and includes soluble and insoluble fiber
TDN	total digestible nutrients – a value that indicates the relative energy value of a feed for an animal.
Trace minerals	see micro minerals.
Ulcer	erosion or disintegration of stomach tissue.
Unsaturated fat	a fat containing from one to three fatty acids that contain one or more double bonds.
Urea	a synthetic, highly concentrated nitrogen product sometimes used as a nitrogen source in rations for ruminants.
VFA	volatile fatty acids which include propionic, acetic and butyric acids.
Volatile fatty acids	short chain fatty acids produced in the rumen of cattle and the cecum and colon of monogastrics that provide energy value to the animal.
Wet cake	see Co-products, ethanol dry milling.

Wet distiller's grains

see Co-products, ethanol dry milling.

Wet milling

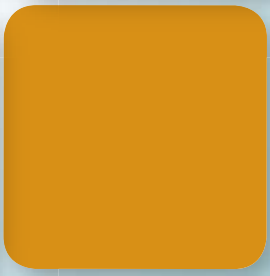
processes used to separate various components of the corn kernel into associated fractions including high fructose corn syrup, corn oil, starch and fiber.

Zearalenone

a mycotoxin produced by fusarium molds under specific climatic and environmental conditions; it has estrogenic effects, causing reproduction problems in animals.

CHAPTER 34

Website Links



Chapter 34

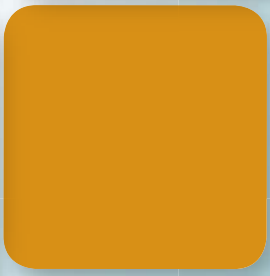
Website Links

Website Links

- U.S. Grains Council: <http://www.grains.org>
- Distillers Grains Technology Council: <http://www.distillersgrains.org/grains/>
- National Corn Growers Association (NCGA): <http://www.ncga.com/>
- Renewable Fuels Association (RFA): <http://www.ethanolrfa.org/>
- Ethanol Producer Magazine: <http://www.ethanolproducer.com/index.jsp>
- The Online Distillery Network: <http://www.distill.com/offlinks.html>
- ep Overviews Publishing Inc.: <http://www.epoverviews.com/>
- University of Minnesota: <http://www.ddgs.umn.edu/>
- United States Department of Agriculture, Foreign Agriculture Service (FAS):
 - o <http://www.fas.usda.gov/ustrade/>
 - o <http://www.fas.usda.gov/>

CHAPTER 35

Key Review Articles and Additional Reading



Chapter 35

Key Review Articles and Additional Reading

DDGS Use in Animal Feeds

- The Midwest Agribusiness Trade Research and Information Center:
<http://www.matric.iastate.edu/DGbook/>
 - Chapter 2. Use of Distillers Co-Products in Diets Fed to **Beef Cattle**
 - Chapter 3. Use of Distillers Co-Products in Diets Fed to **Dairy Cattle**
 - Chapter 4. Use of Distillers Co-Products in Diets Fed to **Swine**
 - Chapter 5. Use of Distillers Co-Products in Diets Fed to **Poultry**
- Corn Distillers Grains: Value-added Feed Source for Beef, Dairy Beef, Dairy, Poultry, Swine, Sheep. <http://www.ncga.com/files/pdf/DistillersGrains9-08.pdf> National Corn Growers Association. Sep. 9, 2008.
- D. J. Schingoethe ,1 K. F. Kalscheur , A. R. Hippen , and A. D. Garcia. 2009. *Invited review: The use of distillers products in dairy cattle.* J. Dairy Sci. 92:5802–5813
<http://download.journals.elsevierhealth.com/pdfs/journals/0022-0302/PIIS0022030209713001.pdf>
- T. J. Klopfenstein, G.E. Erickson, and V.R. Bremer. 2008 BOARD-INVITED REVIEW: Use of distillers by-products in the beef cattle feeding industry. J. Anim. Sci. 86: 1223-1231. <http://dx.doi.org/10.2527/jas.2007-0550>
- Kalscheur, K. F. 2006. Feeding distillers grains to dairy cattle: Impact on milk fat, protein, and yield. Distillers Grains Quarterly, 1(3):20-21 and Part 2. 1(2):24-27.
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DDGS Suppliers List

[Abengoa Bioenergy Trading U.S.](#)

Contact: Thomas Rossmanith

Tel: (636) 728-4500

Email: Thomas.Rossmanith@bioenergy.abengoa.com

Abengoa Bioenergy Trading U.S., LLC was formed to manage the critical functions of grain procurement, ethanol and DDGS co-product marketing, and hedging and risk management for all commodities, including energy needs. The concentration of these functions into one specialized entity for all U.S. operations is critical to achieve the company's goals of consistency, efficiency, and identification of one common brand throughout U.S. Abengoa Bioenergy operations. Currently, Abengoa Trading markets co-products for the six Abengoa owned U.S. ethanol plants. Abengoa's plants are located strategically in the western cattle feeding markets and along the Mississippi River system.

Abengoa Bioenergy Trading U.S. will market approximately 500,000 short tons of DDGS through the center gulf in 2010. Abengoa's unique ability to put this much volume into the market place from identical production facilities leads to the consistency that has been missing from the marketplace in the past. Abengoa also has the ability to pelletize our product without sacrificing the specifications, this leads to increased efficiencies in freight and handling costs for our customers that can benefit from full vessel shipments of DDGS from NOLA.

[Agribase International, Inc.](#)

Contact: Terry English

Tel: (217) 370-5654

Email: terry.english@agribaseinc.com

Agribase International, Inc. is a U.S. feed ingredients exporting company based in Schaumburg, IL. Their core business deals in DDGS, soybeans, whey powder and other ingredients. Terry English, formerly the USGC delegate for the Illinois Department of Agriculture, has been named the delegate to the Council on behalf of Agribase.

[Agniel Commodities, LLC](#)

Contact: Lucien Agniel

Tel: (401) 248-2086

Fax: (401) 248-2087

Email: info@agnielcommodities.com

www.agnielcommodities.com

Brokers for these products: wheat, corn, soybeans, soybean meal, DDGS, corn gluten meal, cotton seed, soy hull pellets

[AG Processing, Inc \(AGP\)](#)

Contact: Craig Pietig
Tel: (402) 492-3322
Email: cpietig@agp.com

Historically, AGP has been a wet distiller's grains marketer, but is now marketing DDGS from two ethanol plants in Iowa and Nebraska. Their export capabilities include barge, rail car and container shipments. AGP owns an export facility located in the Port of Grays Harbor in the state of Washington.

[AgMotion](#)

Contact: Tim Carlson
Tel: (612) 486-3880
Email: trade@agmotion.com
www.agmotion.com

AgMotion, Inc. is a principal trading and exporting company that specializes in DDGS among other major U.S. commodities. The company also operates as US Commodities. Please see their website and contact them directly for more information.

[Archer Daniels Midland Company \(ADM\)](#)

Contact: Ryan J. Brocklesby
Tel: (217) 451-8162
Email: ryan.brocklesby@adm.com (Vessels)

Contact: Tony Ielase
Tel: (217) 451-4776
Email: containers@adm.com (Containers)

Contact: Aaron Taft
Tel: (217) 451-5061
Email: aaron.taft@adm.com (Truck and Rail)
www.adm.com

Every day, the 29,000 people of Archer Daniels Midland Company (NYSE: ADM) work to connect the harvest to the home, turning crops into renewable products that serve the vital needs of a growing world. We trade, transport, store and process corn, oilseeds, wheat and cocoa into products for food, animal feed, chemical and energy uses. We are committed to the responsible, sustainable development of agriculture throughout the world. ADM is a producer and exporter of DDGS with production facilities in North Dakota, Iowa, Nebraska and Illinois. ADM has four gulf export elevators as well as two floating rigs to load DDGS or combination commodity vessels. ADM has three exclusive container loading facilities and also utilizes two additional public container loading facilities. Export capabilities include vessel, barge, rail car and container shipments.

[Attebury Grain, LLC](#)

Contact: Keith Hunt
Tel: (806) 335-1639
Fax: (806) 335-1165

Email: khunt@attebury.com

www.atteburygrain.com

Products: DDGS, Corn and Soybeans

[Big River Resources](#)

Contact: Raymond Defenbaugh

Tel: (319) 753-1100

Email: ray.defenbaugh@bigriverresources.com

www.bigriverresources.com

Big River Resources West Burlington, LLC is an ethanol plant in West Burlington, Iowa. Production at a 40 million gallon per year name plate rate started April 12, 2004. A doubling project from 40 to 92 million gallons per year name plate rate was completed December 2007.

[Bunge North America](#)

Contact: David Barham

Tel: (314) 292-2927

Email: david.barham@bunge.com (Vessel)

Contact: Julio Salinas

Tel: (314) 292-2988

Email: julio.salinas@bunge.com (Vessel)

Contact: Richard Moneymaker

Tel: (314) 292-2923

Email: richard.moneymaker@bunge.com (Rail)

Contact: Elisa Uribe

Tel: (314) 292-2422

Email: elisa.uribe@bunge.com (Rail)

Contact: Kristan Barta

Tel: (712) 366-8830

Email: kristan.barta@bunge.com (Trucks)

Contact: Jim Macfarlane

Tel: (314) 292-2115

Email: jim.macfarlane@bunge.com (Containers)

Bunge North America has marketing agreements and is a minority investor in two ethanol facilities slated to begin production in 2008. With a 200 year history in agribusiness, Bunge can provide not only critical contacts in the North American animal nutrition markets but with our global reach we are able to provide access to developing export markets as well. Bunge's export capabilities include vessel, rail car, and container shipments. Bunge owns an export facility located in Destrehan, LA. Please contact them directly for more information.

C&D (USA) Inc.

Contact: Jerry Wang

Tel: (630) 928-1180

Email: jwang@chinacnd.com

www.chinacnd.com

C&D (USA) Inc. is a wholly-owned subsidiary company of Xiamen C&D Inc., a top 100 ranking, public company in China. Xiamen C&D is one of the biggest importers of grain, oilseeds and feed stuffs in China. After C&D USA opened in Chicago, Ill. in 2008, it quickly set up a suppliers' and logistics network of agricultural commodities in the United States and became one of the largest exporters of U.S. DDGS to China. C&D USA is currently working to develop its buyers' network in Southeast Asia.

Cargill, Inc.

Contact: Daniel Humboldt

Tel: (952) 742-2326

Email: daniel_humboldt@cargill.com

Contact: Mark Jirik

Tel: (952) 742-6068

Email: mark_jirik@cargill.com

Cargill has marketing agreements with dry grind ethanol facilities. They are also investors in those facilities. Cargill takes market positions from other DDGS marketers in the United States. Cargill sells a combination 36% protein-fat DDGS. Export capabilities include vessel, barge, container, rail cars and truck shipments. Cargill markets approximately 1 million metric tons of product per year.

Cenex Harvest States (CHS)

Contact: Clayton Haupt

Tel: (651) 355-6804

Email: clayton.haupt@chsinc.com (Vessel)

Contact: Scott Thiel

Tel: (800) 769-1066

Email: scott.thiel@chsinc.com (Container)

Contact: Sean Broderick (For prices FOB ethanol plants and delivered points in the U.S. Canada and Mexico)

Tel: (800) 769-1066

Email: sean.broderick@chsinc.com

www.chsinc.com

CHS is a diversified energy, grains and foods company committed to providing the essential resources that enrich lives around the world. A Fortune 100 company, CHS is owned by farmers, ranchers and cooperatives, along with thousands of preferred stockholders, across the United States. CHS supplies energy, crop nutrients, livestock feed, grain, food and food ingredients, along with business solutions, including insurance, financial and risk management services. The company operates petroleum

refineries/pipelines and manufactures, markets and distributes Cenex® brand refined fuels, lubricants, propane and renewable energy products. CHS is the largest agricultural coop in the U.S. CHS is also the largest marketer of DDGS with estimated tons marketed in excess of 5 million for 2010. CHS currently has exclusive marketing agreements with 28 U.S. ethanol plants. CHS has container loading capabilities at several locations and owns and operates bulk export capacity in the U.S. Gulf, on the West Coast, and off of the Great Lakes. With offices around the world CHS is positioned to serve your DDGS needs.

[Consolidated Grain and Barge Company \(CGB\)](#)

Contact: Mitchell McGee

Tel: (985) 867-3554

Email: mitchell.mcgee@cgb.com

www.cgb.com

CGB is a full service Ag commodity trading and logistics company that specializes in the trading and exporting of golden DDGS. They focus their service on shipping only those DDGS with a consistent quality, utilizing strong relationships with various origin plants. Their logistical capabilities include truck, rail car, container, barge, and vessel shipments. CGB owns several container and barge loading facilities throughout the Midwest and use third party loaders when necessary. In addition, they can load and unload barges at multiple locations in the Gulf of Mexico, and load DDGS or combination commodity vessels. Currently, CGB services numerous export markets and can streamline the supply chain for quality golden DDGS from origin to destination. Please contact them directly and visit their website for additional information.

[DeLong Co., Inc.](#)

Contact: Brian Arnold

Tel: (608) 676-3039

Email: barnold@delongcompany.com

www.delongcompany.com

As one of the Midwest's largest suppliers of food grade corn and soybeans, the DeLong Co. has more than a quarter-century of experience supplying food grade white and yellow corn to domestic and international markets, including Europe, Asia, Mexico and Canada. With annual sales exceeding \$800 million, the company is active in grain, fertilizer and ag chemicals, seed, feed and pet foods, and transportation. The company also operates 45 trans-loading facilities in the Midwest, where products from farmer producers and elevators in Wisconsin, Illinois, Indiana and Ohio are trans-loaded into containers for shipment.

Flint Hills Resources LLC

Contact: Ryan Sauer

Tel: (515) 817-2987

Email: ryan.sauer@fhr.com

Flint Hills Resources is an independent refining and chemicals company. It strives to create value for its customers and society – through the way its facilities operate, its efficient use of resources, the products it produces and markets, and its involvement in its communities. The company, based in Wichita, Kan., has expanded its operations through capital projects and acquisitions worth more than \$6.2 billion since 2002.

The following Flint Hills plants are members of the U.S. Grains Council:

Flint Hills Resources Fairbank LLC is a 115 million-gallons-per-year plant that began operation in 2006 as the second ethanol production facility in the Hawkeye Renewables system. The facility consumes about 41 million bushels of corn annually and produces about 980 tons of DDGS per day.

Flint Hills Resources Iowa Falls LLC is a 100 million-gallons-per-year ethanol plant that was expanded to its current capacity in 2006. The plant uses 36 million bushels of corn per year and produces about 860 tons of DDGS each day. The plant was the first plant in the Hawkeye Renewables system and was originally constructed as a 50 million-gallons-per-year plant. It began operations in November of 2004.

Flint Hills Resources Menlo LLC is a 115 million-gallons-per-year ethanol plant that was completed in September, 2008. The plant uses 41 million bushels of corn per year and produces about 370,000 tons of DDGS each year. The plant was the third plant in the Hawkeye Energy Holdings system.

Flint Hills Resources Shell Rock LLC is a 115 million-gallons-per-year ethanol plant that was completed in October, 2008. The plant uses 41 million bushels of corn per year and produces about 370,000 tons of DDGS each year. The plant was the fourth plant in the Hawkeye Energy Holdings system.

Fornazor International Inc.

Contact: John Fornazor, Jr.

Tel: (201) 664-4000

Fax: (201) 664-3222

Email: jf@fornazor.com

www.fornazor.com

Products: Corn, Sorghum, Barley, Co-Products (gluten feed, gluten meal), Distillers Grains

Fornazor International is a US trading company and feed manufacturer exporting commodities globally since 1979. Fornazor exports and trades grains, vegetable proteins, marine proteins, and animal proteins primarily to Asian and the Middle Eastern markets. Fornazor owns and operates their own loading facilities on the east coast and also has forage export facility in Kansas where they produce alfalfa pellets as well. Fornazor has a blend facility where they create their own custom feed formulations as well as other finished feeds.

Gavilon

Contact: Tomas Elvir

Tel: (402) 889-4348

Email: tomas.elvir@gavilon.com

www.gavilon.com

Gavilon sources and distributes grain inputs including corn, wheat, soybeans, sorghum, milo and DDGS throughout North America, the Caribbean, Central America, South America, Europe and Asia. Gavilon Grain, with roots that go back well over 130 years as Peavey Grain, achieves quick, efficient handling while protecting quality with 64 high-volume capacity grain elevators. Formerly ConAgra Trade Group, Gavilon was formed as a newly independent entity through the acquisition by a group of investors led by Ospraie Special Opportunities Fund. Gavilon is now positioned to provide its customers with a more complete and robust trading, merchandising and distribution platform than ever before. Gavilon is headquartered in Omaha, NE with 930 employees worldwide and 144 facilities on six continents.

Green Plains Renewable Energy Inc.

Contact: Brent Lorensen

Tel: (402) 315-1643

Email: brent.lorensen@gpreinc.com

www.gpreinc.com

Green Plains Renewable Energy was founded in 2004 and is North America's fourth-largest ethanol producer. GPRE operates a total of eight dry-mill ethanol plants in Indiana, Iowa, Michigan, Nebraska and Tennessee with annual expected operating capacity totaling approximately 670 million gallons. GPRE's eight plants will consume approximately 239 million bushels of corn in the ethanol production process. They also market and distribute ethanol for third-party ethanol producers with annual expected operating capacity totaling approximately 360 million gallons. Today, GPRE markets and distributes over one billion gallons of ethanol, representing about 8% of the total U.S. supply, as well as 2.1 million tons of distillers grains. GPRE owns 51% of Blendstar, LLC, a biofuel terminal operator which operates nine blending or terminaling facilities with approximately 495 million gallons per year of total capacity in seven states in the south central United States. GPRE also operates grain storage facilities with 31 million bushels of storage capacity and complementary agronomy and petroleum businesses at 13 facilities located in Iowa, southern Minnesota and western Tennessee.

Golden Grain Energy

Contact: Walter Wendland

Tel: (563) 238-5555

Email: wwendland@etoh.us

Golden Grain Energy is a privately-held company dedicated to adding value to northern Iowa's corn production by turning locally-grown corn into clean-burning ethanol. The company currently produces approximately 100 million gallons of ethanol annually at a plant in Mason City, Iowa. Owned by more than 750 members, the majority of whom are northeast Iowa farmers, Golden Grain Energy is

committed to being a strong partner in the local community, a key player in the regional economy and a leader in Iowa's ethanol industry. The company employs 45 individuals and purchases more than 33 million bushels of locally-grown corn annually from producers and grain dealers. In addition to ethanol, Golden Grain Energy produces both wet and dry distillers grains, providing a feed source for livestock producers. Golden Grain Energy strives to help meet the growing national demand for domestic biofuels, which are the key components of our nation's efforts to reduce reliance on foreign oil and improve air quality around the country.

[Granite Falls Energy](#)

Contact: Tracey Olson

Tel: (320) 564-3100

Email: tolson@granitefallsenergy.com

Based in Granite Falls, Minn., Granite Falls Energy began producing ethanol in 2005 and has a production capacity of 50 million gallons per year. The plant is a limited liability corporation comprised of over 900 investors. Granite Falls Energy has recently submitted permits to increase its production capacity to 70 million gallons per year. DDGS produced at Granite Falls Energy are marketed by CHS, though the company does market directly to the local end-users. The company recently added a corn oil extraction process to its production capacity.

[Hawkeye Gold, LLC](#)

Contact: Mike Borcharding

Tel: (515) 663-6468

Email: mborcharding@hawkgold.com

This e-mail address is being protected from spambots.

You need JavaScript enabled to view it.

www.hawkgold.com

Hawkeye Gold is an operating subsidiary of Hawkeye Energy Holdings, a privately owned, Iowa-based renewable energy company. The company provides professional marketing services for distillers grains producers. We have an industry leading team with many years of experience in marketing distillers and other commodities and have access to a wide range of local, domestic and international markets. Our client-plants have state of the art ethanol facilities that produce a premium golden color distiller grains that is highly nutritious and well suited for animal feed.

The following Hawkeye plants are members of the U.S. Grains Council: Hawkeye Renewables – Fairbanks is a 115 million-gallons-per-year plant that began operation in 2006 as the second ethanol production facility in the Hawkeye Renewables system. The facility consumes about 41 million bushels of corn annually and produces about 980 tons of DDGS per day. Hawkeye Renewables – Iowa Falls is a 100 million-gallons-per-year ethanol plant that was expanded to its current capacity in 2006. The plant uses 36 million bushels of corn per year and produces about 860 tons of DDGS each day. The plant was the first plant in the Hawkeye Renewables system and was originally constructed as a 50 million-gallons-per-year plant. It began operations in November of 2004. Hawkeye Menlo LLC is a 115 million-gallons-per-year ethanol plant that was completed in September, 2008. The plant uses 41 million bushels of corn per year and produces about 370,000 tons of DDGS each year. The plant was the third plant in the Hawkeye Energy Holdings system. Hawkeye Shell Rock LLC is a 115 million-

gallons-per-year ethanol plant that was completed in October, 2008. The plant uses 41 million bushels of corn per year and produces about 370,000 tons of DDGS each year. The plant was the fourth plant in the Hawkeye Energy Holdings system.

[Homeland Energy Solutions](#)

Contact: Walter Wendland
Tel: (563) 238-5555
Email: wwendland@etoh.us
www.homelandenergysolutions.com

Homeland Energy Solutions, LLC operates an ethanol processing plant which produces 100 million gallons of ethanol annually from 37 million bushels of corn using a 2.8:1 conversion ratio. Based in Lawler, IA, the facility serves corn producers in an 11 county area in northeastern Iowa. The purchase of the 37 million bushels of corn will increase the demand for corn and increase its market value. Based on existing industry experience a projected value increase is expected between \$.05 and \$.08 per bushel. This would amount to an increased income of approximately \$1,850,000.00 to \$2,960,000.00 annually to regional participating producers. The facility would also produce significant distillers' grains which could increase livestock production.

[International Feed](#)

Contact: Bernie Kaiser
Tel: (763) 479-8185
Email: berniek@internationalfeed.com
www.internationalfeed.com

International Feed has over a decade of experience in the production, supply and export of feed ingredients. The company has practical experience in the handling and storage of feed ingredients, and we offer expert advice on the nutritional value of protein meals. International Feed has excellent relationships with numerous container lines, which enable us to offer low-priced freight and fast transit times. The exporting and importing of animal feed ingredients is an involved process that requires many documents and certificates. International Feed has vast experience in the handling and negotiating of export documents.

[J.D. Heiskell & Co.](#)

Contact: Mark Neher
Tel: (515) 663-6483
Email: mneher@heiskell.com
www.heiskell.com

J.D. Heiskell & Company is a professionally managed, family-owned company with a rich 123 year history. As the fourth largest feed manufacturer in the US by volume, we understand and are committed to supplying the same high quality grain and feed ingredients that we use ourselves. Export capabilities include rail car and container shipment, with an extensive list of freight providers to ensure competitive rates, as well as a staff to manage all export documents and certificates. By exporting grains and feed ingredients from various container transloading facilities spread across the

US, we are able to seamlessly adapt to changing markets and originate from the most economical location. J.D. Heiskell had annual sales over \$3 billion last fiscal year. Our culture is driven by relentless pursuit of the highest standards of integrity, accountability, professionalism, excellence and innovation. Customer satisfaction and employee growth opportunities are the benchmarks by which our success is measured.

[Kimshe International Grain & Feed LLC](#)

Contact: Sherif Gendi

Tel: (732) 444-1129

Email: sgendi@kimshellc.com

www.kimshellc.com

Based in Holmdel, NJ, Kimshe International Grain specializes in the procurement of grain from several different locations within the Midwest, east coast and west coast of the USA. While its focus is mostly on procurement of grain, they also have a department that can assist with all logistics from transportation to documentation and grain testing services. Kimshe was formed by a group of specialists who combined have over 60 years of experience in grain purchasing and logistics.

[Land O Lakes Purina Feed, LLC \(LOLPF\)](#)

Contact: Darian Carpenter

Tel: (425) 653-4237

Email: DAcarpenter@landolakes.com

Contact: John Hany

Tel: (651) 375-5652

Email: jahany@landolakes.com

www.ddgsnutrition.com

Land O'Lakes Purina Feed (LOLPF) DDG Marketing has exclusive marketing agreements with ethanol plants for the marketing of distiller grain co-products. LOLPF has a highly recognized and respected history of success in the livestock feeding business. Being recognized as the "Industry Leader" in the Animal Nutrition business, we bring a unique marketing opportunity for our partners in the ethanol business. Combining the expertise of our animal nutrition business with our highly qualified feed ingredient merchandising staff brings value to the company's clients. We have over eighty highly technical feed mills located across the U.S. We also have feed plants in the Province of Ontario in Canada and a partnership in Taiwan. We have a 'State of the Art' Animal Nutrition Research Facility in Missouri. This facility located just Southwest of St Louis spans over 1200 acres and conducts feeding trials on multiple species of livestock. There are eleven research scientists at this facility that allows us to back up our feeding recommendations with test proven research. The Land O'Lakes Purina Feed DDG Marketing team has experience and expertise in all forms of logistics (truck, rail car, containers, barge and vessels). Our export experience has included the St. Lawrence River, Gulf of Mexico, Southwest Pacific Coast and in the near future the Pacific Northwest out of Portland/Seattle.

Lansing Trade Group

Contact: Steven J. Speck

Tel: (419) 897-3182

Email: sspeck@lansingtradegroup.com

www.lansingtradegroup.com

Lansing Trade Group is a trading company largely focused on the movement of physical commodities. The company trades whole grains, feed ingredients, biofuels, freight and many other commodities, including DDGS and corn gluten feed, within North America and internationally. It controls over 12 million bushels of elevator space through ownership or lease arrangements across the U.S. as well as various other strategically located storage and handling facilities for other commodities traded. Originally formed in Michigan in 1931, Lansing Trade Group is now headquartered in Overland Park, Kansas and has 10 U.S. offices as well as international offices in Geneva, Switzerland; Sao Paulo, Brazil and Buenos Aires, Argentina. The company provides customers with market opinion, price discovery, marketing support, timely distribution and works hard to ensure that customers will get the quality of product they purchased.

Lincolnland Agri-Energy LLC

Contact: Eric Mosbey

Tel: (618) 553-3802

Email: ejmosbey@lincolnlandagrienergy.com

www.lincolnlandagrienergy.com

Lincolnland Agri-Energy, LLC was formed by local people to add value to the agricultural community. Located in Palestine, IL, operations began in 2004 after almost five years of planning and has operated successfully since. The company strives to be a leader in dry grind ethanol operation and to be excellent neighbors and environmental stewards. We are here to serve farmers, shareholders, and employees.

Little Sioux Corn Processors

Contact: Steve Roe

Tel: (712) 376-2800

Email: Steve.roe@littlesiouxcornprocessors.com

Little Sioux Corn Processors is a corn-to-ethanol processing facility located in, Marcus, Iowa. The company currently has a nameplate capacity of 92 million gallons of ethanol. It began operation in 2003 and was expanded to its current capacity in 2007. Little Sioux Corn Processors produces DDGS as well as "Modified" Wet Distillers Grains with Solubles (approximately 55% moisture).

Louis Dreyfus Commodities Inc.

Contact: Jose Martinez

Tel: (816) 218-2304

Email: jose_martinez@ldcommodities.com

www.louisdreyfus.com

Louis Dreyfus Commodities Inc. commenced production of Ethanol and DDGS in October of 2007. They are also a full service commodity export and trading company involved in all major commodities. Their trade in DDGS includes exports as well as U.S. domestic truck and rail.

[Marquis Grain Inc.](#)

Contact: Marcus Throneburg

Tel: (815) 925-9590

Fax: (815) 925-9504

Email: marcusthronenburg@marquisgrain.com

www.marquisenergy.com

Products: DDGS

Marquis Grain Inc. supplies golden dried distiller's grains to markets throughout the world. These markets can be reached by rail, container, and bulk vessel, thanks to the location of the Marquis Energy biofuel facilities. Marquis Grain is the proud supplier of Marquis Gold 60. Thanks to a low-heat drying system at Marquis Energy's Hennepin facility, this uniquely bright product is the real gold standard when it comes to DDGS production. For samples, analysis, or pricing information, please contact us anytime. We look forward to reaching new markets and building mutually beneficial business relationships.

[Marinex Grains, Inc.](#)

Contact: Kevin Yoon

Tel: (714) 990-2222

Email: kevin.yoon@marinexgrains.com

www.marinexgrains.com

Marinex Grains Inc. has various transloading facilities to provide state-of-the-art container shipment services to the grain clients, and the capability to export bulk from the U.S. Gulf. MGI serves and distributes corn, wheat, soybeans, sorghum, barley, milo, soybean meal, corn gluten meal, DDGS and other special purpose by-products. The staff of knowledgeable employees and experts provide unique service experiences, superior quality and competitive pricing. Currently, MGI is planning to establish a transloading facility in the west coast to provide more competitive and flexible services to their valuable clients.

[McCaulay Dalton & Company USA LLC](#)

Contact: Graeme B. Foote

Tel: +61-2-9410-0409

Email: graeme@mccaulaydalton.com.au

www.mccaulaydalton.com.au

McCaulay Dalton & Company was formed in 2000 based on the philosophy that business needs to be approached by formulating long-term relationships. Over the course of the company's life span, McCaulay Dalton has evolved from an Australian agricultural marketing consultant to an international

commodity broker and has again reinvented itself to include MCCD Freight Services, offering clients ocean freight support for bulk export.

[Mirasco Inc.](#)

Contact: Daaa Ghaly

Tel: (770) 956-1945

Email: daaa.ghaly@mirasco.com

www.mirasco.com

Based in Atlanta, Mirasco Inc. is a major global exporter and distributor of feed ingredients and raw materials, including corn, barley, sorghum, DDGS and corn gluten meal and feed. Mirasco organizes logistics, finance, and risk management to achieve the maximum results their importers and suppliers. Through global offices located in the US, Uruguay, Brazil, Russia and Egypt, Mirasco is capable of serving its customers worldwide, including importers, distributors and processors. Mirasco's ultimate aim is to build a strong export track record for US grains and co-products to several markets including Asia and the Middle East.

[Northwest Grains International, LLC](#)

Contact: Gary Mao

Tel: (952) 746-2888

Email: gmao@nwgrains.com

www.nwgrains.com

Northwest Grains International is a company dedicated to the marketing and distribution of commodity products. Our committed relationship with a professional network of partners enables us to supply our customers efficiently; exporting commodity products to the Pacific Rim countries and making Northwest Grains International the leading provider of commodity products to industries worldwide. We pride ourselves with outstanding attention to detail. Northwest Grains International employs a selected group of experienced professionals; this staff is well acquainted and involved in every aspect of each transaction, from manufacturing to logistics, we promise quality service and complete satisfaction. Our goal is to provide our customers with trustworthy service, extensive communication and deliverance of constant innovating solutions. We focus our attention in creating complete respect to our different cultural and geographical clientele, always finding a positive response to any problem during the work in progress.

[Pasternak, Baum & Co., Inc.](#)

Contact: Michael Johnson

Tel: (914) 630-8145

Email: mjohnson@pasternakbaum.com

www.pasternakbaum.com

Importers and exporters on six continents have engaged the services of Pasternak, Baum and Co. for more than 70 years. As brokers and merchant consultants, Pasternak has been known by the community of agricultural commodity traders around the globe since the 1920s. An independent third party intermediary between buyer and seller, Pasternak provides competitive prices but each client is

also offered a total solution through a variety of support services. The services include the procurement of freight, financing, insurance and logistics management. This full service brokering allows Pasternak to facilitate transactions of commodities for buyers and sellers around the world. The company brokers nearly one-third of American corn and wheat products. It employs a knowledgeable staff of brokers with an average of 22 years experience in the commodity-trading field.

[Patriot Renewable Fuels](#)

Contact: Judd Hulting

Tel: (309) 935-5700

Email: jhulting@patriotethanol.com

Patriot Renewable Fuels, LLC's mission is to produce high quality, environmentally conscious renewable fuels that will promote energy independence for our community and the nation. The company operates a 100-million gallon per year ethanol producing facility in Annawan, IL. This facility also produces 320,000 tons per year of dried distillers grains. This bi-product is primarily used as a high-quality livestock feed. The company sent its first international shipment of DDGS in April 2009.

[Phibro Ethanol Performance Group](#)

Contact: Tom Slunecka

Tel: (402) 575-5855

Email: tom.slunecka@phibrochem.com

Contact: Michael Giambalvo

Tel: (201) 329-7314

Email: Michael.giambalvo@phibrochem.com

Phibro Ethanol Performance Group (EPG) is a part of PhibroChem. The company was created to focus efforts on developing and marketing products that optimize the fermentation of alcohol during ethanol production. EPG offers LACTROL® antimicrobial, Neotrol and Ethanol Red® Dry Yeast. Together, these products provide a complete fermentation package for EPG customers. EPG and PhibroChem are divisions of Phibro Animal Health Corporation, serving customers worldwide throughout the Animal Health & Nutrition and Performance Products industries. The company has 900 employees to manufacture and market more than 550 specialty products all over the globe. Its combined annual sales are more than \$500 million.

[Platinum Ethanol, LLC](#)

Contact: Nick Bowdish

Tel: (712) 367-2727

Email: nbowdish@fageninc.com

Platinum Ethanol is a 110 million gallon per year ethanol production facility located in Arthur, Iowa. Platinum Ethanol commenced operations in September 2008 and is proud to purchase locally grown corn and produce renewable energy and value-added feed products. Platinum Ethanol employs nearly 50 people and operates around the clock. The company takes pride in its international relationships, which provide an important end market for distiller's dried grains with solubles.

POET Nutrition

Contact: Tarri Rott (Merchandising Manager)

Tel: (605) 965-6279

Email: tarri.rott@poet.com

info@dakotagold.com

www.poet.com or www.Dakotagold.com

POET Nutrition is responsible for one of the more important achievements in biorefining, the development of the standard-setting Dakota Gold distillers grains (DDGS). POET Nutrition's Dakota Gold is an excellent source of livestock feed in demand across the globe. With years developing proprietary biotechnologies and processes, POET Nutrition delivers premium distiller's grains consistent in nutrient concentrations, loaded with protein and blessed with excellent flowability and other important technical characteristics. Our team of PhD nutritionists and their innovative spirit means we not only reap maximum nutrition from each corn kernel, we create a product with ideal properties for use in multiple applications for a variety of livestock feed needs. For product to be given the Dakota Gold label it needs to meet the highest quality standards in the industry. And, because of our tremendous volume, we have unique access to rail, truck and ship to make the delivery of Dakota Gold a simple, predictable affair for our clients all around the world. And as part of POETTM, we're backed by the strength and resources of one of America's largest and most innovative ethanol companies. For more information on POET Nutrition and the Dakota Gold family of products, please visit us at www.dakotagold.com

Renewable Products Marketing Group (RPMG)

Contact: Jim Montbriand

Tel: (952) 465-3248

Email: jmontbriand@rpmgllc.com

Contact: Trevor Kallop

Tel: (651) 465-3252

Email: tkallop@rpmgllc.com

www.rpmgllc.com

The Renewable Products Marketing Group (RPMG) markets 1 billion gallons of ethanol annually from producer-owned ethanol production plants, allowing them to gain economies of scale in their marketing. The company recently added distillers grain marketing services and expects the volume to reach 1 million tons by the end of 2008. RPMG has a staff with more than 80 years experience managing co-products. The company has implemented a quality program and is developing global markets for the client plants. RPMG is poised to market any and all co-products produced by the plants as they utilize fractionation and additional processing technologies in the future. The company, founded in 1996, strives to provide a competitive advantage for producer-owned plants. Marketing ethanol and DDGS through a pool concept allows smaller producers to participate in all markets and utilize all contractual methods to maximize margins. Ethanol and distillers marketing and a group buying program make up the core of RPMG's services. In addition, state-of-the-art logistics management, inventory management, RINs management and support services are provided. With the improvement in technology and the global demand for energy and protein, RPMG is prepared to

provide the necessary services for its clients.

Rycom Trading Ltd.

Contact: Ryan Slozka

Tel: (250) 768-4321

Email: ryan.slozka@rycomtrading.com

www.rycomtrading.com

Rycom Trading Ltd. purchases, sells and distributes agricultural commodities, such as Corn Distillers (DDGS), Canola Meal, protein feeds and energy feeds, for the animal feed industry in both Canada and the United States. Rycom works closely with animal nutritional consultants and frequently tests its products to ensure customers are receiving high quality and beneficial feed products. Rycom also operates a transloading facility in Sunburst, Mont. that facilitates the importing and exporting of agricultural commodities between Canada and the United States.

The Scoular Company

Contact: Jim Harding

Tel: (941) 365-0090

Email: jharding@scoular.com

Contact: Jennifer Li

Tel: (612) 252-3533

Email: JLi@scoular.com

Contact: Doug Grennan

Tel: (612) 335-8205

Email: dgrennan@scoular.com

Contact: Josh Kasprzyk

Tel: (800) 365-0524

Email: jkasprzyk@scoular.com

www.scoular.com

Scoular's export capabilities include barge, rail car and container shipments. They have their own container freight and container transloading division, TSC Container Freight, which is a Scoular subsidiary. Scoular has marketing agreements with ethanol plants for the sale of DDGS.

Touton USA Limited

Contact: Dan Freeman

Tel: (317) 324-6800

Email: d.freeman@touton.com

Formed in June 2008, Touton USA Limited is the U.S. subsidiary of a privately held French company that specializes in trading of raw materials of grain, coffee, and cocoa. The company specializes in the sale of grains and grain products, including DDGS, to markets around the world. It has a specific focus on the Asia market and container shipments. Other Touton locations include the Ivory Coast, Nigeria, Indonesia, Singapore, Australia and it also has business representation in Vietnam, Russia and China.

The revenue of the Group totals \$775 million and employs 800 people. Touton USA Limited is based in Indianapolis, IN.

[Trans Coastal Supply Co.](#)

Contact: Pam Moses

Tel: (217) 421-0203

Email: pam@transcoastalsupply.com

Contact: Bob Briscoe

Tel: (217) 421-0203

Email: briscoe@pcgrain.com

www.transcoastalsupply.com

Trans Coastal Supply Company (TCSC) provides export customers with agricultural grains and products such as yellow corn, distillers dried grains with solubles (DDGS), corn gluten meal, yellow soybeans and Hi Pro soybean meal delivered to the trans loading facilities of Prairie Creek Grain Company Inc., in Elwood, IL and Agri-Load, Inc in Decatur, IL as well as offers to the rail ramps and C&F final port destinations. The company also provides origination, logistics, trans loading and drayage complete with product analysis and export documentation. The company's founders bring more than 20 years of experience in grain and feed ingredient trading, logistics and management, and experience in agricultural businesses ranging from drain tiling, elevator management and trans loading operations.

[Uriman Inc.](#)

Contact: Ryan Kim

Email: rkim@uriman.com

Contact: Joe Onorato

Email: joe.onorato@urimangrain.com

Tel: (714) 257-2080

Fax: (714) 257-2087

Products: DDGS, corn, sorghum, gluten feed and meal.

[Valero Marketing & Supply Company](#)

Contact: Allan Assmann (Manager, DDGS Sales)

Tel: (402) 727-5300

Email: allan.assmann@valero.com

Contact: Ted Hattori (Manager, DDGS Export Sales)

Tel: (210) 345-5304

Email: ted.hattori@valero.com

Contact: Ernest Blansfield (Director, Distillers Grain Sales)

Email: ernest.blansfield@valero.com

www.valero.com

Valero Marketing & Supply Company currently has a fleet of 7 production facilities and 1 development site in five states. Valero is scheduled to have an annual production capacity of approximately 780 million gallons of ethanol and nearly 2.5 million tons of distillers grains by mid 2009.

[Western New York Energy](#)

Contact: Andrew Buck (Marketing Manager – Distillers Grains)

Tel: (585) 798-9693

Email: abuck@wnyenergy.com

Western New York Energy is the first ethanol plant in operation in the northeastern United States. The company was founded in 2004 and began producing ethanol and co-products in November 2007. The plant utilizes approximately 20 million bushels of corn annual and produces 55 million gallons of fuel ethanol; 160,000 tons of high quality “Dairy Distillers Grain,” a unique low-fast distillers grain that is marketed in western New York feed users; and other products such as corn oil, and food grade carbon dioxide.

[Zeeland Farm Services](#)

Contact: Darwin Rader (International Sales Manager)

Tel: (616) 748-1819

Email: darwinr@zfsinc.com

Zeeland Farm Services, Inc. is a family-owned and operated business with over 55 years of service to the agricultural and transportation industries. It was founded in 1950 by Robert (Bob) G. Meeuwsen as Meeuwsen Produce and Grain. In 1977, it was reorganized as Zeeland Farm Services, Inc. to provide customers with a wider variety of agricultural services. Bob sold the company to his sons Cliff, Arlen, and Robb in 1992. Over 200 employees, including 12 Meeuwsen family members, work at ZFS. We endeavor to provide the best possible customer service and offer quality products and services at competitive prices.