THE NUTRIENT COMPOSITION, ECONOMIC ANALYSIS OF LOW-OIL CORN DISTILLERS DRIED GRAINS WITH SOLUBLES AND ITS EFFECTS ON BROILER AND LAYER PERFORMANCE

by

AHMET CEREM GUNEY

(Under the Direction of Dr. Gene M. Pesti)

ABSTRACT

Increased production of ethanol for the automotive industry has led great amounts of distillers dried grains with solubles (DDGS) to be available to poultry and other livestock industries. The U.S. government recently decided to eliminate ethanol blending credit that was provided to ethanol producers in the past. Due to the purpose of creating additional stream of revenue, many ethanol plants considered extraction of corn oil from DDGS being produced. The extracted oil can be used in biodiesel production or sold as a commodity to different industries. DDGS, whose oil is extracted, is commonly called as low-oil DDGS. There are currently very limited research conducted regarding the nutrient composition and applications of low-oil DDGS in poultry industry. In these studies, we determined the nutritional properties, economic value analysis and feeding recommendations in poultry rations for low-oil DDGS.

INDEX WORDS: distillers dried grains with solubles, oil extraction,

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INTRODUCTION AND LITERATURE REVIEW

Distillers dried grains with solubles (DDGS) have been one of the most popular alternative feed ingredients for livestock feeding, particularly for beef and dairy cattle. The use of DDGS in poultry feed dates back to the 1930s even though it has been used much more extensively in the past two decades. Cooley (1938) and Boruff and Miller (1938) invented the first methods of producing DDGS back then. Association of American Feed Control Officials (1940) defined corn distillers dried grains as the “dried residue obtained in the manufacture of alcohol and distilled liquors from corn or a grain mixture in which corn predominates” and distillers corn solubles as a “by-product from the manufacture of alcohol from corn solids obtained by evaporation of the mash liquor after removal of the alcohol and wet grains.” This marked the start of the history of DDGS.

Today, the availability of DDGS to poultry has increased dramatically due to the considerably high demand for ethanol (Batal and Dale, 2006; Lumpkins et al., 2005). Ethanol manufacturers are investigating methods to improve the efficiency of ethanol production every day. In that manner, extraction of corn oil from DDGS has been considered and implemented by some ethanol plants in the past five years. The oil extracted from DDGS can then be sold as a commodity (Saunders et al., 2009). Residual DDGS, whose oil is extracted, is commonly known as low-oil DDGS. New research is being directed to investigate nutrient composition of low-oil DDGS and its use in poultry rations. This will ensure whether or not low-oil DDGS might be used successfully and economically in poultry rations in the future.

Ethanol and co-product DDGS production process

Ethanol, also referred to as ethyl alcohol, is primarily used as liquid fuel in transportation vehicles due to its characteristics which allow it to be used in combustion engines, similar to gasoline. Today, gas stations throughout the U. S. offer gasoline with some amount of ethanol blended inside. The main reasons for mixing ethanol with gasoline include (a) increasing octane ratings; (b) decreasing gasoline usage; (c) decreasing CO_2 emissions. Because of its advantages over gasoline, the U. S. government has passed tax credits and federal incentives to promote increasing levels of ethanol production (Dale and Tyner, 2006).

Yellow dent corn is the most commonly used grain in commercial ethanol production. The corn kernel is composed of the endosperm, germ, and pericarp. The endosperm is the vital component of the corn kernel in ethanol production, for it contains a high concentration of starch (around 87.6%). In addition, the endosperm is responsible for 80 to 85% of the dry weight of a corn kernel while the germ makes up only 8 to 10%. The corn germ contains oil (33.2%), protein (18.4%), and starch (8.3%) (Watson, 1994).

There are two major processes used in the production of ethanol in the U. S. These processes are called “wet-milling” and “dry-milling.” The method of glucose extraction and the co-products produced are the main differences that separate these two processes.

In the wet-milling process, corn is first soaked in a diluted sulfur dioxide solution, which results in the softening of the corn kernels. Water absorbs the soluble nutrients during this process, and the water is later evaporated. After the evaporation, these nutrients become a particle called “Condensed Corn Fermented Extractives.” The corn germ is removed from the water-soaked kernel and is used to recover the oil. The residual part is called the corn germ meal, which is used as a feed ingredient. Once the germ is removed, the bran is passed through the screens to eliminate the starch and the gluten protein. Then, the bran is combined with other co-products to produce corn gluten feed, which goes through the centrifuge system to separate the starch and the gluten protein. The gluten protein part is later concentrated and dried to produce corn gluten meal, which is another feed ingredient. Finally, the remaining starch is further processed to produce ethanol, but DDGS is not produced in the wet-milling process. (Dale and Tyner, 2006; Davis, 2011).

In the dry-milling process, the whole corn kernel is first crushed into a meal using a hammer mill. The corn meal is then mixed with water to form slurry. Alpha-amylase and gluco-amylase are the enzymes used to break down starch into smaller glucose units, which are fermentable sugars. This process is called liquefaction. The alpha-amylase enzyme causes the slurry to become a dextrin solution. The gluco-amylase cleaves the dextrin into smaller gluco-units. After the completion of liquefaction, yeast species are used to convert the dextrose into ethanol and carbon dioxide. Fat and fiber are left untouched in the fermentation tank. The fermenting mash is then sent to the distillation area to extract the ethanol. The water and the solids (protein, fat, and fiber) are collected from the distillation base. These form the particle called whole stillage. Then, the whole stillage goes through the centrifuge system to separate solids from liquids. The liquid part, known as thin stillage, is later evaporated to become Condensed Distillers Solubles. Finally, the solids collected from the centrifuge are combined with condensed solubles to produce corn Distillers Dried Grains with Solubles (DDGS). In general, dry-mills are slightly more efficient and require less capital investment than wet-mills in ethanol production (Dale and Tyner, 2006; Davis, 2011).

History of DDGS and its use in poultry diets

First trials of the use of DDGS in poultry feed started in the 1940s. Shea et al. (1941) and Dickens et al. (1941) discussed the use of DDGS in chick and laying rations. DDGS later was found to be a good source of water-soluble vitamins and a valuable vitamin supplement in chick rations (Synold et al., 1943). Parkhurst et al. (1945) investigated DDGS inclusion in breeding rations. This era of poultry industry was the time period in which lots of questions were being asked but the answers were unknown. Novak et al. (1947) discussed the existence of an unidentified growth factor in DDGS that is necessary for chicks. These unidentified growth factors were mainly vitamins synthesized during fermentation, which were still being studied for discovery in the 20th century (Lumpkins et al., 2005).

Great improvements with DDGS occurred towards the end of the 1960s and 1970s, where DDGS was extensively studied in various trials. Matterson et al. (1966) was the first to conclude that DDGS could be successfully included in laying rations. Several years later, Harms (1969) reported more and mentioned that DDGS can be added to the laying hen diets at a level of 10%. He also determined that DDGS contained approximately 0.40% available Methionine, 0.70% TSAA, and a metabolizable energy in excess of 2640 kcal/kg.

Waldroup et al. (1981) was the first to investigate the potential usage of DDGS in broiler diets. According to this study, DDGS up to 25% inclusion did not show any significant differences in body weights and feed conversion ratio at 42 days of age. This marked the evidence of DDGS being used successfully in broiler diets for the first time. Later on, the protein quality of DDGS was researched due to its high protein content. Parsons et al. (1983) determined that DDGS contained 28.6% crude protein and 0.72% total lysine, which is the first limiting amino acid when DDGS is fed as the sole source of dietary protein. When DDGS was fed as the only protein source, chicks gained weight slower and less efficiently compared to chicks which were fed soybean meal (SBM) as the only protein source. However, broiler performance parameters were similar to birds fed SBM when DDGS was supplemented with synthetic lysine. A rooster assay was also conducted in this study, and true digestibility of lysine in DDGS was determined to be 82.4%. Finally it was concluded that at least 20% SBM could be replaced by DDGS with no detrimental effects, while up to 40% of SBM could be replaced by DDGS (supplemented with lysine) with little depression in growth rate (Parsons and Baker, 1983).

The end of the 1980s and 1990s were silent periods for DDGS due to the extensive use of gold standard ingredients of poultry feed: corn and SBM. The extensive use of these two ingredients practically destroyed the need, and eventually, the use of DDGS in poultry diets. However, in the 2000s, ethanol production began to be encouraged in the United States due to the ongoing environmental issues of the time. The number of ethanol plants in the United States increased dramatically and were suddenly producing more ethanol than they had ever done before. As a result, DDGS was now being produced not only in beverage industry, but also as a part of ethanol production (Lumpkins et al., 2004).

Whether or not the DDGS produced by the ethanol plants hold the same nutrient composition of DDGS being produced in beverage industry was raised. Since all of the previous studies evaluated DDGS produced in the beverage industry, a new set of trials started being conducted to answer this question. Lumpkins et al. (2004) was one of the first to research the inclusion of DDGS in broiler diets. Birds fed up to 15% DDGS had similar performance at 18 days of age compared to the birds fed corn SBM diet. In addition, there was no significant change in performance or carcass yield throughout the 42-day study. However, a depression in BW gain and feed conversion was recorded when birds were fed 18% DDGS in the starter period (0 – 16 day). It was concluded that DDGS coming from ethanol plants is an acceptable feed ingredient in broiler diets and could successfully be used at 6% in the starter and 12 to 15% in the grower and finisher periods of the diets. However, a very recent study by Shim et al. (2011) reported that broilers fed 8, 16 or 24% DDGS showed increased BW gain compared to birds fed no DDGS during the starter period (0 to 18 days), but body weights were similar among the treatments at day 42. This study recommended up to 24% DDGS inclusion when the diets were properly balanced.

Mineral composition of DDGS was analyzed by Batal and Dale (2003). During the production of ethanol from corn, two-thirds of the corn is converted into ethanol and carbon dioxide during fermentation. Accordingly, concentrations of unfermented nutrients, such as minerals, are expected to increase 3-fold. In simpler terms, the content of a particular mineral in DDGS is expected to be three times of the content in corn. In that manner, calcium, sodium and sulfur were the only minerals that did not agree with this prediction. The contents of all other minerals were similar to the predicted values (Batal and Dale, 2003).

The next step was to try DDGS inclusion in laying hen diets, which compose the majority of the poultry diets along with broiler diets. Lumpkins et al. (2005) investigated 0 or 15% inclusion of DDGS in laying hen diets that are fed either a commercial or low-density diet. The results indicated that there were no differences in most of the parameters between the treatments. Only hens fed the low density diet with %15 DDGS had a reduction in hen-day egg production. Overall, it was concluded that DDGS could be used up to 12% in commercial laying hen diets. Recently, Masa'deh (2011) researched high levels of DDGS inclusion (up to 25%) in laying hen diets for a longer period (from 24 to 76 weeks). Most of the measures were same among the treatments except for the egg weight, which was lowered by the increasing levels of DDGS during phase 1 (from 24 to 46 weeks). In phase 2 (from 47 to 76 weeks), yolk color was improved, and nitrogen and phosphorus excretion was decreased as DDGS increased. Egg yolk improvement was also shown by Loar et al. (2010), where yolk color was darker and redder when high levels of DDGS were used. In this study, consumers preferred eggs derived from DDGS fed laying hens during the taste panel. In summary, very recent studies showed that higher levels of DDGS (up to 32%) could be used in laying hen diets without any detrimental effects.

Next studies of DDGS were geared towards its phosphorus content and bioavailability due to the environmental concerns of phosphorus. The discussion of the contribution of poultry manure to environmental contamination was a hot topic in the 2000s. A great deal of interest was concentrated on ways to improve phosphorus utilization in birds (Lumpkins and Batal, 2005), and many attempts were made to change the bad publicity directed towards the poultry industry. In addition, phosphorus bioavailability of DDGS coming from ethanol plants was expected to be higher than that in typical beverage plant due to the fermentation process involved in ethanol production (Singsen et al., 1972; Mahgoub and El Hag, 1997; El Hag et al., 2002). Amezcua et al. (2004) reported that total phosphorus content in DDGS was 0.73 ± 0.04% (with an average dry matter of 88%). P bioavailability was dependent on lysine digestibility of DDGS, but was still higher than value published on NRC (1994). In addition, Lumpkins and Batal (2005) reported P bioavailability between 80 and 100% in lysine deficient diets and bioavailability between 54 and 68% in phosphorus deficient diets. The true digestibility of Lysine was also determined to be 75%, which was relatively lower than the value reported in the previous study by Parsons et al. (1983).

An interesting approach was taken in terms of heat processing or cooking of DDGS to increase phosphorus bioavailability (Amezcua and Parsons, 2007). Previous studies showed that heat application or cooking might increase phosphorus bioavailability in some feed ingredients (Mahgoub and Elhaf, 1997; Duhan et al., 2002; Carlson and Poulsen, 2003). The reason behind this is believed to be the alteration of phytate structure under increased heat and causing of more phosphorus release. In addition, fermentation was believed to reduce phytic acid in DDGS. Mahajan and Chauhan (1998) reported that fermentation reduced phytic acid in several plants. Amezcua and Parsons (2007) found that increased heating of DDGS by autoclaving (at 124 kPa and 121^0C for 60 to 80 minutes) or heating in a drying oven (121^0C for 60 minutes) increased P bioavailability from 70 to 91%. On the other hand, heating was shown to have a detrimental effect on amino acid bioavailability even though it improved phosphorus bioavailability in several feed ingredients (Bjarnason and Carpenter, 1970; Anurag and Geervani, 1987; Parsons et al., 1992). Amezcua (2007) also investigated the effect of heating on several amino acid bioavailabilities. The results from this study indicated that amino acid bioavailabilities were reduced by heating in most cases. In particular, lysine bioavailability was the most affected as it decreased to 8%. Therefore, increased heat processing caused an increase in phosphorus bioavailability but an even bigger decrease in lysine bioavailability.

Amino acid concentrations, digestibilities and energy content of DDGS samples with different colors were studied by Fastinger et al. (2006). Total lysine content of DDGS ranged from 0.48 to 0.76%, which agreed with the previous study of Parsons and Baker (1983). True digestibility of lysine ranged from 65.3 to 82.4%, which were also in line with previous studies

(Parsons and Baker, 1983; Lumpkins and Batal, 2005). Batal and Dale (2006) also reported a total concentration of 0.71% and digestibility of 70% for lysine, and concentration of 0.54% and digestibility of 87% for methionine. Pahm et al. (2009) later on reported lysine bioavailability of 69.0%. Fastinger et al. (2006) mentioned that TME_n values ranged from 2484 to 3047 kcal/kg while Batal and Dale (2005) reported a range from 2490 to 3190 kcal/kg. Interestingly, amino acid availabilities and TME_n content were reduced when the color of DDGS sample was in a certain threshold (lightness between 28 and 34). In particular, lysine digestibility of the darkest DDGS sample was the lowest (Fastinger et al., 2006). The reason was related to the overheating of DDGS during drying, which caused Maillard reactions to be more extensive. Maillard reactions affected the lysine residues and eventually caused lysine to be converted to other compounds. As a result, total lysine content was reduced, and Maillard reactions eventually caused darkening of the color (Parsons et al., 1992).

Particle size always played a very important role in the nutritional value of grains and other feedstuffs. Reduction of the particle size was mainly preferred due to better distribution of particles during mixing and improvement of pellet quality (Amezcua et al., 2007). In addition, previous studies showed that digestibility of nutrients and efficiency of growth of pigs was improved due to the reduction in particle size of the feed ingredients (Wondra et al., 1995; Laurinen et al., 2000; Lahaye et al., 2004). However, recent studies conducted in poultry showed that feeding larger particle size of corn and SBM had ,as a matter of fact, a positive effect on phosphorus utilization in birds (Kasim and Edwards, 2000; Charbeneau and Roberson, 2004; Kilburn and Edwards, 2004). In that curiosity, the effect of particle size on phosphorus utilization was investigated. It was found out that particle size did not significantly affect utilization (Amezcua, 2007).

The effects of DDGS on broiler performance were discussed in many studies, but only a few were conducted to research the effects of DDGS on carcass composition. Wang et al. (2007a, b) reported that DDGS did not affect carcass composition of broilers fed up to 15% DDGS. However, the effects of DDGS on broiler meat quality were not widely studied. Corzo et al. (2009) aimed their study specifically towards meat quality measures of birds that were fed DDGS. These measures were color, pH, cooking loss, shear force, and sensory testing values for breast, lipid oxidation and fatty acid composition for thigh meat. There was no significant effect of 8% DDGS inclusion on color, pH, cooking loss, and shear values compared to the control group, which had no DDGS inclusion. In addition, consumers could not differentiate between the treatments during the sensory test. However, broilers fed 8% DDGS had a greater linoleic and total polyunsaturated fatty acids (vs. birds fed no DDGS), showing that it was more susceptible to oxidation. As a result, overall meat quality of broilers fed 8% DDGS was very similar to the control group. A year later, Schilling et al. (2010) also investigated the effects of DDGS on broiler meat quality. The results of this study were generally in line with Corzo et al. (2009) but also added that DDGS inclusions higher than 12% caused thigh meat to be more susceptible to oxidation. No differences in breast meat and thigh meat quality were shown among the treatments when DDGS was fed up to 12% though.

In the past, researchers were interested in investigating the effects of DDGS on the environmental issues. Several studies were conducted to find ways to improve phosphorus utilization due to its effects on the environment (Mahgoub and El Hag, 1997; El Hag et al., 2002; Amezcua et al., 2004; Lumpkins and Batal, 2005). Very recently, another approach on environmental issues was taken to research the effects of DDGS on air emissions. It was shown in the previous study that 10% DDGS inclusion in laying hen diet caused a decrease in ammonia

(NH_3) and hydrogen sulfide (H_2S)emission from hen manure (Roberts et al., 2007). However, the effects of higher inclusion of DDGS were not discussed in this study. Due to the high availability of DDGS in the poultry industry, Wu-Haan (2010) investigated the effects of DDGS with up to 20% inclusion on air emissions and also on laying hen performance. The results showed that 20% DDGS feeding to laying hens resulted in lower emissions of NH_3 and H_2S with no adverse effects on hen performance.

Effects of distillers dried grains vs. solubles on the nutrient composition of DDGS

DDGS is formed with the addition of condensed solubles to the grains after the fermentation process. The amounts of grains vs. solubles in DDGS could have an effect on the composition of DDGS since each of those (grains and solubles) has different nutritional composition. Amezcua et al. (2007) investigated the nutritional composition of grains and solubles, individually. The results showed that the solubles had considerably lower crude protein than grains (18.70 vs. 27.11%) but higher levels of crude fat, ash, and phosphorus. The grains had higher total amino acid concentrations than the solubles except for lysine, where the total lysine concentration was equal (0.8%) for both grains and solubles. This was likely due to the low total lysine concentration (0.5%) in the resulting DDGS and possible heat damage of the DDGS during drying. In addition, amino acid digestibilities of the grains were higher than the solubles. (Amezcua et al., 2007).

Corn fractionation techniques and High-protein DDGS

Ethanol plants have been researching new ways to optimize the fermentation process for a greater yield of ethanol and decreased overall costs. New corn processing and fractionation techniques were evaluated and implemented by some of the traditional dry-grind ethanol plants in the past seven years. A modification system, which fractionates the non-fermentable parts (germ, pericarp fiber, and bran) from the fermentable part (endosperm) of the corn kernel, was developed. Three different examples of this modification technique are quick germ (QG), quick germ quick fiber (QGQF), and enzymatic milling (E-mill) (Singh et al., 2005). The removal of the non-fermentable parts of the corn kernel at the beginning of the dry-grind ethanol production process results in (a) additional production of ethanol per batch due to the sole use of corn endosperm, which is rich in fermentable starch;(b) DDGS with increased protein content at the end of fermentation; (c) recovery of high quality germ that is used in the recovery of corn oil. Resulting DDGS with high protein content is often called high-protein DDGS (HP-DDGS) (Applegate et al., 2009; Kim et al., 2008; Jung and Batal, 2009; Singh et al., 2005).

The effects of three different corn fractionation techniques on the composition of DDGS were investigated by Singh et al. (2005). Protein content of residual DDGS products was 28, 36, 49 and 58% for conventional, QG, QGQF and E-Mill, respectively. The fat content ranged from 3.8 to 4.8% for DDGS samples produced by the fractionation techniques. Traditional dry-grind ethanol production process resulted in a DDGS with expected fat content of 12.7%. The removal of the germ, which is high in oil, was the main reason for the decreased fat content of DDGS samples.

Several studies were conducted to evaluate the nutritional value of HP-DDGS. Kim et al. (2008) investigated the phosphorus bioavailability, TME, and amino acid digestibilities of HP-DDG. Total P content of HP-DDG was much lower compared to conventional DDGS (0.33 vs. 0.76%) while P bioavailabilities were similar for HP-DDGS and conventional DDGS (60 vs. 56%, respectively). TME_n of HP-DDGS was 2,957 kcal/kg, which was lower than traditional

DDGS (3,554 kcal/kg). Applegate et al. (2009) reported AME_n of 2,526 kcal/kg, which was 431 kcal/kg less than TME_n reported by Kim et al. (2008).Recently, Rochell et al. (2011) reported AME_n values of 2,708 and 2,932 for two HP-DDGS samples. The variation between the energy values among the HP-DDGS samples were likely due to the percentage of solubles content in HP-DDGS, experimental methodology (chick assay vs. rooster assay), or both. In general, however, lower oil content of HP-DDGS was the main cause of decreased TME_n and AME_n compared to traditional DDGS. HP-DDGS had higher total lysine content than traditional DDGS (0.95 vs. 0.88%) but similar digestibility coefficients (73.1 vs. 73.9%). The total methionine content (0.81 vs. 0.53%) and digestibility coefficient (90.2 vs. 84.4%) were much higher than traditional DDGS (Kim et al., 2008). However, Jung and Batal (2009) reported an average Lysine concentration of 1.23% (minimum 1.13%) and an average Methionine concentration of 0.97% (minimum 0.84%). Digestibilities of Lysine and Methionine were similar in the two studies (Kim et al. vs. Jung and Batal). Overall, increased amino acid concentrations were expected due to the higher crude protein content of HP-DDGS.

The effects of HP-DDGS on the performance of broilers and laying hens were also studied to evaluate its inclusion in poultry rations. Applegate et al. (2009) reported that inclusion up to 50% HP-DDGS in replacement of SBM (with 48% CP) had no negative effect on bird performance and breast yield at 42 days of age but that it decreased body weight gain and increased feed to gain ratio from 14 to 28 days of age. In addition, birds fed 50% HP-DDGS consumed 17.1% more nitrogen and excreted more manure and manure nitrogen (21.9 and 31.8% more, respectively) than the control group. It was concluded that HP-DDGS could successfully be included up to 50% in replacement of SBM in broiler diets, but it also resulted in increased manure and nitrogen excretion (Applegate et al, 2009). Jung and Batal (2009) researched the inclusion of HP-DDGS up to 12% in laying hen diets. No differences in feed intake, egg yolk color, or specific gravity were determined when HP-DDGS was fed up to 12%. The only difference was observed in the addition of 3% HP-DDGS, which resulted in improved egg mass. It was concluded that HP-DDGS was an acceptable feed ingredient when it was used up to 12% in laying hen diets (Jung and Batal, 2009).

Low-oil DDGS

Why extract oil?

There are currently more than 200 ethanol production plants throughout the U.S. and Canada. The U.S. government mandated the use of 15 billion gallons of ethanol by 2015, which will result in an estimated amount of 50 million tons of DDGS per year (Hagen and Musser, 2011). However, the U.S. government decided to eliminate the 45 cents/gallon ethanol blending credit that was provided to ethanol producers in the past. In addition, the extension of the 54 cents/gallon import tariff is still being debated, but no decisions have been made yet (Musser, 2012). Due to these reasons, ethanol producers are in search of alternative sources of revenue for the sustainability of their businesses. In that manner, extraction of corn oil from DDGS was considered a very good option.

Economics of oil extraction

Ethanol plants consider oil extraction as a part of the overall ethanol production process due to its economics. The current value of corn oil is around 40 cents/lbs. Currently, a typical DDGS costs around 10 cents/lbs and has between 10 and 12% corn oil. For example, a 100-million-gallon (per year) ethanol plant produces about 900 tons of DDGS per day that typically contains 10.7% corn oil. Furthermore, the oil extraction technology applied in an ethanol plant can reduce this down to 7.2%, which results in a reduction of 3.5% and 70 lbs of oil per ton of DDGS. This equals approximately 11,000 tons of corn oil and revenue of $6.6 million just for the corn oil itself. There is obviously a capital cost of implementing this technology to an operating ethanol plant, and it's reported that this cost is paid back within a year of operation (Musser, 2012).

Evaluation of ethanol plants

A commercial company (Nutriquest) has been collecting and analyzing DDGS samples from 140 different ethanol plants during the several past years. Later, a database that reflects various nutrient analyses of DDGS as well as product consistency of ethanol plants was created from the information gathered. More importantly, this database helps inform DDGS users about which plants are and are not extracting oil. According to this database, since the beginning of 2012, 74 out of 140 ethanol plants (little over 50%) were either not extracting oil, or DDGS that was oil extracted had above 10% fat. Remaining 64 plants were doing some oil extraction, which results in less than 10% fat content. 46 out of oil extracting 64 plants had DDGS that were less than 9% fat. The company also reported an increase in the number of ethanol plants producing low-oil DDGS (with less than 10% fat content) from 28% in January to 37% in August 2011. This clearly shows that the number of ethanol plants implementing oil extraction is increasing over time (Musser, 2012; Hagen and Musser, 2011).

History of oil extraction

Even though the research studies were conducted in the 1990s, implementation of oil extraction technology evolved in the past five years. Prior to 2007, some traditional dry-grind ethanol plants implemented different corn fractionation technologies to improve ethanol yield. The primary goal of this fractionation process was to get a higher yield of ethanol. Fractionation resulted in DDGS with higher protein content. Fractionation process simply separated the non-fermentable parts from the endosperm (fermentable part) of the corn kernel at the beginning of the ethanol production process. This technology is also called "front-end fractionation" due to its occurrence prior to the fermentation, and residual DDGS is often called "high protein DDGS" (HP-DDGS). After 2007, a new process was discovered, which removed the corn oil after the entire corn kernel was fermented to produce ethanol (Jung and Batal, 2009). The primary goal of this process was to extract corn oil and is often called "back-end oil extraction." This technology heats the concentrated stillage and then uses centrifuge technology to extract crude corn oil out of the heated concentrated stillage. The residual DDGS produced by this method is often called "low-oil DDGS" (LO-DDGS).

Front-end fractionation vs. Back-end oil extraction

HP-DDGS does not always have low oil content despite its high protein content. There are some corn fractionation methods which remove only the fiber part of the corn kernel. This results in reduced fiber content, but similar or even a higher fat content with traditional DDGS. One example of this type of fractionation technique is called "Elusieve." This process removes the fiber by sieving and air classification during the fractionation process. Residual DDGS produced by this method has 40.8% crude protein, 15.0% fat, and 19.7% total dietary fiber (Amezcua et al., 2007; Srinivasan et al., 2005).

Some corn fractionation techniques such as quick germ (QG) or quick germ quick fiber (QGFB) result in HP-DDGS with reduced fat content due to the removal of the corn germ, which has high oil content. Later, the corn germ is used in the recovery of corn oil. The corn oil produced by front-end fractionation technology is very high quality and can be used in either food manufacturing or biodiesel production (Watkins, 2007). On the other hand, the corn oil extracted on the back-end is feed or fuel grade oil, which can be used as raw material for biodiesel production (Watkins, 2007; S.A., 2006; McElroy, 2007). A study conducted at the University of Toronto reported that it would be easier to perform an oil extraction at the back-end of the ethanol plant using centrifuge technology because capital costs would be much less than what would be required to produce refined oils from an ethanol plant with a front-end fractionation process. (McElroy, 2007).

Studies of oil extraction and low-oil DDGS

Attempts to extract oil from corn were researched in several previous studies (Chang et al., 1995; Chen and Hoff, 1987; Chien et al., 1998; Chien et al., 1990; Hojilla-Evangelista et al., 1992). However, Singh and Cheryan (1998) were the first to study the feasibility of extracting corn oil from DDGS. In this study, corn oil was extracted using ethanol as a solvent since ethanol is readily available in dry-grind ethanol plants. It was concluded that the optimum volume of ethanol was 6 mL per gram of DDGS. This resulted in about 50% extraction of the oil or 66 mg crude oil per gram of DDGS (Singh and Cheryan, 1998).

Research studies later moved towards the low-oil DDGS due to the increase in its availability in the market. One of the first studies about low-oil DDGS investigated its common physical and chemical properties (Saunders and Rosentrater, 2009). Physical properties included moisture content, water activity, thermal properties, bulk density, angle of repose, and Hunter color values while chemical properties were basically proximate analysis items such as crude protein, fiber, fat, ash, and nitrogen-free extract (NFE). Moisture content and water activity of the samples averaged 7.74% and 0.235 (a_w), respectively, which were lower compared to the value for traditional (unmodified) DDGS. Water activity is a measure of the free water available for microbial growth in that substance. Therefore, lower water activity value is an indicator of less microbial growth and, eventually, longer shelf life. Thermal properties (conductivity, resistivity, and diffusivity) and bulk density value were similar in low-oil and traditional DDGS while angle of repose values were lower than value for traditional DDGS. Bulk density and angle of repose are two key parameters for storage of bulk items. Therefore, an increased amount of low-oil DDGS can be stored in the same volume of area compared to traditional DDGS. Hunter color values showed that low-oil DDGS was brighter, contained less red pigments, but had yellow pigments similar to traditional DDGS. The chemical properties: crude protein, fiber, fat, ash, and NFE averaged 34.0, 8.4, 2.7, 4.8 and 50.1%, respectively (Saunders and Rosentrater, 2009). A similar study was conducted that compared physical and flow properties of traditional and low-oil DDGS (Ganesan et al., 2009). This study evaluated many physical and flow parameters of low-oil DDGS. In conclusion, low-oil DDGS was determined to be slightly better in some flow properties, and much better in compressibility compared to traditional DDGS. The compressive modulus of low-oil DDGS was 28.2% higher than traditional DDGS, which explained that low-oil DDGS was less easily deformed. In other words, low-oil DDGS could take less stress for a given amount of deformation (Ganesan et al., 2009).

There are currently no low-oil DDGS studies conducted to evaluate its inclusion in poultry rations or its effects on bird performance. However, one study determined the energy values of fifteen corn co-products on broiler chicks from 15 to 24 days of age, and one of these fifteen corn co-products was a low-oil DDGS sample (Rochell et al., 2011). Nutritional composition of each co-product was also determined in this study. Bulk density, crude protein, fiber, and fat were in the range of values of low-oil DDGS reported by Saunders and Rosentrater (2009). However, moisture and ash were 12.64 and 5.16%, respectively, which were higher than the maximum values (moisture: 8.83% and ash: 4.9%) reported by Saunders and Rosentrater (2009). In addition, gross energy and AME_n were 5,076 and 2,146 kcal/kg, respectively (Rochell et al., 2011).

Recently, a study was conducted in pigs to investigate amino acid digestibility and energy content of low-oil DDGS (Jacela et al., 2011). The low-oil DDGS sample used in this study had similar proximate composition to the sample reported by Rochell et al. (2011). Apparent (AID) and standardized ileal digestibilities (SID) of lysine were 50.4 and 47.2%, respectively. AID and SID of methionine were 80.4 and 79.4%, respectively. Four energy values were determined: gross, digestible, metabolizable, and net energy values were 5,098, 3,100, 2,858 and 2,045 kcal/kg, respectively. In addition, effects of low-oil DDGS on pig growth performance and carcass characteristics were investigated. The results showed that increasing levels of low-oil DDGS did not affect performance measures and carcass characteristics in nursery pigs, but had a negative effect on finishing pig ADG and ADFI. It also had a negative effect on carcass weight, yield, and loin depth of finishing pigs. It was concluded that low-oil DDGS had a greater crude protein and amino acid digestibility, but lower energy content compared to the traditional DDGS. It was recommended that up to 30% low-oil DDGS could be included in nursery pig diets without any detrimental effects but that high levels of low-oil DDGS had a negative effect on both performance parameters and carcass quality of finishing pigs (Jacela et al., 2011).

End users of DDGS such as poultry and swine producers were negatively affected as a result of implementation of oil extraction technology. Variation in DDGS samples among the plants and among the batches was the main reason for the problem. Nutritionists could face amino acid and phosphorus levels being as high as 50% different and energy levels as high as 20% different from the formulated dietary levels due to the variation among samples (Hagen and Musser, 2011). The company, which built a database for DDGS variation, gave the example that pig performance would be reduced and feed conversion would worsen when a book value of 10.7% of fat level was entered in diet formulation, but the actual DDGS used in the diet had a fat level of 8.5% (Musser, 2012). On the other hand, low-oil DDGS could be very desirable in markets such as beef cattle, dairy cattle, and the hog industry. Inclusion levels of DDGS might increase since fat is a limiting factor in those markets (McElroy, 2007).

While traditional DDGS and HP-DDGS have been extensively studied in the past, there is no present literature that extensively investigates LO-DDGS in poultry. These projects were designed to determine the nutritional composition of LO-DDGS, its applicability in poultry rations, and effects on the birds. Specifically, the aims of this project are to:

1. Determine the nutrient profile of several low-oil DDGS samples gathered from various ethanol plants in the U.S.
2. Determine TME values of the samples using a rooster assay
3. Perform an economic analysis model and compare low-oil DDGS and traditional DDGS values among many poultry diets
4. Determine the 18-day performance of broilers fed diets containing various low-oil DDGS percentage levels

5. Determine layer hen performance fed diets containing various low-oil DDGS percentage levels
6. Evaluate the quality of eggs of laying hens fed diets containing various low-oil DDGS percentage levels

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CHAPTER 2

NUTRIENT COMPOSITION OF LOW-OIL DISTILLERS DRIED GRAINS WITH SOUBLES[1]

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SUMMARY

Increased demand for ethanol has resulted in large amounts of distillers dried grains with solubles (DDGS) to be readily available to various livestock industries. Particularly in the poultry industry, DDGS is accepted as a good alternative feed ingredient, having been used for many years. Due to the high market prices of corn oil, steps may be taken to extract corn oil from DDGS during its production process. DDGS, whose oil is extracted, is called low-oil DDGS.

This study evaluated the nutritional composition of low-oil DDGS in various ways. Proximate composition, particle size, energy value, mineral composition, total essential and non-essential amino acid concentration, protein quality measures and true protein were determined for thirteen low-oil DDGS samples received from ethanol plants throughout the United States. An additional five low-oil DDGS samples were received towards the end of the study and only proximate analysis was conducted on those five samples. Correlations between nutrients and best fit regression models for estimating gross energy and TME_n were determined.

Low-oil DDGS samples had an average of 8.0% crude fat, 27.6% crude protein, 13.1% moisture, 8.4% crude fiber and 5.3% ash (for thirteen samples). Average geometric mean of particle size was 765 μm. Average gross energy and TME_n were 4617.7 and 3062.0 kcal/kg, respectively. Calcium values averaged at 0.02%, (much lower than traditional DDGS, 0.14%). The concentrations of some of the essential amino acids (threonine, leucine, phenylalanine, lysine, histidine, and arginine) were higher than in reports on traditional DDGS. Crude protein, fiber, ash, crude fat, and nitrogen free extract (NFE) influenced ($P<0.102$) gross energy. In addition, crude fat was positively correlated with both gross energy and TME_n. Overall, there was a considerable variation in the nutrient composition among the low-oil DDGS samples; coefficients of variation ranged from 7.3% for crude protein to 106.7% for non-protein nitrogen.

Analysis of individual samples or supplier history on sample compositions would seem prudent prior to diet formulation.

DESCRIPTION OF PROBLEM

Demand for ethanol has increased constantly in order to ease the dependence on crude oil and overcome environmental issues [1]. Increased production of ethanol led to the availability of very large amounts of corn co-product; distillers dried grains with solubles (DDGS). The original research about DDGS started back in 1940s when DDGS was produced as a co-product of beverage industry [2, 3]. The research studies conducted in the past 20 years concentrated on DDGS produced as co-product of ethanol. Overall, DDGS has been studied extensively, included in poultry diets successfully during the past 100 years, and accepted as a good alternative feed ingredient [4, 5].

As the price of crude and corn oils reached the highest levels in history, extracting corn oil from DDGS became economically feasible. During standard fermentation process of producing ethanol, corn oil is left untouched. As a result, DDGS has a high oil content (up to 12.8%). Many ethanol plants in USA have considered and actually implemented oil extraction technology as a part of their overall process. The extracted corn oil can be used in biodiesel and as a commodity in different industries [6].

The DDGS, whose oil content has been extracted, has much lower fat content (down to 2.7%) than traditional (unmodified) DDGS, and is called low-oil DDGS. The composition of low-oil DDGS is now well known: Saunders and Rosentrater [6] researched physical and chemical properties of low-oil DDGS. However, their study was aimed more towards general properties rather than nutritional composition. So, there is no literature available at the moment that investigates the nutritional composition of low-oil DDGS.

The CP is important as an indicator of amino acids for poultry, and overestimated the true protein. Sriperm et al. [7] evaluated ingredient-specific nitrogen-to-protein (N:P) conversion factor and true protein values of corn DDGS. They concluded that the mean k_A is 5.74 for corn DDGS which is lower than N:P conversion factor (6.25).

In the present study, we investigated eighteen low-oil DDGS samples received from various ethanol plants across the USA for: 1) proximate analysis, mineral composition, amino acid concentrations and particle size: 2) gross energy and TME_n using a rooster assay: 3) protein quality measures: 4) interactions among the nutrients: 5) prediction of gross energy and TME_n from fat content; and 6) ingredient-specific N:P conversion factor and true protein values.

MATERIALS AND METHODS

Eighteen low-oil DDGS samples were received from various ethanol plants in the USA and stored at -20^{o} C until analyzed. Moisture, crude protein, crude fiber, fat and ash levels in the DDGS samples were determined using AOAC [8] methods by the University of Georgia Agricultural and Environmental Services Laboratories[2]. The rest of the analyses such as particle size, mineral composition, carbohydrate and protein quality were conducted on the thirteen low-oil DDGS samples. The remaining five samples were only analyzed for complete proximate analysis.

Particle size was measured using the method described by the American Society of Agricultural Engineers [9]. Mineral composition of each sample was determined using AOAC method 968.08 [8]. All samples were also analyzed for gross energy using an adiabatic bomb calorimeter using ASTM method D5865 [10].

Amino acid concentrations of the thirteen low-oil DDGS samples were determined by HPLC according to methods described by the AOAC [10] for standard protein hydrolysis (method 45.3.05). The samples were also analyzed for several protein quality measures by Minnesota Valley Testing Laboratories[3]. Protein solubility in KOH was determined by the method specified by Araba and Dale [12] and Parsons et al. [13]. Protein dispersibility index (PDI) was determined using AOCS method Ba 1065 [14]. Dispersible protein was measured using AOCS methods [14]. Non-protein nitrogen (NPN) was determined using AOAC method 941.04 [8].

Several analyses were conducted to analyze carbohydrate quality of the samples. These quality measures were starch, lignin, acid detergent fiber (ADF) and neutral detergent fiber (NDF) using AOAC [8] methods.

Rooster assays

The TME_n was determined for the first thirteen low-oil DDGS samples using a traditional precision-fed rooster assay [15] with conventional Single Comb White Leghorn roosters. The birds were placed in individual cages with raised wire floors in an environmentally regulated room. Adult leghorn roosters were fasted for 24 h and then precision-fed 35 g of one of thirteen low-oil DDGS samples. Excreta were then collected for 48 h. Four additional roosters were fasted to measure endogenous excretion of DM, energy and N. The excreta samples were dried, weighed and ground through a mesh screen using a Thomas-Wiley mill (Arthur H. Thomas Company, Philadelphia. PA) equipped with a 1-mm screen to ensure a homogeneous mixture.

Feed and excreta were analyzed for N or CP (method 990.03) [16] and for gross energy using an adiabatic bomb calorimeter standardized using ASTM method D5865 [17] and TME_n was calculated as described by Parsons et al. [18].

Statistical Analysis

Data from proximate analysis results of the total eighteen low-oil DDGS samples were first adjusted to a fixed moisture content of 10% in order to eliminate moisture variation and its interaction with other nutrients. Then, the adjusted data were subjected to analysis of variance procedures using the general linear model procedure (PROC GLM) of SAS® [19]. Effects of nutrients on gross energy were based on Type III sum of squares. The correlations between nutrients in the samples were also calculated PROC CORR of SAS® [19]. Finally, the SAS GLM procedure was used to determine the best fit regression models for estimating the gross energy and TME_n of the low-oil DDGS samples using the data adjusted for fixed moisture content.

[2] University of Georgia Agricultural and Environmental Services Laboratories, Feed and Environmental Water Laboratory, Athens, GA
[3] Minnesota Valley Testing Laboratories, New Ulm, MN

RESULTS AND DISCUSSION

Results of the proximate analysis (Table 1) indicated that there was a large variation for each parameter among the samples, especially for non-protein nitrogen (NPN) (CV = 106.7%), lignin (CV = 47.6%), and starch (CV = 24.1%). Crude fat, which is the most important parameter for low-oil DDGS samples, ranged from 6.3 to 10.3% and averaged 8.0% with a standard deviation of 1.14%. The samples acquired from plants 5 and 10 had a crude fat values of 10.3 and 9.8%, respectively. These two values are actually within the range of crude fat values of traditional (unmodified) DDGS [20]. Therefore, they cannot be considered as low-oil DDGS.

The remaining nine samples are actually within the limits of crude fat values of low-oil DDGS mentioned by Jacela et al. [21]. In general, dry matter and crude fat were lower while crude protein, crude fiber and ash were similar to the values reported by Feedstuffs [22] for a typical traditional (unmodified) DDGS. The concentrations of NPN were similar, except for the sample received from plant 12, which showed an incredibly high NPN value of 1.3%.

Particle sizes of most of the samples (Table 2) were distributed between 16 and 40 US standard sieve number (1191 and 420 μm). Geometric mean diameters (Table 3) differed considerably among samples, ranging from 509 to 1090 μm. The average of all of the mean diameters was 765 μm with a standard deviation of 184 μm. DDGS sample received from plants 2 and 11, interestingly, had a high geometric standard deviation of 2.16 and 1.93 μm, respectively, even though geometric mean diameters of both samples were below average. Previous studies showed that particle size might have an effect on utilization of P: Kasim and Edwards [23] and Kilburn and Edwards [24] reported that chicks fed larger particle size corn and soybean meal had greater utilization of P. Therefore, utilization of P in birds fed different particle size of low-oil DDGS might be studied in the future.

Sample gross energy levels showed considerably less variation than the TME_n values (Table 4). The gross energy of the samples averaged at 4617.7 kcal/kg with a standard deviation of 82.84 kcal/kg. Interestingly, the DDGS sample received from plant 1 had a gross energy of 4449.9 kcal/kg, which was almost of 70 kcal/kg different from the sample with the least gross energy. TME values ranged from 2830.6 to 3351.8 kcal/kg and averaged at 3062.0 kcal/kg with a standard deviation of 132.52 kcal/kg. Percentage of TME_n divided by gross energy was calculated for each sample and it averaged at 66.3% with a standard deviation of 2.93%. This percentage showed considerably less variation than the actual energy values and so it can be used for quick estimation of TME_n by the determined gross energy.

Calcium, sodium, and magnesium showed less variation compared to the other macro minerals such as potassium and sulfur (Table 5). Calcium values averaged at 0.02%, which is considerably much lower compared to the value reported by Feedstuffs [22] for traditional DDGS (0.14%). Total phosphorus contents (CV = 16%) showed similar variation as phytate phosphorus contents (CV = 17%) did. Phosphorus values ranged from 0.45 to 0.90% and averaged 0.75%. Phosphorus values were lower than the value reported by Feedstuffs [22] for traditional DDGS (0.75 vs. 0.89%). All micro minerals varied considerably among the samples and were lower than the values reported by Feedstuffs [20] for a typical traditional DDGS.

There was a considerable variation for each essential amino acid among the samples (Table 6). Threonine, leucine, phenylalanine, lysine, histidine, and arginine were higher while valine, methionine, isoleucine, and tryptophan were similar to the values reported by Feedstuffs [22] for a typical traditional (unmodified) DDGS. There was also a considerable variation for each non-essential amino acid among the samples (Table 7). Due to the variation among the samples, amino acid composition must be determined for a particular low-oil DDGS sample in order to achieve more accuracy in feed formulation. Measures of protein quality (Table 8), protein solubility, dispersible protein and protein dispersibility index (PDI) were determined for all the samples. Protein quality measures were correlated with each other ($P<0.001$), but interestingly, they were not correlated to TME_n or GE (Table 13).

The basic statistical information about the nutrient compositions is presented in There was a considerable variation of each nutrient among the samples Table 9. Crude fat values ranged from 6.47 to 10.69%, which was a larger variation compared to the variation observed in traditional DDGS samples that were reported by Belyea et al. [25]. It is assumed that oil extraction caused the big range of fat contents in low-oil DDGS. The variation in energy values was mainly due to the variation of fat content in the samples, and the variation in GE was low (CV = 1.8%) despite large variations in the ash contents of the samples (CV = 15.3).

The variation between the samples might cause problems for nutritionists when formulating diets using low-oil DDGS. The problems due to the variation among the samples were also reported in previous DDGS studies [25, 26]. Belyea et al. [25] investigated the sources of variation in traditional DDGS, and reported that specific fermentation batches were responsible for the variation in DDGS rather than the particular plant were they were produced or the time of production. Differences in corn characteristics and processing conditions were probably associated with batch to batch differences [25].

All nutrients of the eighteen samples were analyzed by PROC GLM , and their influences on gross energy are presented in Table 10. Crude protein, fiber, ash, crude fat, and nitrogen free extract (NFE) all influenced $(P<0.102)$ gross energy. These probabilities were based on type III sums of squares, in which each probability was calculated after the influences of the other independent variables had been corrected for. However, the strong influence of crude fat on gross energy ($P<0.10$) is presented in Table 11 when only three nutrients were selected in a stepwise regression analysis. This was expected due to the nature of interactions of nutrients within each other and also reported by Tahir et al. [20].

The influence of crude fat on gross energy (Table 12) was indicated once more with a positive and significant Pearson's correlation coefficient ($P<0.05$). Crude fiber had a positive correlation and NFE had a negative correlation with crude protein. NFE was also negatively correlated to crude fiber. Since NFE is difference of the sum of crude protein, fat, water, ash and fiber from 100 [8], the negative correlations of NFE with crude protein and fiber were expected. However, the reason why crude fiber is positively correlated with crude protein is unknown.

The k_A to calculate SCP (k_A) is estimates of the true protein in feed ingredients [7]. The k_A is the specific values to use instead of 6.25, and using k_A to calculate SCP(k_A) gives the closest estimate of true protein in these dataset (Table 14). CP values sometimes presently used to estimate protein composition of feed and total amino acid needs of poultry. True protein values will become important as feed formulations are refined or improved to maximum gain and minimum environmental N pollution.

The relationship between crude fat and gross energy is presented with a regression line in. Estimation of gross energy based on the crude fat content of the samples was a good fit with a R^2 value of 0.7615 (Figure 1). There was a positive correlation between crude fat and gross energy. In addition, Figure 2 presents the relationship between crude fat and TME_n and the corresponding regression line. Unfortunately, the relationship between TME_n and crude fat was not as good as the relationship between TME and gross energy (R^2 = 0.3360 vs. 0.7615). There was also a positive correlation between crude fat and TME_n as expected. The correlations between fat content and energy values were also reported in previous literature [27 – 29].

CONCLUSION AND APPLICATIONS

1. There was large variation in the proximate compositions of low-oil DDGS samples, and proximate analysis of individual samples might be considered prior to diet formulation.
2. It was difficult to determine a single TME_n value for a typical low-oil DDGS sample due to the large variation among the samples, and it is more accurate to estimate TME_n from gross energy by using the coefficient of 0.663 (or 66.3%).

3. Calcium content of low-oil DDGS samples were very low compared to the value of typical traditional (unmodified) DDGS in ingredient composition tables (0.02 vs. 0.14%).
4. Threonine, leucine, phenylalanine, lysine, histidine, and arginine concentrations were higher compared to the typical traditional (unmodified) DDGS.
5. CP levels were higher than true protein. Using k_A to calculate SCP(k_A) gives the closest estimate of true protein in these dataset.
6. Crude fat values of the low-oil DDGS samples were positively correlated to the gross energy and TME_n.
7. The regression model for predicting gross energy from crude fat is GE = 4134.4 + 77.788*Fat and for TME_n is TME_n = 2562.2 + 73.238*Fat.

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Table 2.1 Nutrient composition (%) of 13 DDGS samples[1], as-fed basis

Plant No.	Moisture	CP	NPN[2]	Crude fat	Ash	Starch	Crude fiber	Lignin	ADF[2]	NDF[2]
1	12.5	27.7	0.4	6.3	5.2	4.9	8.7	2.6	10.9	22.1
2	12.8	28.5	0.2	6.9	6.2	5.1	7.8	4.4	12.9	21.7
3	13.2	26.6	0.4	8.8	5.4	7.4	6.4	1.6	8.4	21.8
4	13.1	28.3	0.4	7.4	5.6	6.6	8.6	3.5	11.0	22.8
5	13.3	25.8	0.1	10.3	4.8	4.1	7.6	2.8	11.6	22.9
6	12.4	27.3	0.1	7.4	4.9	7.0	10.8	2.0	11.0	27.7
7	11.6	29.1	0.5	8.2	6.2	5.1	7.4	2.8	10.6	23.9
8	13.5	27.3	0.2	7.3	6.0	6.5	7.2	2.1	10.0	24.1
9	13.3	25.7	0.2	8.1	5.1	4.8	8.0	4.5	11.3	25.2
10	15.6	26.8	0.2	9.8	5.9	5.2	8.8	4.4	10.6	22.3
11	11.8	32.9	0.2	7.6	3.2	3.2	11.2	8.3	15.6	31.0
12	14.4	27.8	1.3	8.9	5.6	6.3	7.1	4.9	9.6	21.2
13	12.7	24.6	0.1	7.4	5.0	3.7	9.5	5.2	13.4	33.7
Mean	13.1	27.6	0.3	8.0	5.3	5.4	8.4	3.8	11.3	24.6
Minimum	11.6	24.6	0.1	6.3	3.2	3.2	6.4	1.6	8.4	21.2
Maximum	15.6	32.9	1.3	10.3	6.2	7.4	11.2	8.3	15.6	33.7
Range	4.0	8.3	1.2	4.0	3.1	4.2	4.9	6.7	7.2	12.5
Standard deviation	1.06	2.02	0.32	1.14	0.81	1.30	1.45	1.81	1.82	3.87

[1] Distillers dried grain with solubles (DDGS) samples were obtained from different ethanol plants throughout the United States.

[2]NPN=Non-protein nitrogen; ADF = Acid detergent fiber; NDF = Neutral detergent fiber.

Table 2.2 Particle size distribution of 13 DDGS samples[1]

Plant No.	U.S. standard sieve No. (µm size)										
	8 (2380)	12 (1680)	16 (1191)	20 (841)	30 (594)	40 (420)	50 (297)	70 (212)	100 (150)	140 (103)	>200 (<73)
1	0.20	2.29	11.44	22.59	29.25	21.29	8.36	2.29	1.00	0.70	0.60
2	2.30	4.01	10.72	16.03	19.34	17.74	11.92	7.31	4.51	2.71	2.00
3	4.41	12.54	28.08	26.38	17.55	6.82	1.91	0.60	0.30	0.30	0.30
4	0.00	0.91	8.77	17.64	24.50	22.78	14.31	6.75	2.72	1.11	0.50
5	1.00	6.67	24.38	31.94	24.78	8.06	1.49	0.40	0.50	0.50	0.20
6	0.50	4.70	21.92	30.73	27.13	11.61	2.40	0.40	0.30	0.20	0.10
7	0.20	0.91	5.45	13.54	23.33	26.06	18.69	8.69	2.42	0.51	0.20
8	0.00	0.50	5.54	17.22	30.41	29.51	12.89	2.82	0.60	0.30	0.30
9	2.51	3.82	13.97	22.71	26.73	18.19	7.14	2.21	0.80	0.50	0.70
10	0.90	6.30	27.00	32.00	22.70	8.00	1.60	0.50	0.20	0.20	0.50
11	0.10	1.40	7.01	14.53	21.24	20.34	14.83	9.72	6.91	2.61	1.30
12	1.71	6.94	22.33	32.19	26.86	8.05	0.91	0.00	0.30	0.20	0.40
13	0.20	2.51	13.83	23.35	27.76	19.34	8.02	2.51	1.30	0.60	0.60
Mean	1.08	4.12	15.42	23.14	24.74	16.75	8.04	3.40	1.68	0.80	0.59
Minimum	0.00	0.50	5.45	13.54	17.55	6.82	0.91	0.00	0.20	0.20	0.10
Maximum	4.41	12.54	28.08	32.19	30.41	29.51	18.69	9.72	6.91	2.71	2.00
Range	4.41	12.04	22.63	18.65	12.86	22.69	17.78	9.72	6.71	2.51	1.90
Standard deviation	1.27	3.25	7.94	6.73	3.67	7.24	5.84	3.33	1.94	0.83	0.50

[1] Distillers dried grain with solubles (DDGS) samples were obtained from different ethanol plants throughout the United States.

Table 2.3 Geometric mean diameters (d_{gw}) and geometric standard deviations (S_{gw}) of particle diameter for 13 DDGS samples[1]

	DDGS	
Plant No.	d_{gw} (µm)	S_{gw} (µm)
1	700	1.68
2	612	2.16
3	1,090	1.69
4	588	1.75
5	957	1.59
6	902	1.55
7	545	1.69
8	615	1.55
9	775	1.79
10	971	1.59
11	509	1.93
12	967	1.57
13	718	1.71
Mean	765	1.71
Minimum	509	1.55
Maximum	1,090	2.16
Range	581	0.61
Standard deviation	184.43	0.17

[1] Distillers dried grain with solubles (DDGS) samples were obtained from different ethanol plants throughout the United States.

Table 2.4 Energy values of 13 DDGS samples[1], as-fed basis

Plant No.	Gross energy, kcal/kg	TME_n[2], kcal/kg	TME_n/GE, %
1	4449.9	2988.6	67.2
2	4591.8	2937.0	64.0
3	4589.3	3062.6	66.7
4	4628.1	3046.6	65.8
5	4736.1	3165.3	66.8
6	4611.3	2830.6	61.4
7	4766.3	3100.0	65.0
8	4518.2	3212.4	71.1
9	4637.1	2946.2	63.5
10	4686.9	3083.9	65.8
11	4583.7	3074.7	67.1
12	4626.0	3351.8	72.5
13	4605.0	3005.8	65.3
Mean	4617.7	3062.0	66.3
Minimum	4449.9	2830.6	61.4
Maximum	4766.3	3351.8	72.5
Range	316.4	521.2	11.1
Standard deviation	82.84	132.52	2.93

[1] Distillers dried grain with solubles (DDGS) samples were obtained from different ethanol plants throughout the United States.

Table 2.5 Mineral composition of 13 DDGS samples[1], as-fed basis

Plant No	Macro Minerals (%)							Micro Minerals (ppm)					
	Calcium	Phos-phorus	Phytate phosphorus	Sodium	Potassium	Sulfur	Magnesium	Choline chloride	Copper	Zinc	Manganese	Iron	Selenium
1	0.03	0.90	0.17	0.21	1.17	1.16	0.29	754	5.8	71	16	89	0.19
2	0.03	0.81	0.12	0.06	1.13	0.86	0.31	678	4.5	56	13	92	0.31
3	0.02	0.76	0.19	0.13	1.00	1.03	0.26	576	4.2	51	11	85	0.27
4	0.02	0.78	-	0.23	1.03	0.54	0.28	332	4.5	50	13	135	0.12
5	0.02	0.82	-	0.15	1.06	0.66	0.28	542	6.0	74	14	119	0.14
6	0.02	0.63	0.17	0.08	0.74	0.49	0.21	371	4.5	48	10	76	0.25
7	0.04	0.82	-	0.11	1.05	0.56	0.29	610	5.0	55	13	95	0.44
8	0.02	0.80	0.17	0.20	1.01	0.72	0.27	<100	5.2	60	13	144	0.4
9	0.03	0.75	0.13	0.13	1.00	0.51	0.25	543	5.0	53	12	90	0.41
10	0.02	0.87	0.21	0.21	1.14	0.48	0.30	<100	5.7	55	13	82	0.21
11	0.01	0.45	0.13	0.05	0.42	0.46	0.13	<100	5.0	51	8	64	0.42
12	0.01	0.58	0.21	0.13	0.79	0.94	0.21	461	4.0	38	10	44	0.12
13	0.03	0.73	0.20	0.18	1.01	0.33	0.25	<100	6.2	68	15	106	0.31
Mean	0.02	0.75	0.17	0.14	0.96	0.67	0.26	541	5.0	56	12	94	0.28
Minimum	0.01	0.45	0.12	0.05	0.42	0.33	0.13	332	4.0	38	8	44	0.12
Maximum	0.04	0.90	0.21	0.23	1.17	1.16	0.31	754	6.2	74	16	144	0.44
Range	0.03	0.45	0.09	0.18	0.75	0.83	0.18	422	2.3	36	8	100	0.32
Standard deviation	0.01	0.12	0.03	0.06	0.20	0.24	0.05	128.72	0.68	9.53	2.20	26.08	0.11

[1]Distillers dried grain with solubles (DDGS) samples were obtained from different ethanol plants throughout the United States

Table 2.6 Total essential amino acid (TEAA) concentrations of 13 DDGS samples[1], as-fed basis

Plant No.	Threonine	Valine	Methionine	Isoleucine	Leucine	Phenyl-alanine	Lysine	Histidine	Arginine	Tryptophan
1	1.05	1.37	0.58	0.97	2.93	1.39	0.91	0.74	1.33	0.20
2	1.07	1.40	0.49	0.96	3.01	1.40	0.96	0.73	1.25	0.22
3	1.12	1.35	0.49	0.93	3.02	1.44	1.04	0.74	1.31	0.20
4	1.14	1.38	0.53	0.97	3.27	1.52	0.88	0.77	1.29	0.22
5	1.05	1.22	0.50	0.85	2.81	1.36	0.90	0.69	1.22	0.21
6	1.09	1.34	0.54	0.96	3.20	1.44	0.99	0.75	1.30	0.23
7	1.13	1.42	0.52	1.02	3.30	1.55	0.97	0.78	1.32	0.20
8	1.07	1.33	0.57	0.93	3.00	1.39	0.97	0.76	1.30	0.20
9	1.05	1.30	0.48	0.92	2.86	1.35	0.95	0.70	1.21	0.19
10	1.06	1.37	0.52	0.97	3.00	1.40	0.97	0.75	1.28	0.22
11	1.26	1.64	0.73	1.20	4.06	1.73	1.08	0.91	1.47	0.24
12	1.01	1.35	0.51	0.96	2.91	1.36	0.93	0.73	1.26	0.21
13	0.95	1.21	0.52	0.84	2.48	1.20	0.89	0.65	1.17	0.21
Mean	1.08	1.36	0.54	0.96	3.07	1.43	0.96	0.75	1.29	0.21
Minimum	0.95	1.21	0.48	0.84	2.48	1.20	0.88	0.65	1.17	0.19
Maximum	1.26	1.64	0.73	1.20	4.06	1.73	1.08	0.91	1.47	0.24
Range	0.31	0.43	0.25	0.36	1.58	0.53	0.20	0.26	0.30	0.05
Standard deviation	0.07	0.10	0.06	0.08	0.35	0.12	0.06	0.06	0.07	0.01

[1] Distillers dried grain with solubles (DDGS) samples were obtained from different ethanol plants throughout the United States.

Table 2.7 Total non-essential amino acid (TNEAA) concentration of 13 DDGS samples, as-fed basis

Plant No.	Aspartic acid	Serine	Glutamic acid	Glycine	Proline	Alanine	Cysteine	Tyrosine
1	1.68	1.14	3.34	1.13	1.85	1.80	0.52	0.93
2	1.70	1.16	3.26	1.06	1.84	1.80	0.47	0.91
3	1.77	1.27	3.28	1.07	1.83	1.83	0.50	0.97
4	1.77	1.31	3.57	1.11	2.01	1.95	0.50	1.05
5	1.57	1.16	2.99	1.01	1.81	1.66	0.50	0.93
6	1.73	1.23	3.63	1.05	2.01	1.87	0.50	0.96
7	1.77	1.27	3.57	1.10	2.03	1.93	0.50	1.02
8	1.69	1.18	3.39	1.07	1.97	1.80	0.51	0.95
9	1.68	1.15	3.23	1.03	1.80	1.74	0.44	0.89
10	1.70	1.14	3.31	1.07	1.88	1.80	0.48	0.94
11	2.07	1.44	5.02	1.23	2.60	2.33	0.63	1.20
12	1.66	1.08	3.32	1.06	1.85	1.78	0.49	0.88
13	1.53	1.00	2.86	0.96	1.61	1.52	0.44	0.78
Mean	1.72	1.19	3.44	1.07	1.93	1.83	0.50	0.95
Minimum	1.53	1.00	2.86	0.96	1.61	1.52	0.44	0.78
Maximum	2.07	1.44	5.02	1.23	2.60	2.33	0.63	1.20
Range	0.54	0.44	2.16	0.27	0.99	0.81	0.19	0.42
Standard deviation	0.12	0.11	0.50	0.06	0.22	0.18	0.04	0.10

[1] Distillers dried grain with solubles (DDGS) samples were obtained from different ethanol plants throughout the United States.

Table 2.8 Protein quality of 13 DDGS samples[1], as-fed basis

Plant No.	Protein solubility in KOH	Protein solubility defatted	Dispersible protein	PDI[2]
1	36.8	31.9	4.41	16.81
2	28.9	26.4	3.71	13.67
3	36.2	33.5	3.86	14.71
4	19.3	17.9	2.89	10.10
5	25.3	22.2	3.00	12.09
6	18.5	19.1	1.57	5.88
7	24.9	24.0	3.33	11.50
8	23.0	20.9	2.70	10.13
9	22.6	21.0	2.91	11.55
10	22.2	19.2	2.54	9.60
11	13.7	12.5	0.76	2.37
12	23.6	22.7	3.94	14.65
13	19.4	18.0	1.80	7.39
Mean	24.2	22.3	2.88	10.80
Minimum	13.7	12.5	0.76	2.37
Maximum	36.8	33.5	4.41	16.81
Range	23.1	21.0	3.65	14.44
Standard deviation	6.35	5.51	0.99	3.79

[1] Distillers dried grain with solubles (DDGS) samples were obtained from different ethanol plants throughout the United States.
[2]PDI = Protein dispersibility index.

Table 2.9 Proximate composition[1] of the 18 DDGS samples[2,3]

Variable	Mean	Minimum	Maximum	Std. Error	CV
Crude protein	28.94	25.35	33.61	0.48	7.06
Crude fat	8.30	6.47	10.69	0.30	15.24
Crude fiber	8.90	6.59	11.66	0.34	16.45
Ash	5.70	3.08	7.56	0.27	20.42
Gross Energy	4780.02	4576.00	4998.67	26.55	2.36
NFE	38.17	29.06	42.06	0.73	8.10

[1] Moisture was fixed at 10%, and remaining variables were adjusted for fixed moisture
[2] Distillers dried grain with solubles (DDGS) samples were obtained from different ethanol plants throughout the United States.
[3] NFE = nitrogen free extract

Table 2.10 Linear regression model showing the probabilities that gross energy was a function of crude protein, fiber, ash and NFE *(P<0.10)*, based on type III sum of squares[1,2]

Source	df	Type III sum of squares	Mean square	*F*-value	*P > F*
Crude protein	1	7171.28	7171.28	3.28	0.0951
Crude fat	1	6852.33	6852.33	3.14	0.1019
Crude fiber	1	7089.49	7089.49	3.25	0.0968
Ash	1	7055.28	7055.28	3.23	0.0975
NFE	1	7161.89	7161.89	3.28	0.0953
Error	12				

[1] Moisture was fixed at 10%, and remaining variables were adjusted for fixed moisture
[2] NFE = nitrogen free extract

Table 2.11 Linear regression model showing the probabilities that gross energy was a function of crude fat (P<0.10), based on type III sum of squares[1]

Source	df	Type III sum of squares	Mean square	*F*-value	*P > F*
Crude protein	1	47.66	47.66	0.01	0.9080
Crude fat	1	165746.10	165746.10	48.15	<0.0001
Crude fiber	1	2183.99	2183.99	0.63	0.4390
Error	14				

[1] Moisture was fixed at 10%, and remaining variables were adjusted for fixed moisture

Table 2.12 Correlations between nutrients in DDGS (n=18) using data adjusted on moisture content[1,2]

	GE	CP	Fat	CF	Ash	NFE
GE	--					
CP	0.0088 (0.973)	--				
Fat	0.8727 (<0.001)	-0.0698 (0.783)	--			
CF	0.0831 (0.743)	0.4681 (0.050)	-0.0440 (0.8624)	--		
Ash	-0.0406 (0.873)	0.0072 (0.9773)	-0.2584 (0.300)	-0.3651 (0.136)	--	
NFE	-0.3863 (0.113)	-0.8561 (<0.001)	-0.2449 (0.329)	-0.6270 (0.005)	-0.1023 (0.686)	--

[1] Probabilities are in parentheses.
[2] Moisture was fixed at 10%, and remaining variables were adjusted for fixed moisture

Table 2.13 Correlations between protein quality measures and energy values of DDGS samples[1] (n=13)

	GE	TME_n	PS[2]	PS[3]	DP[4]	PDI[5]
GE	--					
TME_n	0.1649 (0.590)	--				
PS[2]	-0.3034 (0.314)	-0.0044 (0.989)	--			
PS[3]	-0.2682 (0.376)	-0.0265 (0.931)	0.9860 (<0.001)	--		
DP[4]	-0.1234 (0.688)	0.2552 (0.400)	0.8579 (<0.001)	0.8573 (<0.001)	--	
PDI[5]	-0.1411 (0.646)	-0.2391 (0.432)	0.8763 (<0.001)	0.8685 (<0.001)	0.9906 (<0.001)	--

[1] Probabilities are in parentheses.
[2] Protein solubility in KOH
[3] Protein solubility defatted
[4] Dispersible protein
[5] Protein dispersibility index

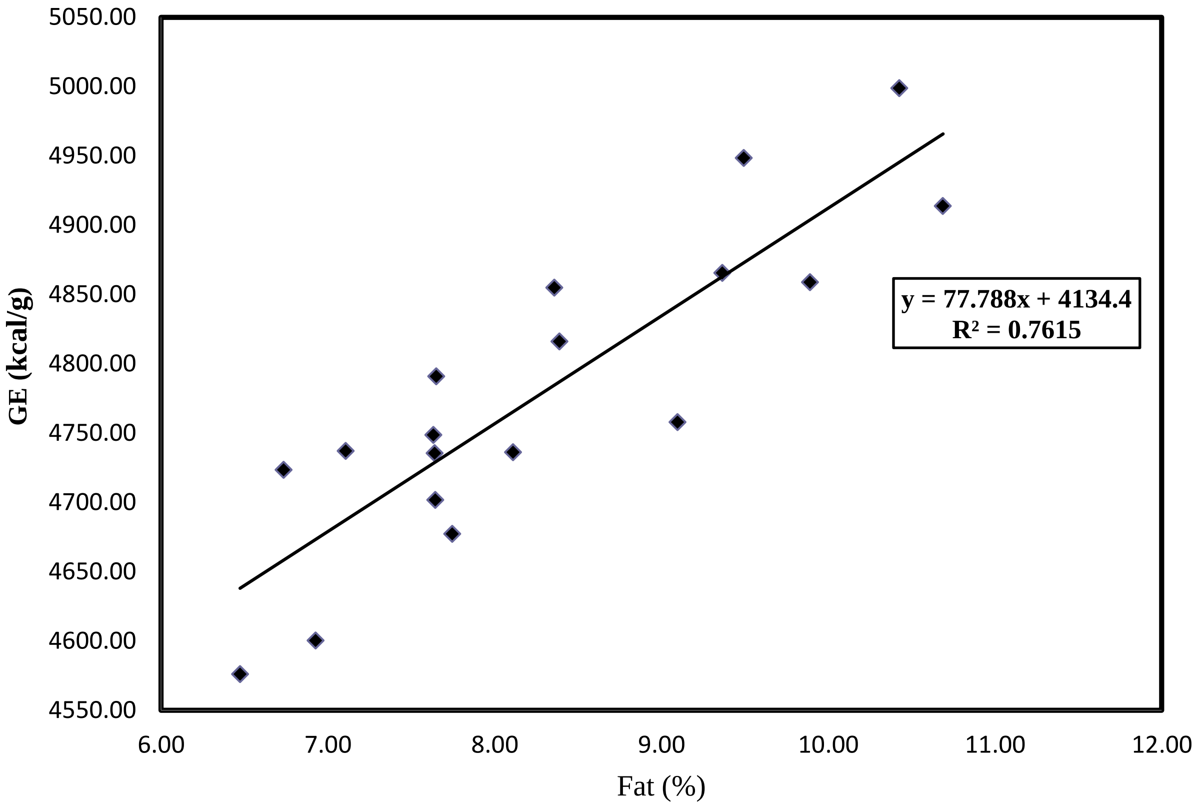
Table 2.14 Nitrogen to protein (N:P) conversion factors, total nitrogen content, nitrogen recovery, specific CP, CP and true protein content of 13 DDGS samples[1]

Plant No.	Total N (N_L) (g kg^{-1})	$(\sum E_i)$[2] (g kg^{-1})	$(\sum D_i)$[3] (g kg^{-1})	Nitrogen recovery[4]	Ingredient-specific N:P conversion factors[5]			Specific CP (SCP, g kg^{-1})			CP[9] (g kg^{-1})	True Protein[10] (g kg^{-1})
					k_A	k_P	k	SCP(k_A)[6]	SCP(k_P)[7]	SCP(k)[8]		
Sriperm et al. [5]	47.2	235.2	41.0	0.87	5.74	4.99	5.36	270.7	235.2	252.9	294.8	274.3
1	44.3	204.5	36.9	0.83	5.55	4.62	5.08	245.9	204.7	225.0	276.9	238.6
2	45.6	203.1	36.5	0.80	5.56	4.45	5.01	253.5	202.9	228.5	285.0	236.9
3	42.6	207.1	37.2	0.88	5.56	4.87	5.21	236.9	207.5	221.9	266.3	241.6
4	45.3	216.4	38.3	0.85	5.64	4.78	5.21	255.5	216.5	236.0	283.1	252.4
5	41.3	192.4	34.9	0.85	5.51	4.66	5.09	227.6	192.5	210.2	258.1	224.4
6	43.7	212.9	37.9	0.87	5.62	4.87	5.25	245.6	212.8	229.4	273.1	248.2
7	46.6	217.8	38.6	0.83	5.64	4.68	5.16	262.8	218.1	240.5	291.3	254.0
8	43.7	206.5	37.1	0.85	5.57	4.73	5.15	243.4	206.7	225.1	273.1	240.8
9	41.1	196.9	35.5	0.86	5.54	4.79	5.17	227.7	196.9	212.5	256.9	229.7
10	42.9	204.6	36.8	0.86	5.56	4.77	5.17	238.5	204.6	221.8	268.1	238.6
11	52.6	264.6	52.6	0.86	5.84	5.03	5.43	307.2	264.6	285.6	328.8	308.4
12	44.5	200.2	36.1	0.81	5.54	4.50	5.02	246.5	200.3	223.4	278.1	233.5
13	39.4	178.5	32.9	0.83	5.43	4.54	4.98	213.9	178.9	196.2	246.3	208.2
Mean	44.1	208.1	37.8	0.84	5.58	4.71	5.15	246.5	208.2	227.4	275.8	242.7
Minimum	39.4	204.4	34.7	0.85	5.91	5.04	5.48	232.5	204.5	218.7	246.3	208.2
Maximum	52.6	305.9	50.6	0.96	6.04	5.81	5.93	317.7	305.6	311.9	328.8	308.4

Range	13.2	101.5	15.9	0.11	0.13	0.77	0.45	85.2	101.1	93.2	82.5	100.2
SD	3.23	19.88	4.70	0.02	0.10	0.16	0.12	22.4	19.8	20.9	20.2	23.1

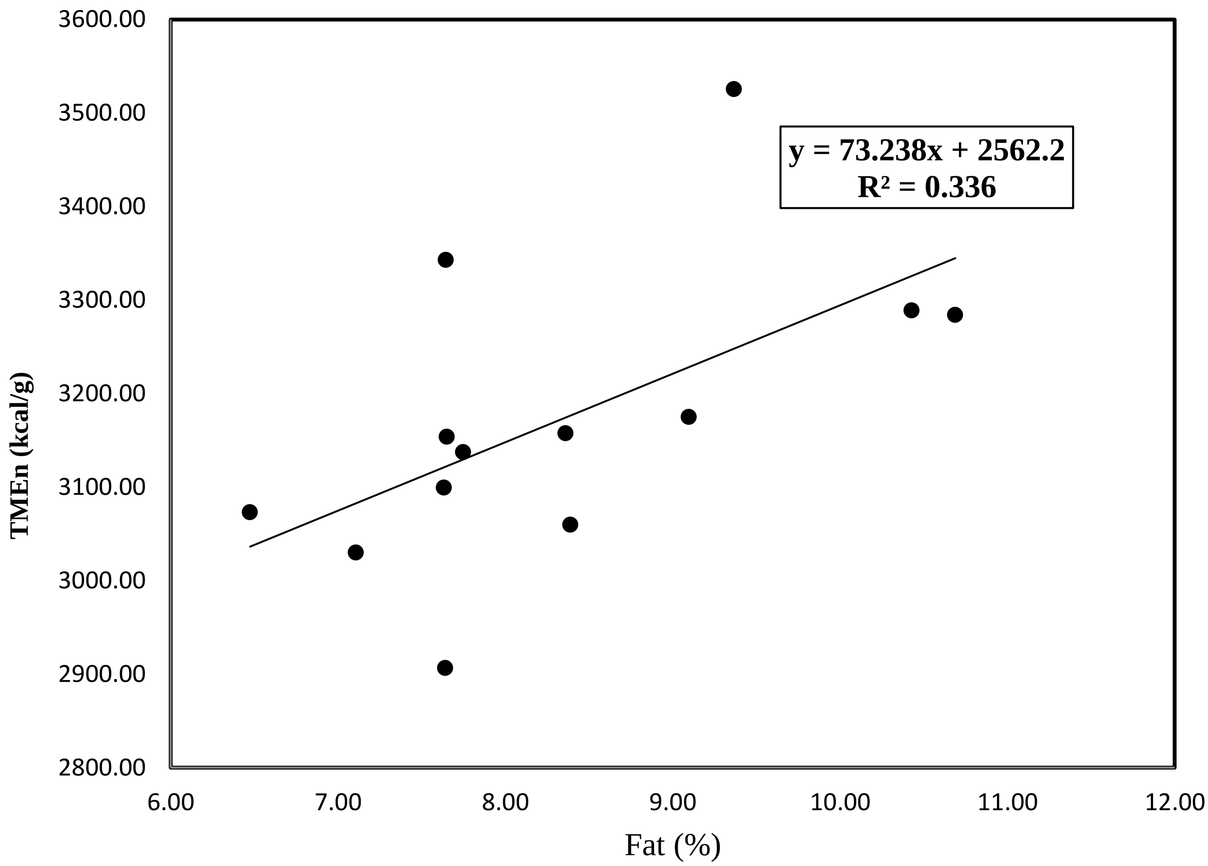
[1] Distillers dried grain with solubles (DDGS) samples were obtained from different ethanol plants throughout the United States.
[2] $\sum E_i$ is the sum of anhydrous amino acid residues.
[3] $\sum D_i$ is the sum of the total N from amino acids and NH_3.
[4] The ratio of total N from amino acids and NH_3 to total N from the Dumas method ($\sum D_i/N_L$), or k_P/k_A.
[5] $k_{A.}$ is the ratio of $\sum E_i$ and $\sum D_i$; k_P is the ratio of $\sum E_i$ and N_L; k is the average of k_A and k_P.
[6] $SCP(k_A) = N_L \times k_A$.
[7] $SCP(k_P) = N_L \times k_P$.
[8] $SCP(k) = N_L \times k$.
[9] $CP = N_L \times 6.25$.
[10] True protein is sum of the total amino acid residues from the amino acid analysis.

Figure 2.1 The relationship between crude fat and gross energy for 18 low-oil DDGS samples[1,2]



[1] Model GE = $b_0 + b_1$Fat, where b_0 is the intercept and b_1 is the coefficient for Fat.
[2] Fat values and gross energy were adjusted according to the fixed moisture content of 10%.

Figure 2.2 The relationship between crude fat and TME_n for 13 low-oil DDGS samples[1,2]



[1] Model $TME_n = b_0 + b_1Fat$, where b_0 is the intercept and b_1 is the coefficient for Fat.
[2] Fat values and TME_n were adjusted according to the fixed moisture content of 10%.

CHAPTER 3

EVALUATION OF THE COMPARATIVE VALUES OF TRADITIONAL AND LOW-OIL DDGS IN DIETS FOR POULTRY [4]

[4]Guney, A. C., M. Tahir, M. Y. Shim, G. M. Pesti. Submitted to *Applied Poultry Research*, 6/28/12.

SUMMARY

As corn origin ethanol production increases, additional amounts of corn distillers dried grains with solubles (DDGS) are becoming available to the poultry industry. A typical DDGS might have up to 12.8% oil content. So, the lipid fraction in DDGS represents a great opportunity for oil production. DDGS may be further processed to extract oil. The residual material is called low-oil DDGS (LO-DDGS).

This study evaluated comparisons of traditional DDGS and LO-DDGS inclusions in broiler, layer, broiler breeder and turkey diets. A series of diets were formulated to determine ingredient usage of traditional and LO-DDGS as well as corresponding feed costs.. The ingredient composition matrix was based on NRC tables except for digestible amino acids and protein. Requirements were for broiler starter and finisher feeds (Ross 308/708 and Cobb 500), layer starter, prelay, and peak feed (Hy-Line W36 and ISA Brown), broiler breeder starter and breeder feeds (Cobb 500 Breeder Fast Feathering), and turkey starter and finisher feeds (BUT). Ingredient costs were USA local market prices in the fall of 2011. Each diet was formulated with or without 3% poultry by-product meal (PBPM). Shadow prices of traditional DDGS and LO-DDGS were determined for each diet.

The results showed that formula costs were highest at $333 per ton for turkey starter diets and lowest at $275 per ton for broiler breeder diets when diets were formulated without PBPM. Formula costs were highest at $329 per ton for broiler starter diets and lowest at $273 per ton for broiler breeder diets when diets were formulated with 3% PBPM inclusions. Shadow prices for LO-DDGS were highest at $324 per ton while shadow prices for traditional DDGS were highest at $284 per ton for layer prelay diets with no effect of PBPM inclusion. High shadow prices

compared to market prices demonstrate that both low-oil and traditional DDGS are very affordable in these particular diets.

DESCRIPTION OF PROBLEM

As ethanol production increases, additional corn distillers dried grains with solubles (DDGS) are becoming available to the poultry industry. Many ethanol producers have adopted a dry-grind process due to its simplicity, low capital cost and high yield of ethanol. A typical dry-grind ethanol plant produces ethanol and co-products, which are distillers dried grains (DDG) or distillers dried grains with solubles (DDGS) and carbon dioxide [1-3]. However, the potentially valuable oil is included in DDGS.

A typical DDGS might have up to 12.8% oil. Therefore, the lipid fraction in DDGS represents a great opportunity for oil production. The oil extracted from DDGS can be used in biodiesel and as a commodity in different industries [4]. In addition, extracting oil should improve the economics of ethanol plants without sacrificing market value of DDGS since DDGS is usually sold based on protein content [1]. Therefore, many ethanol manufacturers consider oil extraction as a next step forward.

During the past decade, oil extraction from DDGS has been adopted by some ethanol manufacturers. The co-product after the oil extraction from DDGS is called LO-DDGS (LO-DDGS). Some preliminary studies were done to determine proximate composition of LO-DDGS [4]. Moisture content values for LO-DDGS ranged between 7.04 and 8.83% whereas unmodified (traditional) DDGS had between 13.2 and 21.2% moisture. In addition, LO-DDGS had much lower fat contents; 2.7% (dry matter basis) on average. Average protein and fiber levels were 34.0% and 8.4% (dry matter basis), respectively. Ash content averaged about 4.8% (dry matter basis), which falls within the typical range of traditional DDGS [4].

The use of linear programming to formulate poultry diets and determine feed costs with respect to a set of restrictions (requirements and ingredient minimums and maximums) was developed in the 1950's [5-8]. Present commercial diet formulation software still uses the same basis of diet formulation as in the 1950s. For this study, a Microsoft excel workbook was developed to implement least-cost feed formulation [9]. This excel workbook is able to find the ingredient mixture to meet diet specifications at minimal cost. In addition, it determines shadow prices of traditional DDGS and LO-DDGS using the sensitivity analysis option of Excel's Solver add-in (Microsoft Corp., Redmond, WA).

The purpose of this study was to determine the relative values of DDGS and LO-DDGS in poultry feeds. The procedures followed were 1) Formulate a series of common poultry and turkey diets; 2) Determine corresponding diet formula costs using the least-cost feed formulation technique; 3) Establish shadow prices for both traditional DDGS and LO-DDGS for each formulated diet; and 4) Compare traditional DDGS values with LO-DDGS values by creating parametric cost-ranging graphs. The results can be used to determine what types of diets DDGS is most valuable in, and whether oil extraction decreases the value of DDGS more than the value of the oil.

MATERIALS AND METHODS

There were differences in the nutritional requirement recommendations between breeding companies: Cobb 500 broilers didn't have requirements of linoleic acid, potassium, isoleucine, valine compared to Ross 308/708. Also, there were major differences in choline requirements for both broiler starter (Ross: 1.6 mg/g vs. Cobb: 0.4 mg/g) and broiler finisher (Ross: 1.40 mg/g vs. Cobb: 0.35 mg/g). Hy-line W36 management guides didn't have requirements for manganese, zinc, and choline compared to ISA Brown. However, ISA didn't have requirements for linoleic acid and arginine compared to Hy-line W36. Also ISA Brown had requirements of isoleucine and valine only for the peak period.

For both the first and second parts of these studies , a matrix for formulating diets was compiled in Windows User-friendly Feed Formulation [9] from several sources: 1) the ingredient composition was from the NRC [10] except amino acid digestibility values; 2) the digestible amino acid values were compiled from the Evonik Degussa (ED) database [11]; 3) Ingredient costs were local market prices gathered from an American poultry producer during the fall 2011; and 4) Bird nutrient requirements were from individual commercial breeding companies. Each diet was formulated to include either no poultry by-product meal (PBPM) or 3% PBPM to represent commercial applications. Moreover, all diets were formulated on digestible amino acid basis.

The first part of this study was to formulate a series of common poultry diets to determine diet costs and shadow prices of traditional DDGS and LO-DDGS. Two different strains (Ross 308/708 and Cobb 500) and two different feeds (starter and finisher) were selected for broilers (Table 1). Two different strains (Hy-line W36 and ISA Brown) and three different feeds (starter, prelay and peak) were selected for layers. These diets are broiler starter and finisher (Ross 308/708 and Cobb 500), layer starter, prelay, and peak (Hy-Line W36 and ISA Brown), broiler breeder starter (Cobb 500 Breeder Fast Feather), broiler breeder (Cobb 500 Breeder Fast Feather), and turkey starter and finisher (BUT) [12-15].

The second part of this study was to compare traditional DDGS shadow prices with LO-DDGS shadow prices. Parametric cost ranging graphs were created to illustrate the results. A more limited number of poultry diets were formulated for this part: broiler starter (Ross 308/708), broiler finisher (Ross 308/708), broiler breeder starter (Cobb 500 Breeder Fast

Feather), broiler breeder (Cobb 500 Breeder Fast Feather), layer starter (Hy-Line W36), layer prelay (Hy-Line W36), layer peak (Hy-Line W36), turkey starter (BUT), and turkey finisher (BUT).

RESULTS AND DISCUSSION

The results show that the lowest formula cost feed was the Cobb 500 breeder feed ($275) and the highest was the Ross 308/708 starter feed ($334). Ross 308/708 feeds were relatively more expensive than Cobb 500 diets for starter ($334 vs $311) and for finisher ($331 vs $324). Also Hy-line W36 diets were relatively more expensive than ISA Brown diets for starter ($320 vs $307), prelay ($296 vs $279) and peak ($329 vs $317).

The results for corn and soybean based feeds (Table 2) and corn, soybean meal and poultry by-product meal based feeds (Table 3) were very similar for some feeds, and quite different for other feeds (Table 2 vs Table 3). The shadow prices of traditional and LO-DDGS were the same (to two decimal places) for turkey starter feeds with and without DDGS. In contrast, traditional DDGS was worth $25.79/ton more in the ISA layer starter feed without PBPM; however the LO-DDGS was worth $5.84/ton less when the diet contained 3% PBPM.

Traditional DDGS was most valuable for the ISA layer prelay feed and least valuable in the turkey starter feed. In contrast, LO-DDGS was most valuable in the ISA layer peak feed and least valuable in the turkey starter feed. These relationships were exactly the same for the feeds with and without PBPM.

The parametric cost ranging graphs (Figures 1-9) illustrate that the value of LO-DDGS is practically always higher for LO-DDGS compared to traditional DDGS. Very high (approaching 90%) levels of DDGS could be used in poultry feeds if they could be tolerated.

The shadow prices for traditional and LO-DDGS compare favorably to the market price of DDGS ($205/ton) that corresponded to the other ingredient prices used in this analysis.

The value of LO-DDGS was $50 per ton (or more) greater than the traditional DDGS in all but the broiler breeder and turkey finisher diets. Relatively small differences between shadow prices of LO-DDGS and traditional DDGS demonstrate that LO-DDGS inclusion in broiler breeder diets is not particularly advantageous over traditional DDGS. The additional protein (over traditional DDGS) in LO-DDGS is of less value in the broiler breeder diets. Very high inclusion percentages demonstrate that both the use of LO-DDGS and traditional DDGS in the turkey finisher diets would greatly decrease formula costs as long as the corresponding shadow price is matched.

The high levels of inclusion in Figure 1 – 9 resulted because the models used had no upper limit set for DDGS usage. In practice no detrimental effects should be allowed by setting upper limits on DDGS usage. Previous studies showed that DDGS can be included up to 24% or 25% in broilers with no adverse effect on performance and 8% with no significant differences in broiler breast and thigh meat quality [16 - 18]. Lumpkins [19] had also shown that DDGS can be safely used at 6% in the starter period and 12 to 15% in the grower and finisher periods of broilers. For laying hens, earlier studies done in 1960s showed that DDGS can safely be included up to 10% [20]. However, recent studies showed that DDGS inclusion up to 20 or 25% had no negative effects on feed intake, egg production, Haugh units or specific gravity [21, 22]. The reason could be the use and development of new techniques in the production of DDGS during the past few decades, or differences in the genetic composition of corn.

LO-DDGS showed a higher shadow price than traditional DDGS in all the diets formulated in these models. This makes LO-DDGS more affordable and advantageous compared to traditional DDGS regardless of the value of oil for biodiesel. When the market price of LO-DDGS is at or below the shadow price, its inclusion in least-cost formulation will eventually decrease overall feed costs for producers. Based on assumption that ethanol plants are willing to sell LO-DDGS at the same price as traditional DDGS, LO-DDGS should be the choice of preference.

CONCLUSIONS

1. Formula costs were highest at $333 per ton for turkey starter diets and lowest at $275 per ton for broiler breeder diets when diets were formulated without PBPM.
2. Shadow prices for LO-DDGS were highest at $324 per ton for layer peak diets making it very affordable in diets formulated without PBPM.
3. Shadow prices for traditional DDGS were highest at $284 per ton for layer prelay diets making it reasonably priced in diets formulated without PBPM.
4. Formula costs were highest at $329 per ton for broiler starter diets and lowest at $273 per ton for broiler breeder diets when diets were formulated with 3% PBPM.
5. The highest shadow prices for both low-oil and traditional DDGS in diets with and without 3% PBPM were the same.
6. Ross 308/708 and Hy-line W36 diets were more expensive than Cobb 500 and ISA brown diets, respectively, regardless of PBPM inclusion in the diets.
7. The lowest shadow price of $218.9 per ton for traditional DDGS in the turkey starter diet makes it very easy to make economic decision to include with the market price of $205 per ton.

8. Due to its richer nutrient composition, LO-DDGS had higher shadow prices in all diets studied compared to the traditional DDGS, making it more effective in lowering feed costs.

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Table 3.1 Nutrient specifications of broiler, layer and turkey diets from breeder management guides using digestible amino acid values

Nutrients	Ross Starter[1]	Ross Finisher [1]	Cobb Starter [2]	Cobb Finisher [2]	Hy-line Starter 1 [3]	Hy-line Prelay [3]	Hy-line Peak [3]	ISA Starter [4]	ISA Prelay [4]	ISA Peak [4]	Cobb Breeder Starter [5]	Cobb Breeder 1 [5]	Turkey Starter BUT [6]	Turkey Finisher BUT [6]
M.E. (Kcal/g)	3.03	3.20	2.98	3.17	3.08	2.95	2.95	2.97	2.75	3.00	2.80	2.76	2.82	3.01
Protein (%)	22.00	19.00	21.00	18.00	20.00	17.00	19.05	20.50	16.80	18.80	18.54	15.43	-	-
Linoleic acid (%)	1.00	1.00	0.00	0.00	1.00	1.00	1.19	0.00	0.00	0.00	1.22	1.25	1.25	1.27
Calcium (%)	1.05	0.85	1.00	0.90	1.00	2.50	4.76	1.10	2.10	3.80	1.00	2.89	1.35	0.74
Avail. Phos. (%)	0.50	0.42	0.50	0.45	0.50	0.48	0.60	0.48	0.42	0.41	0.45	0.43	0.76	0.37
K (%)	0.40	0.40	-	-	-	-	-	-	-	-	0.60	0.63	-	-
Cl (%)	0.16	0.16	0.20	0.20	0.18	0.18	0.21	0.15	0.14	0.16	0.18	0.15	0.18	0.19
Mn (mg/kg)	120	120	100	100	-	-	-	60	60	70	100	120	120	100
Na (%)	0.16	0.16	0.22	0.19	0.18	0.18	0.21	0.16	0.15	0.16	0.18	0.15	0.15	0.16
Zn (mg/kg)	100	100	100	100	-	-	-	60	60	60	100	110	100	70
Choline (mg/g)	1.60	1.40	0.40	0.35	0.00	0.00	0.00	1.60	1.40	1.40	0.30	0.25	0.40	0.10
ARG (%)	1.31	1.02	1.14	1.02	1.12	0.83	1.03	-	-	-	0.95	0.57	1.82	0.78
HIS (%)	-	-	-	-	-	-	-	-	-	-	0.29	0.22	-	-
ILE (%)	0.85	0.67	0.00	0.00	0.74	0.62	0.76	0.00	0.00	0.67	0.63	0.48	-	-
LEU (%)	-	-	-	-	-	-	-	-	-	-	1.06	0.71	-	-
LYS (%)	1.27	0.97	1.08	0.95	1.05	0.78	0.96	1.00	0.71	0.74	0.90	0.64	1.66	0.72
MET (%)	0.47	0.38	0.41	0.39	0.47	0.38	0.47	0.48	0.38	0.40	0.40	0.30	0.59	0.34
TSAA (%)	0.94	0.76	0.80	0.74	0.74	0.66	0.80	0.78	0.60	0.64	0.68	0.55	1.10	0.63
THR (%)	0.83	0.65	0.70	0.64	0.69	0.55	0.67	0.67	0.48	0.52	0.63	0.48	1.03	0.43
TRP (%)	0.20	0.16	0.17	0.17	0.18	0.16	0.20	0.19	0.16	0.17	0.20	0.16	0.27	0.11
VAL (%)	0.95	0.75	-	-	0.76	0.66	0.86	-	-	0.71	0.60	0.51	-	-

[1] Ross 308/708 broiler management guides, Alabama, USA.
[2] Cobb 500 broiler management guides, Arkansas, USA.
[3] Hy-line W36 layer management guides, Iowa, USA.
[4] ISA Brown layer management guides, Ontario, Canada.
[5] Cobb 500 broiler breeder management guides, Arkansas, USA.
[6] British United Turkeys (BUT) 10 turkey management guides, West Virginia, USA.

Table 3.2 Diet composition table, corresponding diet formula costs and shadow prices for both traditional DDGS and low-oil DDGS

Ingredients	Cost $/ton	Ross Starter[1]	Ross Finisher [1]	Cobb Starter [2]	Cobb Finisher [2]	Hy-line Starter 1 [3]	Hy-line Prelay [3]	Hy-line Peak [3]	ISA Starter [4]	ISA Prelay [4]	ISA Peak [4]	Cobb Breeder Starter [5]	Cobb Breeder 1 [5]	Turkey Starter BUT [6]	Turkey Finisher BUT [6]
		digestible amino acid basis (dAA), no poultry by-product meal (PBPM) ------- % -------													
Corn, Grain ED	286	51.72	65.32	63.68	68.97	64.29	68.35	43.23	64.92	64.65	54.21	62.08	66.25	42.55	78.46
SBM -48% ED	336	41.60	27.82	32.35	24.91	30.15	23.43	35.96	31.27	23.74	29.77	29.29	22.03	51.31	15.11
Poultry Fat	880	3.21	3.90	0.55	2.88	2.17	1.00	7.51	0.28	0.00	5.52	0.00	0.00	1.44	0.00
Limestone	40	0.81	0.66	0.69	0.65	0.68	4.71	10.04	1.05	9.48	8.43	6.36	9.61	0.38	4.31
Defluor. Phos.	100	1.94	1.60	1.99	1.78	2.02	1.97	2.61	1.89	1.66	1.58	1.76	1.73	3.30	1.42
Common Salt	96	0.17	0.16	0.26	0.21	0.18	0.23	0.29	0.17	0.17	0.20	0.23	0.18	0.14	0.19
Vit. Premix	9061	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Min. Premix	1125	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
DL-Methionine	3375	0.30	0.23	0.23	0.24	0.19	0.17	0.25	0.21	0.14	0.14	0.15	0.09	0.38	0.21
L-Lysine	1511	0.08	0.12	0.11	0.18	0.14	0.01	0.00	0.04	0.00	0.00	0.00	0.00	0.28	0.18
L-Threonine	2254	0.04	0.05	0.03	0.07	0.05	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.11	0.00
Choline Cl	997	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.04	0.00	0.00	0.00	0.00
TOTAL		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Formula Cost:		$334.18	$331.13	$311.59	$324.28	$320.08	$296.76	$329.36	$307.79	$279.03	$317.42	$289.14	$275.66	$333.18	$291.83
Traditional DDGS Shadow Price		$244.98	$244.10	$243.48	$242.19	$229.67	$242.19	$249.68	$244.10	$284.23	$256.25	$266.53	$262.89	$219.32	$256.80
Low-oil DDGS Shadow Price		$321.77	$314.70	$311.97	$312.77	$298.40	$312.77	$324.63	$314.70	$319.88	$324.10	$303.22	$298.41	$292.36	$297.68

[1] Ross 308/708 broiler management guides, Alabama, USA.
[2] Cobb 500 broiler management guides, Arkansas, USA.
[3] Hy-line W36 layer management guides, Iowa, USA.
[4] ISA Brown layer management guides, Ontario, Canada.
[5] Cobb 500 broiler breeder management guides, Arkansas, USA.
[6] British United Turkeys (BUT) 10 turkey management guides, West Virginia, USA.

Table 3.3 Diet composition table, corresponding diet formula costs and shadow prices for both traditional DDGS and low-oil DDGS

Ingredients	Cost $/ton	Ross Starter[1]	Ross Finisher[1]	Cobb Starter[2]	Cobb Finisher[2]	Hy-line Starter 1[3]	Hy-line Prelay[3]	Hy-line Peak[3]	ISA Starter[4]	ISA Prelay[4]	ISA Peak[4]	Cobb Breeder Starter[5]	Cobb Breeder 1[5]	Turkey Starter BUT[6]	Turkey Finisher BUT[6]
		digestible amino acid basis (dAA), 3% poultry by-product meal (PBPM)													
		%													
Corn, Grain ED	286	53.23	67.29	64.93	70.89	65.35	69.70	46.11	65.41	64.32	56.19	61.21	64.98	43.69	77.76
SBM -48% ED	336	38.31	24.03	28.69	21.13	27.18	20.27	31.49	27.74	20.46	26.09	26.77	20.07	48.33	12.34
Poultry BP Meal	310	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Poultry Fat	880	2.45	3.10	0.00	2.09	1.50	0.27	6.55	0.00	0.00	4.69	0.00	0.00	0.75	0.00
Limestone	40	0.79	0.63	0.98	0.63	0.66	4.69	10.02	1.75	10.54	8.41	7.20	10.30	0.36	5.17
Defluor. Phos.	100	1.52	1.19	1.58	1.37	1.60	1.56	2.21	1.48	1.25	1.17	1.35	1.31	2.89	1.01
Common Salt	96	0.14	0.18	0.29	0.24	0.18	0.19	0.26	0.14	0.14	0.18	0.21	0.16	0.10	0.20
Vit. Premix	9061	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Min. Premix	1125	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
DL-Methionine	3375	0.28	0.22	0.21	0.22	0.19	0.16	0.24	0.20	0.14	0.14	0.13	0.06	0.36	0.19
L-Lysine	1511	0.12	0.17	0.16	0.23	0.17	0.04	0.00	0.09	0.00	0.00	0.01	0.00	0.31	0.21
L-Threonine	2254	0.04	0.06	0.04	0.08	0.05	0.01	0.01	0.02	0.00	0.00	0.01	0.00	0.11	0.00
Choline Cl	997	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.02	0.00	0.00	0.00	0.00
TOTAL		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Formula Cost:		$329.51	$326.27	$307.63	$319.62	$316.26	$292.36	$322.93	$304.45	$276.10	$312.01	$286.77	$273.77	$328.90	$289.58
Traditional DDGS Shadow Price		$246.32	$245.39	$268.30	$243.48	$231.25	$231.63	$247.65	$269.89	$284.66	$258.50	$263.43	$261.22	$219.32	$257.19
Low-oil DDGS Shadow Price		$320.64	$313.90	$307.31	$311.97	$298.01	$301.59	$322.18	$308.86	$319.89	$324.13	$302.39	$323.51	$292.36	$297.66

[1] Ross 308/708 broiler management guides, Alabama, USA.
[2] Cobb 500 broiler management guides, Arkansas, USA.
[3] Hy-line W36 layer management guides, Iowa, USA.
[4] ISA Brown layer management guides, Ontario, Canada.
[5] Cobb 500 broiler breeder management guides, Arkansas, USA.
[6] British United Turkeys (BUT) 10 turkey management guides, West Virginia, USA.

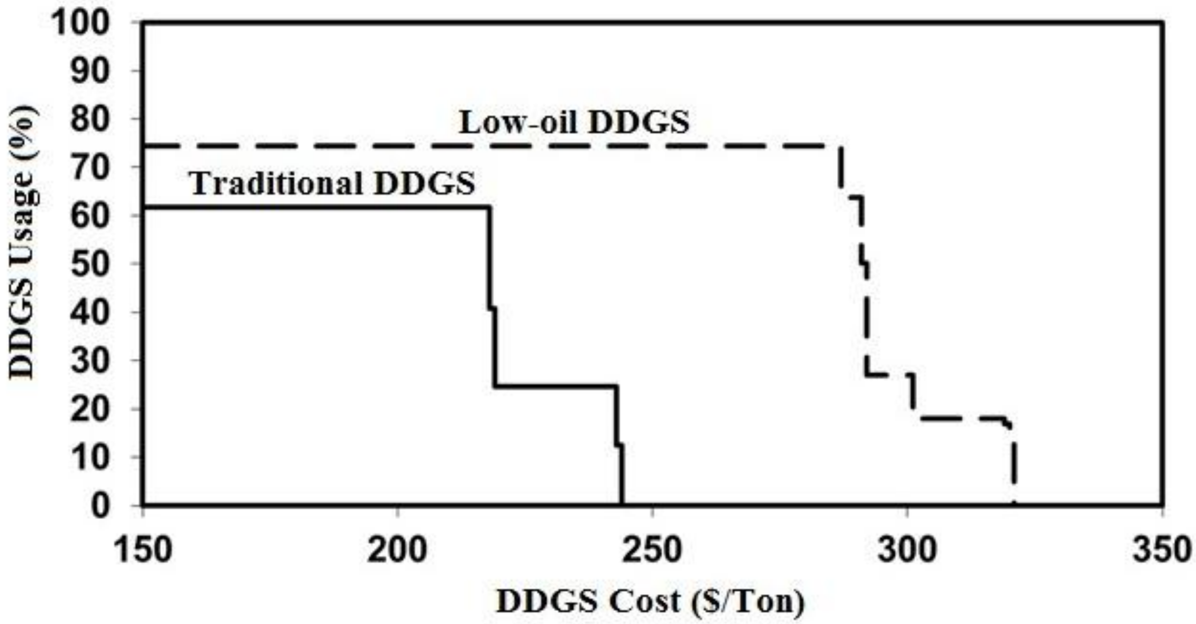

Figure 3.1 Parametric cost ranging of low-oil and traditional DDGS in Ross 308 broiler starter diet [Ross 308 nutritional requirement recommendations, Alabama, USA]

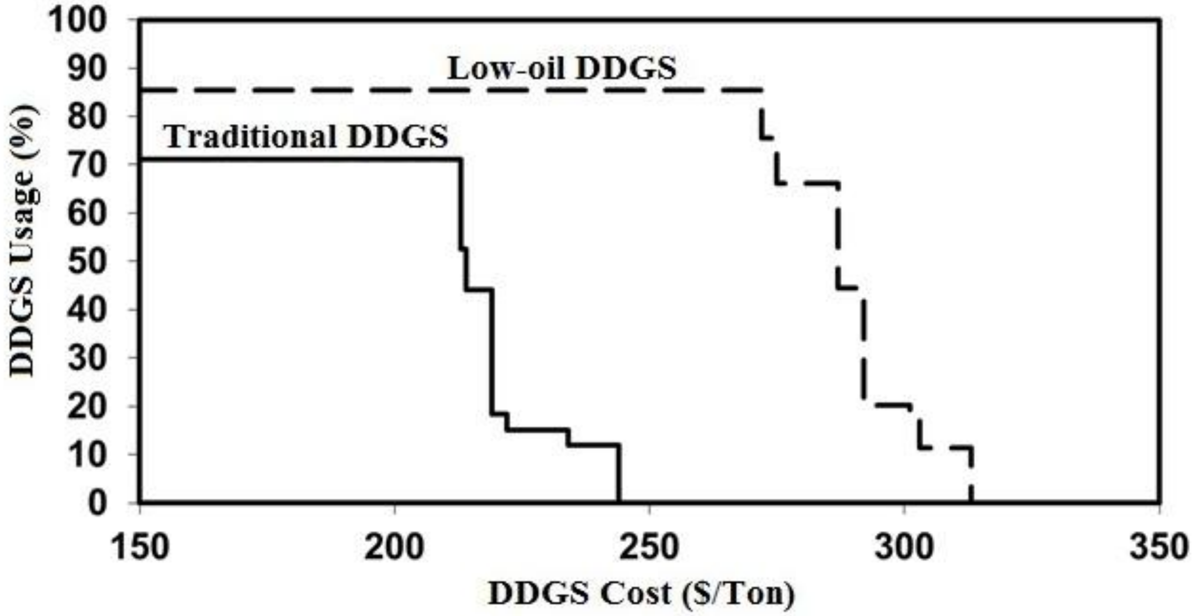

Figure 3.2 Parametric cost ranging of low-oil and traditional DDGS in Ross 308 broiler finisher diet [Ross 308 nutritional requirement recommendations, Alabama, USA]

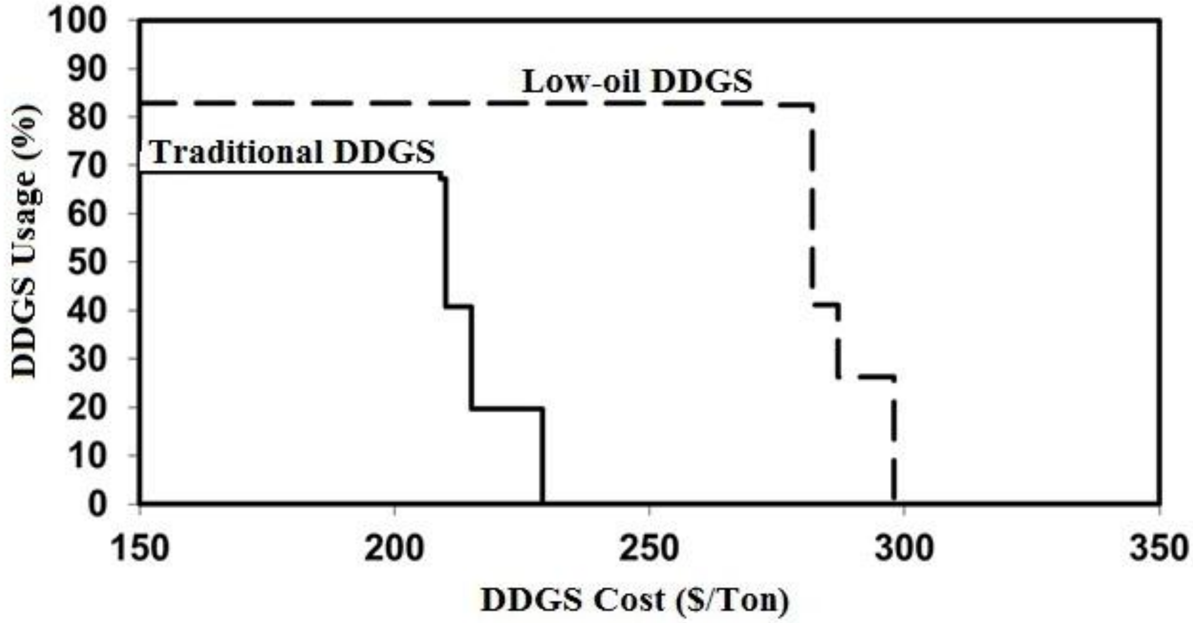

Figure 3.3 Parametric cost ranging of low-oil and traditional DDGS in Hy-line W36 layer starter 1 diet [Hy-line W36 nutritional requirement recommendations, Iowa, USA]

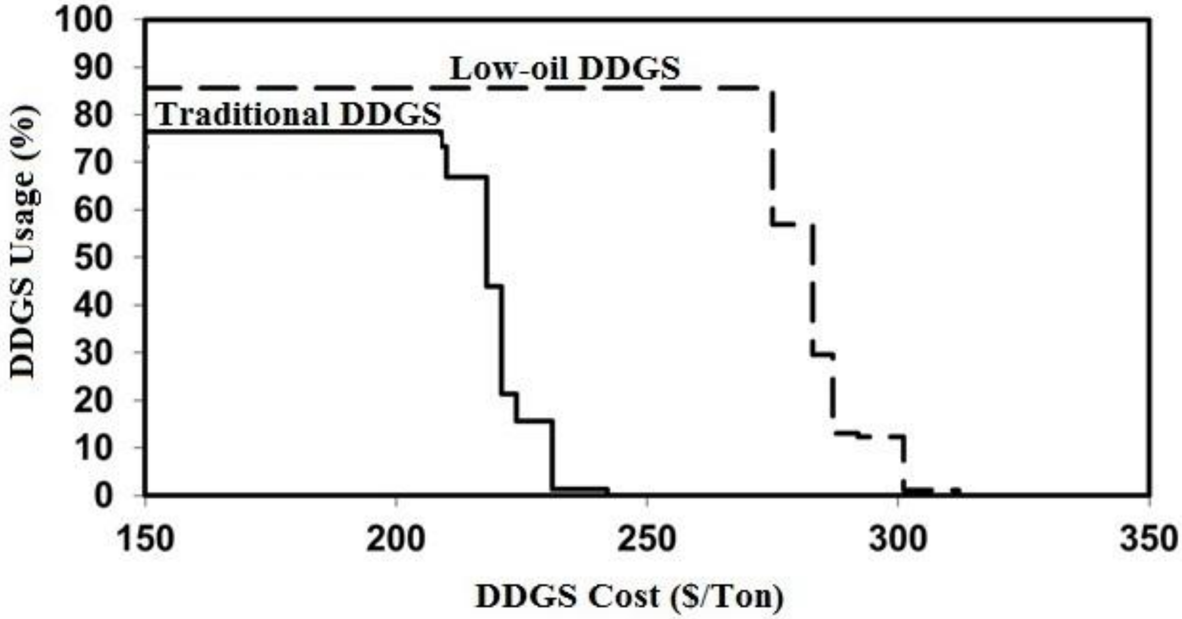

Figure 3.4 Parametric cost ranging of low-oil and traditional DDGS in Hy-line W36 layer prelay diet [Hy-line W36 nutritional requirement recommendations, Iowa, USA]

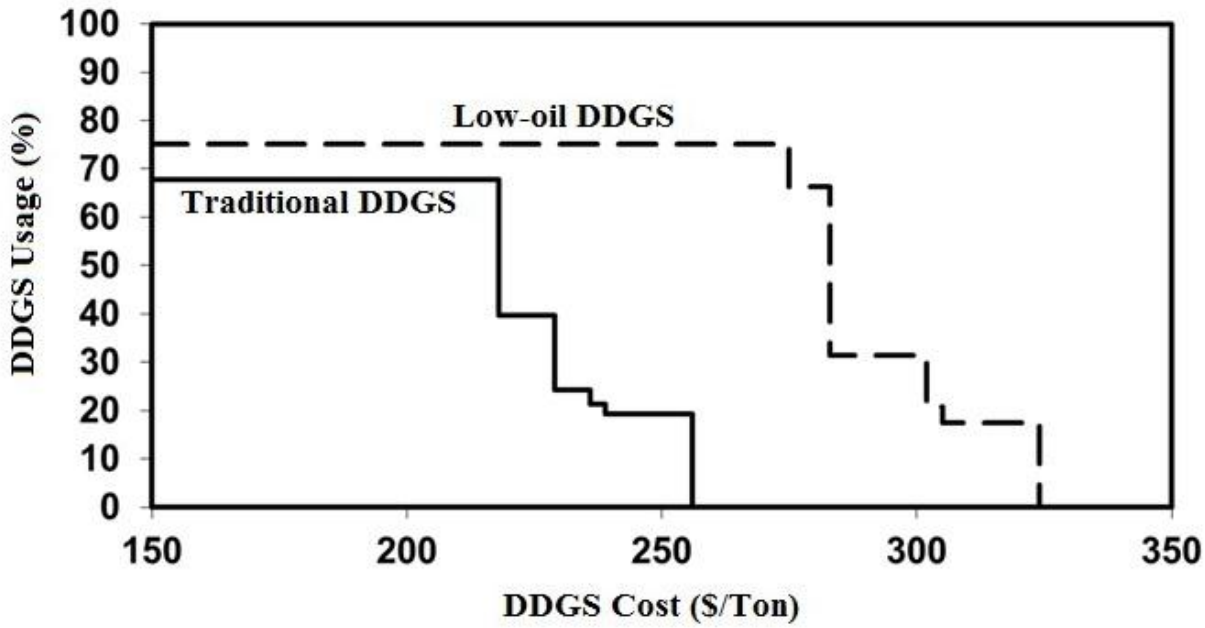

Figure 3.5 Parametric cost ranging of low-oil and traditional DDGS in Hy-line W36 layer peak diet [Hy-line W36 nutritional requirement recommendations, Iowa, USA]

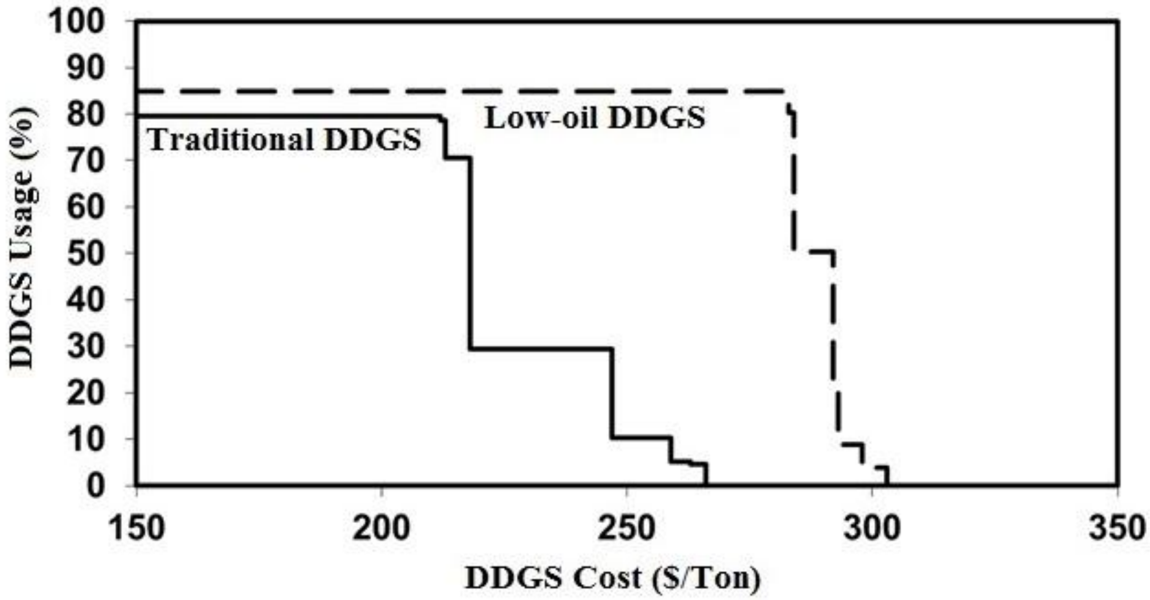

Figure 3.6 Parametric cost ranging of low-oil and traditional DDGS in Cobb 500 broiler breeder starter diet [Cobb 500 broiler breeder nutritional requirement recommendations, Arkansas, USA]

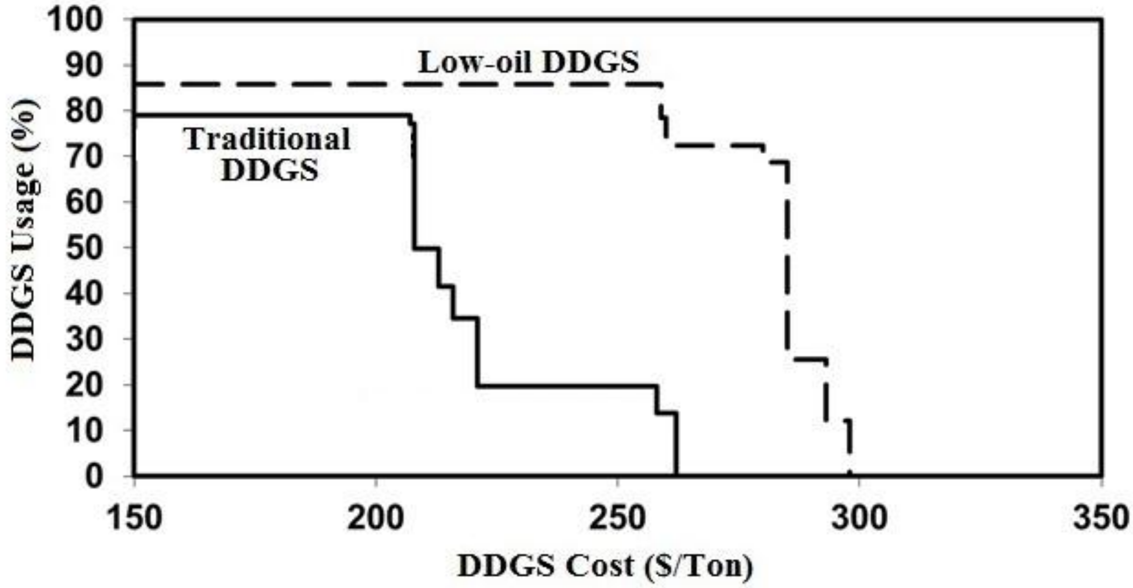

Figure 3.7 Parametric cost ranging of low-oil and traditional DDGS in Cobb 500 broiler breeder 1 diet [Cobb 500 broiler breeder nutritional requirement recommendations, Arkansas, USA]

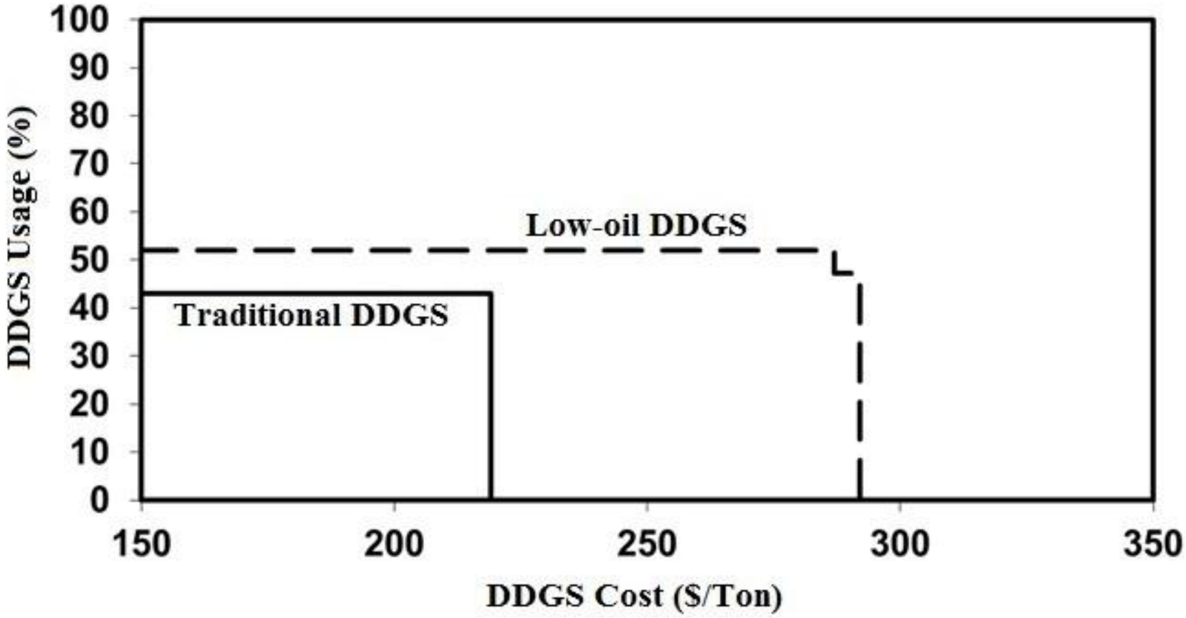

Figure 3.8 Parametric cost ranging of low-oil and traditional DDGS in BUT 10 turkey starter diet [BUT 10 nutritional requirement recommendations, West Virginia, USA]

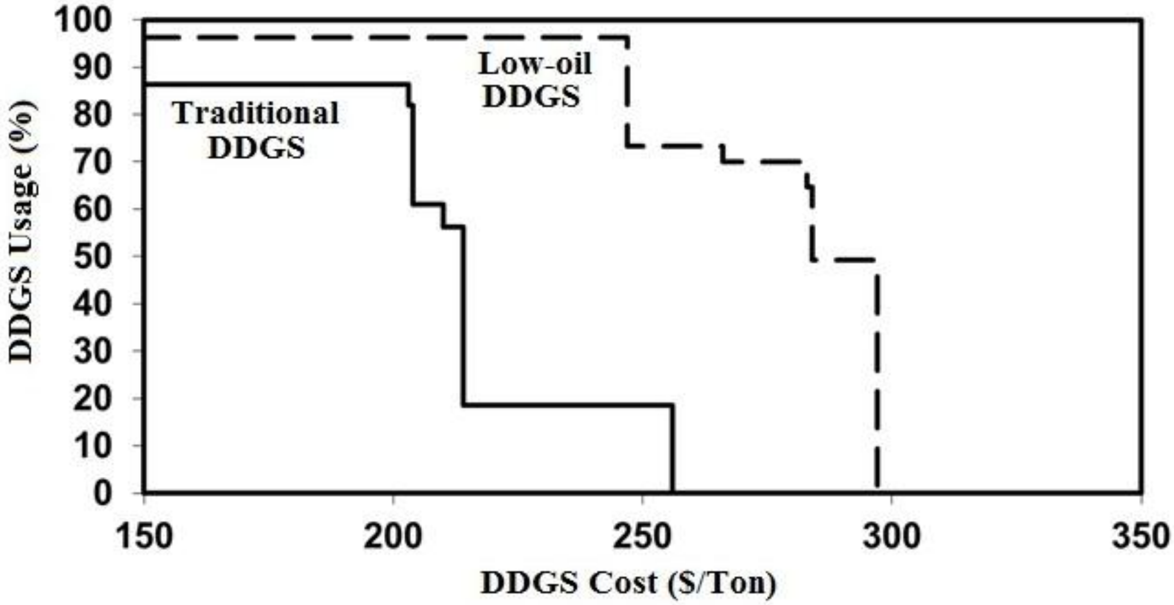

Figure 3.9 Parametric cost ranging of low-oil and traditional DDGS in BUT 10 turkey finisher diet [BUT 10 nutritional requirement recommendations, West Virginia, USA]

CHAPTER 4

EFFECT OF FEEDING LOW-OIL DISTILLERS DRIED GRAINS WITH SOLUBLES ON THE PERFORMANCE OF BROILERS [5]

[5]Guney, A. C., M. Y. Shim, G. M. Pesti. To be submitted to *Poultry Science*.

ABSTRACT Distillers dried grains with solubles (DDGS) manufacturers are changing practices to extract corn oil from DDGS in the process of ethanol production. The resulting product is called low-oil DDGS and it may be included in broiler diets. Two low-oil DDGS and one traditional DDGS were used in a broiler performance trial to determine maximum levels of inclusion without detrimental effects. Corn and soybean meal based mash diets, were used with different DDGS samples included at either 10 or 20%. Six hundred and thirty Cobb 500 by-product male chicks were randomly assigned to six replicate pens containing fifteen chicks each and fed diets from 0-18 d of age. There was an increase in BW at d 11 and 18 when 10 and 20% of low-oil DDGS is included compared to the control group. There was also a significant effect of level on BW at d 18 ($P<0.05$). Feed efficiency from d 0 to 18 was improved when 10% low-oil DDGS was used compared to 20% inclusion. Abdominal fat pad weights were higher when low-oil DDGS samples were included at either 10 or 20% compared to the control group. There was a significant effect of DDGS source, level and bird BW on fat pad weights ($P<0.05$). Producers may achieve an increase in performance when including 10% low-oil DDGS in broiler diets. Up to 20% inclusion levels will have no detrimental effect on performance parameters compared to the standard corn-soybean diet.

Key words: low-oil DDGS, broiler, ethanol, oil extraction

INTRODUCTION

Increased demand for ethanol in United States has lead to great amounts of distillers dried grains with solubles (DDGS) available to the poultry and other livestock industries. DDGS has been studied extensively in various poultry diets during the past decade and it has been considered a good choice of an alternative feed ingredient for broiler diets (Lumpkins et al., 2004; Shim et al., 2011).

In the past several years, ethanol producers have considered extracting corn oil from DDGS due to the current high prices of oil. A typical DDGS might have up to 12.55% oil content (Liu, 2010). So, the lipid fraction in DDGS represents a great opportunity for oil production for food or fuel. The oil extracted from DDGS can be used in biodiesel production or as a commodity in different industries (Saunders et al., 2009), so its' value is directly related to crude oil. The left-over product after oil extraction from DDGS is called low-oil DDGS. A low-oil DDGS sample might have as little as 2.1% (dry matter basis) of fat content after the extraction (Ganesan et al., 2009).

There are currently very limited numbers of studies conducted with low-oil DDGS. Some studies have been conducted to determine the effects of low-oil DDGS in swine (Jacela et al., 2011; Anderson et al., 2012; Dahlen et al., 2011). However, no study has been conducted to research low-oil DDGS inclusion in poultry, specifically in broiler diets. Therefore, the objectives of this study were: 1) to investigate the effects of different levels of low-oil DDGS on broiler performance and bird abdominal fat pad weight; 2) to compare the effects of low-oil DDGS inclusion against diets that includes traditional DDGS and industry standard corn-soybean diet; and 3) to determine maximum level of inclusion of low-oil DDGS in broiler diets without any detrimental effects.

MATERIALS AND METHODS

Diet Formulation

Two low-oil and one traditional DDGS products ranging in oil content levels (Table 1) were obtained from different ethanol plants in the United States. Diets were formulated as corn-soybean meal mash diets and not pelleted or crumbled, using a different DDGS sample for each treatment at either 10 or 20% (Table 2). There was a control (corn-soybean) and 6 dietary treatments consisting of a starter diet from 0 to 11 d, and a grower diet from 12 to 18 d. All diets were formulated to be isocaloric based on an *in vivo* rooster TME_n assay for each DDGS sample and table values for the other ingredients. Diets were also formulated on a digestible AA basis by using coefficients for corn and SBM from Ajinomoto Heartland LLC (2004). Amino acid digestibility coefficients for DDGS were based on values reported by Batal and Dale (2006). Diets were formulated to have the same levels of crude protein, calcium, available phosphorus, lysine, TSAA, and threonine. Nutrient requirements were taken from commercial breeder management guide[6] except vitamins and minerals, which were designed to meet or exceed NRC (1994) requirements. Moisture, crude protein, crude fiber, crude fat, and ash levels in all of the DDGS samples were determined using AOAC (1984) methods by the University of Georgia Agricultural and Environmental Services Laboratories[7].

Performance Trial

The University of Georgia Animal Care and Use Committee approved all procedures. Six hundred and thirty by-product male broiler chicks (Cobb 500) from a female parent stock were obtained from a local commercial hatchery. Chicks were housed in thermostatically controlled Petersime[8] starter batteries with raised wire floors in an environmentally controlled building. At hatch, chicks were weighed and randomly allotted to pens so that each pen of fifteen chicks had a similar initial weight and pen weight distribution. Chicks were allowed *ad libitum* access to the control (corn-soybean) and six dietary treatments through 18 days of age. There were 6 pens of fifteen chicks per replication assigned to the seven corn-soybean meal diets and chicks were randomly allocated to the pens. Feed and average pen weights were recorded on day 0, 11 and 18. At the end of the study, birds were tagged, euthanized by carbon dioxide and stored in the cooler overnight. Next day, the birds were weighed individually; fat pads were removed and weighed.

Statistical Analysis

All data were subjected to analysis of variance procedures using the general linear model procedure (PROC GLM) of SAS® (SAS Institute, 1990). The one-way ANOVA model was

$Y_{ij} = \mu + Trt_i + e_{ij}$

where Y_{ij} is the dependent variable, μ is the overall mean, Trt_i is the treatment effect, and e_{ij} is the observational error for the $(ij)^{th}$ observation. The two-way model was:

$Y_{ijk} = \mu + Source_i + Level_j + Level*source_{ij} + e_{ijk}$

where Y_{ijk} is the dependent variable, μ is the overall mean, $Source_i$ is the effect of DDGS sample, $Level_j$ is the effect of level of DDGS inclusion, $Level*source_{ij}$ is the combined effect of DDGS sample and inclusion level, and e_{ijk} is the observational error for the $(ijk)^{th}$ observation Growth performance data from 0-18 d of age plus relative pancreas weights were fitted to linear and quadratic response curves (Draper and Smith, 1981) using the GLM procedure of SAS (SAS Institute, 1990). Differences were considered significant when $P < 0.05$.

[6] Aviagen Cobb 500 commercial broiler management guide
[7] University of Georgia Agricultural and Environmental Services Laboratories, Feed and Environmental Water Laboratory, Athens, GA
[8] Petersime Incubator, Gettysburgh, OH 45328.

RESULTS AND DISCUSSION

Crude fat value of DDGS samples was the measure that determined whether it was considered low-oil or traditional DDGS. The fat value of Sample 1 was 12.45% (Table 1), which was considered in the range of traditional DDGS (Tahir et al., 2012). However, samples 2 and 3 had lower fat values of 6.29 and 7.41%, respectively. These fat values were in the range of low-oil DDGS samples used in other studies (Jacela et al., 2011). Therefore, samples 2 and 3 were used as representatives of low-oil DDGS in this study.

Proximate analysis results (Table 1) indicated that concentrations of moisture were about the same among three samples, ranging from 12.42 to 13.83%. The other proximate analysis components (except crude fat) were higher for the low oil products, as expected. Oil extraction basically causes DDGS to be a denser product, except for the oil. Since fat is more energy dense and has a higher biological energy value than protein and carbohydrates (WPSA, 1989), low-oil DDGS samples are expected to have slightly lower gross energy values compared to traditional DDGS.

There was a significant treatment effect on body weight at 11 and 18 d of age (Table 3). Level alone, as well as level and source (sample) interaction had significant effects on body weight at day 18 *($P<0.05$)* while these parameters didn't affect body weight at day 11. Both the positive and negative effects of DDGS increased over time. Overall, chicks fed samples 1 and 3 performed well at both 10 and 20% inclusion levels. Chicks fed 10% inclusion levels of samples 1 and 3 had an improved body weight at day 18 when compared to 20% inclusion level of same samples. However, chicks fed 10% inclusion level of sample 2 had unexpectedly a worse body weight at 18 d of age when compared to chicks fed 20% inclusion level of any DDGS sample.

Feed intake was very similar among chicks fed all the treatments and there was no significant effect of treatment, source or level during any feed intake period (Table 3). There were no significant effects of treatment, source or level on feed efficiency to 11 d of age. However, treatment and level had significant effects *($P<0.05$)* on feed efficiency at 0-18 d of age. 10% inclusion level of any DDGS sample utilized feed more efficiently compared to those fed the 20% inclusion level. This is due to the higher body weight at 18 d of age when 10% DDGS is included and very similar feed intake at both 10 and 20% inclusion levels.

Source, level, and body weight had a significant effects *($P<0.05$)* on fat pad weights with a high R^2 value of 0.584 (Table 4). Only DDGS level had a significant effect ($P<0.05$) on relative fat pad percentage. The effect of BW on relative fat pad was not considered since body weight interaction is included in the calculation of relative fat pad percentage. 20% inclusion of sample 1 and 2 had a higher fat pad amount when compared 10% inclusions of same samples. However, this was not the case for sample 3. The fat pad amounts tended to be higher in birds with increased body weights; this might be due to the unbalanced protein feeding (Mabray et al., 1980; Griffiths et al., 1977).

For body weight at day 11, chicks fed sample 3 had the highest predicted level of inclusion to maximize body weight (17.5%) and a maximum body weight of 361.1 g (Figure 1). However, sample 1 had the highest predicted level of inclusion (11.9%) and a maximum body weight of 649.7 g at d 18 (Figure 2). The maximum inclusion levels determined by the prediction equation were more conservative compared actual data points. However, effect of source as well as inclusion level on body weight is clearly illustrated here. Clearly to predict the influence of low oil or traditional DDGS, the producer must know the quality of the particular DDGS being fed.

Low-oil DDGS can be an excellent choice of alternative feed ingredient when availability and price of corn and soybean meal are not more advantageous. As the demand for ethanol is increasing and oil extraction from DDGS is being considered by ethanol plants, poultry producers will have the opportunity to use more low-oil DDGS. DDGS samples create difficulties for producers due to variation between the samples (Tables 1 to 4; Ortin et al., 2009). DDGS sample type and origin are some factors that cause variation in the sample (Liu, 2010; Belyea et al., 2010). Bioassay of a low-oil DDGS sample should be considered to determine its nutrient composition and energy value since fat content tends to fluctuate. We attempted to formulate the diets used here to balance all known nutrients and expected performances to be equal. Clearly there are positive and negative factors in DDGS that remain unknown that lead to improvements and decreases in performance as the levels of DDGS are increased. Neither of these factors seems related to palatability and voluntary consumption, since feed intake was constant regardless of DDGS level. Amino acid composition would seem to be a candidate for the negative factor since abdominal fat pads were increased at 18 days. Increased fat pad size is related to lower protein and amino acid levels. The positive and negative factors in DDGS may also be related to its fiber content. It is possible that the chicks need a certain level of fiber present in DDGS, but higher levels are detrimental. Similarly, differences in the diets' fat levels or endogenous versus exogenous fat sources could conceivably be involved in dietary interactions not directly related to dietary energy level that are related to differences in chick responses.

Body weights of birds that were fed low-oil DDGS samples up to 20% were above or similar to the birds fed industry standard corn and soybean meal based diet. But obviously these birds were not reaching their genetic potential since birds fed the diets with 10% DDGS performed better. These results agree with previous studies done with traditional DDGS (Shim et al., 2011; Waldroup et al., 1980). This might be due to its increased protein content and more balanced AA composition of low-oil DDGS compared to traditional DDGS or corn. Even though the energy value of low-oil DDGS samples was lower than regular DDGS, it did not show any detrimental effects once the energy requirement was met using in combination with a fat source in the least cost formulation. When including low-oil DDGS samples in broiler diets, 20% inclusion level will have no detrimental effect on performance parameters compared to the standard corn and soybean diet.

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Table 4.1 Proximate composition[1] of DDGS samples[2]

	Sample 1[a]	Sample 2[b]	Sample 3[b]
Moisture (%)	13.51	13.83	12.42
CP (%)	27.70	27.84	28.78
Crude fiber (%)	6.05	6.29	7.41
Fat (%)	12.45	7.52	6.74
Ash (%)	5.63	7.22	6.59
Gross Energy (kcal/g)	4.86	4.52	4.48

[1] Values reported from the analysis conducted at the University of Georgia Agricultural and Environmental Services Laboratories, Feed and Environmental Water Laboratory, Athens, GA

[2] There were total of three DDGS samples consisting of two low-oil DDGS and one traditional DDGS

[a] is considered traditional DDGS (crude fat > 9.90%)

[b] is considered low-oil DDGS (crude fat < 9.90%)

Table 4.2 Ingredient composition and nutritive value (%) of diets

Item	Control diet	10% Sample 1	20% Sample 1	10% Sample 2	20% Sample 2	10% Sample 3	20% Sample 3	Control diet	10% Sample 1	20% Sample 1	10% Sample 2	20% Sample 2	10% Sample 3	20% Sample 3
	Starter Phase, d 0 to 11							Grower Phase, d 12 to 18						
Ingredient[1]				%							%			
Corn	59.85	55.89	51.93	55.29	50.73	55.51	51.18	62.60	59.94	55.99	59.34	54.78	59.56	55.23
SBM	34.33	28.86	23.38	28.97	23.61	28.71	23.09	29.64	23.96	18.48	24.07	18.71	23.81	18.19
Poultry Fat	1.28	0.66	0.03	1.14	0.99	1.15	1.02	2.75	1.65	1.02	2.13	1.99	2.15	2.02
DDGS	0	10	20	10	20	10	20	0	10	20	10	20	10	20
Limestone	1.28	1.40	1.51	1.41	1.55	1.41	1.55	1.85	1.36	1.48	1.38	1.52	1.38	1.52
Dical. Phos.	1.95	1.74	1.54	1.76	1.57	1.76	1.57	1.89	1.68	1.47	1.69	1.51	1.70	1.51
Common Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.43	0.43	0.43	0.43	0.43	0.43	0.43
Vitamin Premix[2]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Mineral Premix[3]	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
DL-Methionine	0.19	0.18	0.18	0.18	0.17	0.18	0.17	0.18	0.18	0.17	0.17	0.16	0.17	0.16
L-Lysine HCL	0.05	0.17	0.29	0.15	0.26	0.16	0.28	0.08	0.20	0.32	0.19	0.30	0.20	0.31
L-Threonine	0.00	0.03	0.07	0.02	0.05	0.03	0.05	0.00	0.03	0.07	0.02	0.05	0.03	0.05
Calculated composition														
ME (kcal/g)	2.98	2.98	2.98	2.98	2.98	2.98	2.98	3.08	3.08	3.08	3.08	3.08	3.08	3.08
CP	21.00	21.00	21.00	21.00	21.00	21.00	21.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00
Crude Fat	3.72	4.15	4.57	4.12	4.51	4.06	4.39	5.24	5.23	5.66	5.20	5.60	5.14	5.48
Ca	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Available P	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.48	0.48	0.48	0.48	0.48	0.48	0.48

1 DDGS = distillers dried grains with solubles; SBM = soybean meal (CP content of SBM: 48.3%).

[2]Vitamin premix provided the following (per kg of diet) : Thiamin·mononitrate, 2.4mg; nicotinic acid, 44mg; D-Ca pantothenate, 12 mg; vitamin B_{12}(cobalamin), 12.0µg; pyridoxine·HCl, 4.7mg; D-biotin, 0.11mg; folic acid, 5.5mg; menadione sodium bisulfate complex, 3.34mg; choline chloride, 220mg; cholecalciferol, 27.5µg; trans-retinyl acetate, 1,892µg; all rac α tocopheryl acetate, 11mg; ethoxyquin, 125mg.

[3]Trace mineral mix provided the following (per kg of diet): manganese ($MnSO_4 \cdot H_2O$), 60mg; iron ($FeSO_4 \cdot 7H_2O$), 30mg; zinc (ZnO), 50 mg; copper ($CuSO_4 \cdot 5H_2O$), 5mg; iodine (ethylene diamine dihydroiodide), 0.15mg; selenium ($NaSeO_3$), 0.3mg.

Table 4.3 Effect of diets with different DDGS samples varying in oil content (%) on body weight, feed intake, and FCR from 0 to 18 d of age

DDGS source	Inclusion level	Body Weight (g/bird)		Feed Intake (g/bird/day)			Feed Efficiency[1] (g:g)	
		11d	18d	0-11d	11-18d	0-18d	0-11d	0-18d
Control	0	328±10	596±9	39.5±1.3	75.6±2.8	53.6±0	1.32±0.04	1.61±0.02
1	10	357±5	666±9	41.3±1.8	79.2±3.0	56±2.1	1.27±0.07	1.51±0.06
1	20	342±6	615±12	42.9±1.6	78.7±1.7	56.8±1	1.38±0.07	1.66±0.03
2	10	339±9	607±22	40.4±1.2	75.8±4.0	54.2±1	1.31±0.05	1.61±0.03
2	20	356±6	615±8	41.6±1.1	78.3±2.5	55.9±1	1.28±0.06	1.63±0.06
3	10	357±4	650±9	39.9±0.4	74.3±1.6	53.3±0	1.23±0.03	1.47±0.02
3	20	359±4	598±7	43.7±1.8	76.9±1.6	56.7±1	1.33±0.05	1.70±0.04
	df	Significance Probabilities						
ANOVA								
One-way	6	0.024	0.002	0.344	0.836	0.448	0.616	0.009
Two-way								
Source	2	0.334	0.073	0.704	0.483	0.524	0.730	0.652
Level	1	0.831	0.005	0.064	0.489	0.117	0.175	0.001
Level*source	2	0.081	0.037	0.623	0.805	0.699	0.390	0.073
Error	33							
R^2		0.340	0.441	0.175	0.076	0.152	0.119	0.382

[1] Feed efficiency = feed intake / bw gain

Table 4.4 Effect of diets with different DDGS samples varying in oil content (%) on fat pad weights at 18 d of age

DDGS source	Inclusion level	Fat Pad (g)	Relative Fat Pad[1] (%)
Control	0	3.41±0.36	0.56±0.06
1	10	3.83±0.28	0.56±0.04
1	20	3.95±0.34	0.63±0.05
2	10	3.51±0.45	0.55±0.06
2	20	4.22±0.33	0.67±0.04
3	10	4.69±0.19	0.71±0.02
3	20	3.81±0.38	0.62±0.05
	df	Significance Probabilities	
ANOVA			
One-way	6	0.209	0.199
Two-way			
Source	2	0.011	0.066
Level	1	0.001	0.025
Body weight		0.001	-
Level*source	2	0.091	0.121
Error	33		
R^2		0.584	0.217

[1] Relative Fat Pad = Fat Pad (g) / BW (g).

Figure 4.1 Best fit regression model for estimating the influence of DDGS inclusion level on the d 11 body weight response of broiler chickens

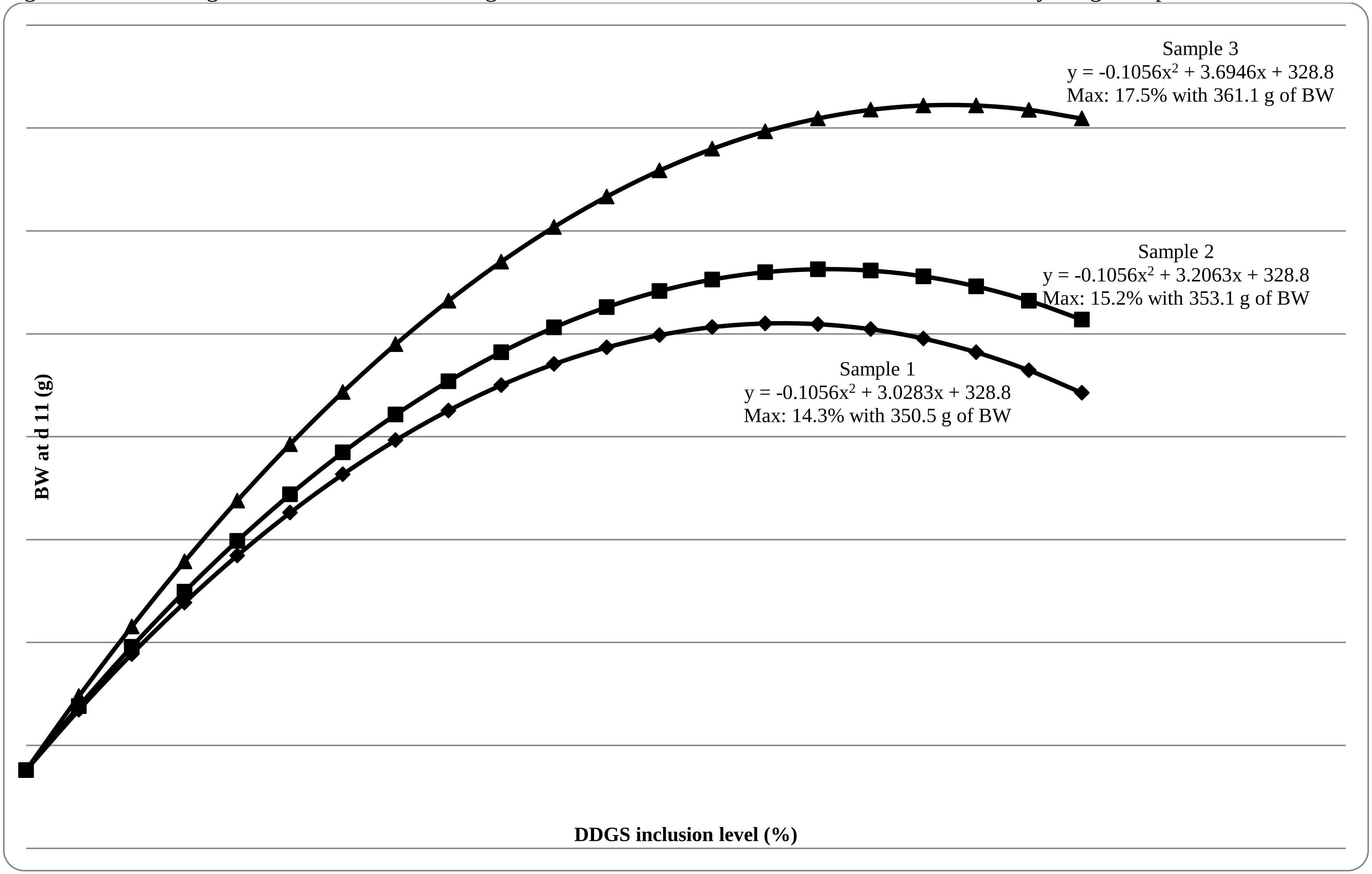
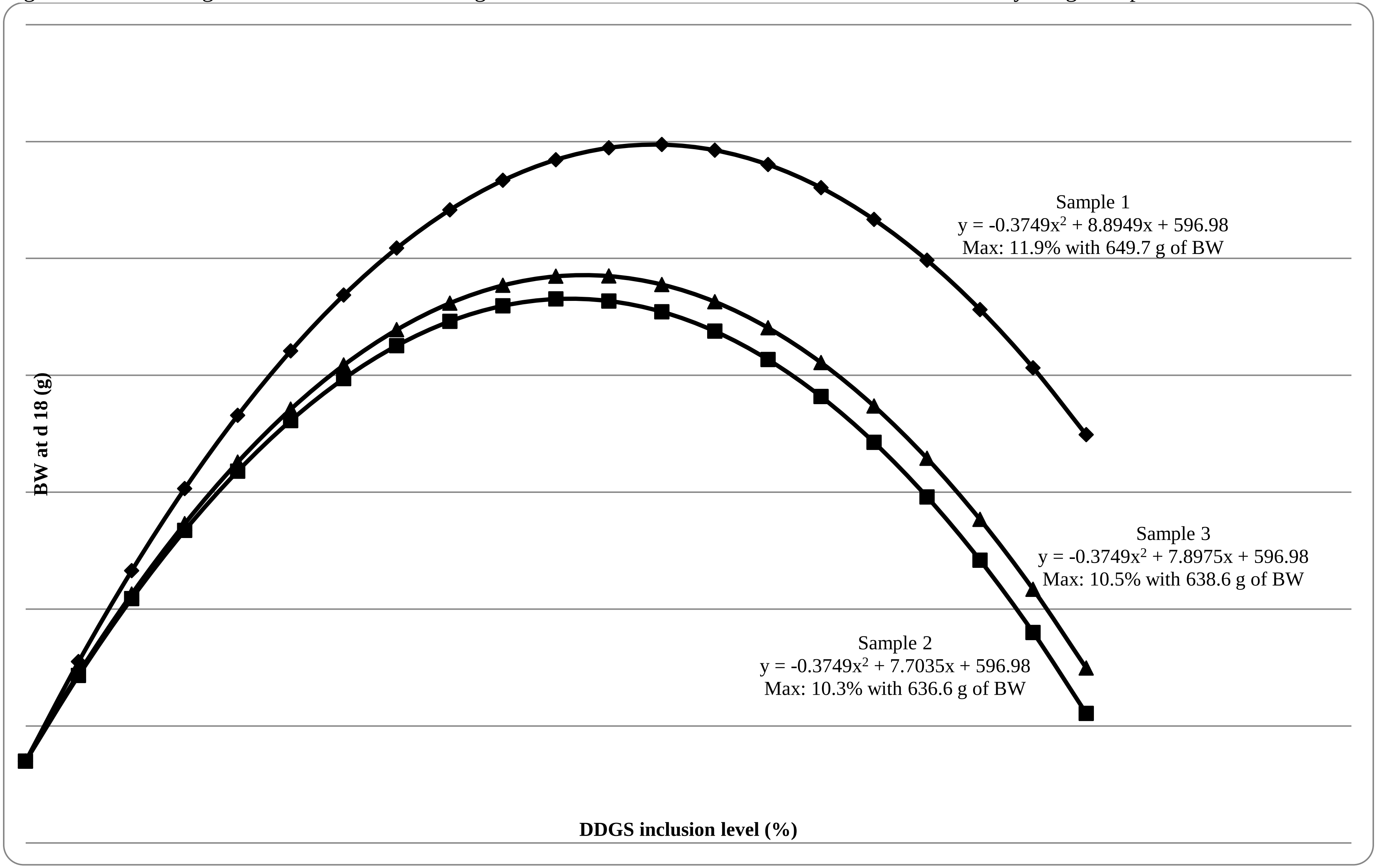


Figure 4.2 Best fit regression model for estimating the influence of DDGS inclusion level on the d 18 body weight response of broiler chickens



CHAPTER 5

EFFECT OF FEEDING LOW-OIL DISTILLERS DRIED GRAINS WITH SOLUBLES ON LAYER PERFORMANCE AND EGG QUALITY MEASURES [9]

[9]Guney, A. C., M. Y. Shim, G. M. Pesti. To be submitted to *Poultry Science.*

ABSTRACT Distillers dried grains with solubles (DDGS) manufacturers are changing practices to extract corn oil from DDGS in the process of ethanol production. The resulting product is called low-oil DDGS and it may be included in laying hen diets. One low-oil DDGS and one traditional DDGS were used in a layer performance and egg quality trial to determine maximum levels of inclusion without detrimental effects. Corn and soybean meal based mash diets, were used with different DDGS samples included at either 10 or 20%. One-hundred-fifty Hy-line W36 laying hens were randomly assigned to ten replicate pens containing three birds each and given diets from 21 to 41 weeks of age. There were no differences in feed intake, egg mass and feed efficiency among treatments (except for egg mass at week 26 – 31). Hen-day egg production was similar among the treatments despite the stress caused on birds due to vitamin deficiencies. Also, no differences were seen in BW, body weight gain (BWG) and egg weight (except BWG at week 21 – 26). There was a significant effect ($P<0.05$) of treatment on specific gravity where birds fed 20% LO-DDGS had decreased values than the birds fed control diet. Yolk color measures were improved with any level of LO-DDGS inclusion. Producers may expect similar performance when including 10% low-oil DDGS in laying hen diets. In addition, yolk color improvement will be seen with any level of LO-DDGS inclusion.

Key words: low-oil DDGS, layer, ethanol, oil extraction

INTRODUCTION

Increased demand for ethanol in United States has led to great amounts of distillers dried grains with solubles (DDGS) available to the poultry and other livestock industries. DDGS has been studied extensively in various poultry diets during the past decade and it has been considered a good choice of an alternative feed ingredient for broiler diets (Lumpkins et al., 2004; Shim et al., 2011).

In the past several years, ethanol producers have considered extracting corn oil from DDGS due to the current high prices of oil. A typical DDGS might have up to 12.55% oil content (Liu, 2010). So, the lipid fraction in DDGS represents a great opportunity for oil production for food or fuel. The oil extracted from DDGS can be used in biodiesel production or as a commodity in different industries (Saunders et al., 2009), so its' value is directly related to crude oil. The left-over product after oil extraction from DDGS is called low-oil DDGS. A low-oil DDGS sample might have as little as 2.1% (dry matter basis) of fat content after the extraction (Ganesan et al., 2009).

There are currently very limited numbers of studies conducted with low-oil DDGS. Some studies have been conducted to determine the effects of low-oil DDGS in swine (Jacela et al., 2011; Anderson et al., 2012; Dahlen et al., 2011). However, no study has been conducted to research low-oil DDGS inclusion in poultry, specifically in laying hen diets. Therefore, the objectives of this study were: 1) to investigate the effects of different levels of low-oil DDGS on layer performance and egg quality measures; 2) to compare the effects of low-oil DDGS inclusion against diets that includes traditional DDGS and industry standard corn-soybean diet; and 3) to determine maximum level of inclusion of low-oil DDGS in laying hen diets without any detrimental effects.

MATERIALS AND METHODS

All procedures concerning animal care and use were approved by the University of Georgia Committee on Laboratory Animal Care. 150 Hyline W-36 White Leghorn pullets were reared according to the breeder's management guide. At 21 weeks of age, pullets were placed in a completely enclosed fan-ventilated building with wire cages and subjected to 16L:8D per day. Ten replicates of three birds were assigned to the five treatments. The treatments were control diet (Corn-SBM), diets containing 2 levels of traditional DDGS (10 and 20%), and 2 levels of LO-DDGS (10 and 20%). The diets were mixed in 2 batches according to the breeder's management guide. First batch was fed from 21 to 33 weeks of age, and second batch was fed from 34 to 41 weeks of age (Table 1). Feed and water were given ad libitum throughout the 20 week period. Both batches were formulated to be isonitrogenous and isocaloric. The diets were also formulated based on digestible amino acid recommendations from breeder management guide, and had the same level of digestible lysine, TSAA, and threonine among the treatments.

Analyses

Eggs were collected each day and egg production was calculated on a hen-day basis. Exterior (shell) quality was tested by specific gravity every 4 weeks with the eggs collected for that day. Every 4 week, yolk color was tested using a Minolta colorimeter. The colorimeter took 3 measurements and averaged them into 3 axis values of L* (lightness), for white and black; a* (redness), representing red and green; and b* (yellowness), representing yellow and blue. Low values for L* indicated a dark color, whereas higher scores indicated a light color (0 = black, 100 = white). Higher values for a* and b* indicated greater degrees of redness and yellowness, respectively. Body weight gain, feed intake, egg weight and feed efficiency were calculated every 5 weeks. When mortality occurred, the hen-day egg production and feed intake were adjusted accordingly.

Statistical Analysis

All data were subjected to analysis of variance procedures using the general linear model procedure (PROC GLM) of SAS® (SAS Institute, 1990). The one-way ANOVA model was

$Y_{ij} = \mu + Trt_i + e_{ij}$

where Y_{ij} is the dependent variable, μ is the overall mean, Trt_i is the treatment effect, and e_{ij} is the observational error for the (ij)th observation. The two-way model was:

$Y_{ijk} = \mu + Source_i + Level_j + Level*source_{ij} + e_{ijk}$

where Y_{ijk} is the dependent variable, μ is the overall mean, $Source_i$ is the effect of DDGS sample, $Level_j$ is the effect of level of DDGS inclusion, $Level*source_{ij}$ is the combined effect of DDGS sample and inclusion level, and e_{ijk} is the observational error for the (ijk)th observation. Differences were considered significant when $P < 0.05$.

RESULTS AND DISCUSSION

The composition of the traditional DDGS and LO-DDGS is presented in Table 2. LO-DDGS had much lower fat content than traditional DDGS (7.52 vs. 12.45%) while dry matter, crude protein, and crude fiber were similar. Gross energy of LO-DDGS was also lower than traditional DDGS (4522 vs. 4858 kcal/kg) because of the difference in fat contents.

Feed intake, egg mass and feed efficiency values were similar among the treatments with the exception of egg mass measured between week 26 and 31 (Table 3). Feed intake between week 31 and 36 was reduced due to the effects of vitamin deficiencies. However, feed intake was increased between week 36 and 41 after the reformulation of diets at week 33. Despite the stress caused due to the vitamin deficiencies, birds fed DDGS did not show any differences in feed intake, egg mass, and feed efficiency compared to the birds fed control diet. The only difference was observed for egg mass between week 26 and 31, where treatment had a significant effect (P<0.05). Egg mass of birds fed 20% LO-DDGS was lower than the egg mass of birds fed control and 10% LO-DDGS. Two-way ANOVA results showed that there was significant effect (P<0.05) of DDGS source and level combined on feed intake (week 26 – 31 and week 21 – 41), egg mass (week 26 – 31 and week 21 – 41) and feed efficiency (week 36 – 41). However, there was no significant effect of either DDGS source or level on any of these measures (Table 4).

Hen-day egg production was similar among the treatments for each of the 5-week periods (Table 5). However, there was a significant effect (P<0.05) of treatment when the overall egg production throughout the 20-week study was calculated. The orthogonal contrast between showed that ????. The vitamin deficiencies affected egg production from week 29 to 33 the most. Since the egg production was calculated every 5 weeks, the same reduction in egg production was seen from week 26 to 36 (Table 5). During the same period, there was also an increase in variation of egg production, which was shown with the larger standard error values. There was a significant effect (P<0.05) of DDGS source and level combined on overall egg production as well as between week 26 and 31 (Table 6).

There was no differences in body weight, body weight gain (BWG), and egg weight among the treatments except BWG between week 21 and 26 (Table 5). Birds fed LO-DDGS gained less weight than birds fed control diet during the first 5-week period of the study. However, no differences among the treatments were observed in overall BWG throughout the study. The BW at week 31 and 36 were very similar where birds hardly gained any weight due to the effects of vitamin deficiencies. The same effect was seen for BWG between week 31 and 36, where values were either zero or close to zero. Interestingly, there was no decrease in egg weight during the weeks effected by vitamin deficiencies. There was a significant effect (P<0.05) of

DDGS source and level combined on BW at week 36 and overall BWG (Table 6). Also, DDGS source had a significant effect (P<0.05) on BWG during the first 5-week period (week 21 – 26). However, no significant effects (Two-way ANOVA) were seen on egg weight values.

Egg specific gravity and yolk color score were significantly (P<0.05) affected by treatment with the exceptions of specific gravity and yellowness (b*) measure at week 37 (Table 7). Birds fed 20% LO-DDGS had a decrease in specific gravity values compared to the birds fed control diet. However, birds fed 10% LO-DDGS showed a decrease in specific gravity at weeks 25, 29 and 33; showed an increase at 37 and 41 compared to the birds fed control diet. There was also significant effect of DDGS source and level combined on specific gravity in each measurement except the ones at week 25 and 37 (Table 8). Egg yolk color parameters were improved when improved with any level of LO-DDGS inclusion compared to the control diet (Table 7). This was also shown in previous literature and the improvement in yolk color was due to the high vitamin content of DDGS???. There was a significant effect (P<0.05) of DDGS level on lightness (L*) score, effect of DDGS source, level, and combined on redness (a*) score, effect of DDGS source and level on yellowness (b*) score on particular weeks (Table 8).

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Table 5.1 Composition of dietary treatments (as fed basis)

	Treatment, 21 to 33 week of age					Treatment, 34 to 41 week of age				
Item	Control	10% DDGS	20% DDGS	10% LO-DDGS[1]	20% LO-DDGS	Control	10% DDGS	20% DDGS	10% LO-DDGS	20% LO-DDGS
Ingredient, %										
Corn	49.53	45.73	41.87	45.13	40.67	57.62	53.65	49.69	53.05	48.49
SBM (48%)	30.52	25.03	19.54	25.15	19.77	24.98	19.53	14.05	19.64	14.28
DDGS	0	10	20	10	20	0	10	20	10	20
Poultry fat	5.51	4.84	4.18	5.33	5.15	4.04	3.41	2.79	3.90	3.75
Limestone	10.85	10.97	11.09	10.99	11.12	10.24	10.36	10.48	10.38	10.52
Dical. Phos	2.58	2.37	2.17	2.39	2.20	2.13	1.92	1.72	1.94	1.75
Salt	0.47	0.43	0.38	0.43	0.38	0.42	0.42	0.42	0.42	0.42
Vitamin Mix[2]	0.03	0.03	0.03	0.03	0.03	0.30	0.30	0.30	0.30	0.30
Mineral Mix[3]	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10
DL-Methionine	0.27	0.27	0.26	0.26	0.25	0.17	0.16	0.15	0.15	0.14
L-Lysine	0.05	0.17	0.29	0.16	0.27	0.00	0.12	0.23	0.10	0.21
L-Threonine	0.04	0.07	0.11	0.06	0.09	0.00	0.00	0.00	0.00	0.00
Calculated Content, %										
M.E, kcal/g	2.89	2.89	2.89	2.89	2.89	2.90	2.90	2.90	2.90	2.90
CP	18.50	18.50	18.50	18.50	18.50	16.32	16.32	16.32	16.32	16.32
Calcium	4.76	4.76	4.76	4.76	4.76	4.42	4.42	4.42	4.42	4.42
Available P	0.60	0.60	0.60	0.60	0.60	0.70	0.70	0.71	0.71	0.72
Lysine	0.96	0.96	0.96	0.96	0.96	0.51	0.51	0.51	0.51	0.51
TSAA	0.80	0.80	0.80	0.80	0.80	0.00	0.00	0.00	0.00	0.00
Threonine	0.67	0.67	0.67	0.67	0.67	0.69	0.68	0.68	0.68	0.68
Analyzed Content, %										
Moisture	12.30	10.43	12.09	11.80	13.04	11.12	10.95	10.38	10.39	10.54
CP	19.76	18.07	21.48	18.64	18.55	15.89	16.29	17.45	16.53	17.09
Crude fat	6.89	7.37	8.87	7.62	7.94	6.25	6.38	6.45	6.41	7.00
CF	2.75	4.30	3.62	2.80	3.32	2.36	2.95	3.32	2.66	2.77
Ash	14.52	17.67	10.26	12.95	12.74	15.65	14.62	65.48	15.64	11.78
Calcium	4.65	6.22	2.63	4.17	3.75	5.13	4.79	4.90	5.14	3.53
Total P	0.91	0.98	0.72	0.79	0.79	0.78	0.76	0.74	0.78	0.67

[1]LO-DDGS = low-oil distillers dried grains with solubles

[2]Vitamin premix provided the following (per kg of diet) : Thiamin·mononitrate, 2.4mg; nicotinic acid, 44mg; D-Ca pantothenate, 12 mg; vitamin B_{12}(cobalamin), 12.0μg; pyridoxine·HCl, 4.7mg; D-biotin, 0.11mg; folic acid, 5.5mg; menadione sodium bisulfate complex, 3.34mg; choline chloride, 220mg; cholecalciferol, 27.5μg; trans-retinyl acetate, 1,892μg; all rac α tocopheryl acetate, 11mg; ethoxyquin, 125mg.

[3]Trace mineral mix provided the following (per kg of diet): manganese ($MnSO_4 \cdot H_2O$), 60mg; iron ($FeSO_4 \cdot 7H_2O$), 30mg; zinc (ZnO), 50 mg; copper ($CuSO_4 \cdot 5H_2O$), 5mg; iodine (ethylene diamine dihydroiodide), 0.15mg; selenium ($NaSeO_3$), 0.3mg.

[4]The diet samples were sent to a laboratory for proximate composition and mineral scan analyses (University of Georgia Agricultural and Environmental Services Laboratories, Athens, GA)

Table 5.2 Composition of traditional DDGS and low-oil DDGS (LO-DDGS), as fed basis

Item	Traditional DDGS,[1]	LO-DDGS,[1]
Analyzed content, %		
GE, kcal/kg	4,858.10	4,522.11
DM	86.49	86.17
CP	27.70	27.84
Crude fat	12.45	7.52
CF	6.05	6.29
Ash	5.63	7.22

[1]The traditional DDGS and LO-DDGS sample for this experiment was sent to a laboratory for proximate composition and mineral scan analyses (University of Georgia Agricultural and Environmental Services Laboratories, Athens, GA)

Table 5.3 Effect of diets with different DDGS samples varying in oil content (%) to laying hens on feed intake, egg mass, and feed efficiency

Variable	P<[1]	Control	10% DDGS	20% DDGS	10% LO-DDGS	20% LO-DDGS
Feed intake, g/d per hen						
Week 21 – 26	0.863	88.60±2.11	90.78±1.33	89.60±2.16	87.90±2.17	88.67±1.59
Week 26 – 31	0.157	90.30±2.28	86.56±2.71	92.70±2.13	89.10±2.64	83.00±4.01
Week 31 – 36	0.808	87.90±1.39	85.56±2.20	87.30±1.75	88.20±2.16	86.11±1.21
Week 36 – 41	0.561	104.30±2.62	100.22±1.34	104.70±1.94	102.70±1.85	102.22±2.15
Week 21 – 41	0.266	92.50±1.20	90.56±0.99	93.30±1.02	92.00±1.30	89.89±1.41
Egg mass,[2] g						
Week 21 – 26	0.170	51.27±0.59	52.76±0.92	52.94±0.68	52.32±0.44	51.14±0.50
Week 26 – 31	0.001	49.82±0.37	46.20±0.78	51.52±0.61	50.23±0.72	44.97±0.64
Week 31 – 36	0.167	51.01±0.44	49.80±0.57	49.80±0.51	51.11±0.49	49.89±0.54
Week 36 – 41	0.633	56.91±0.88	58.22±0.97	57.53±0.59	56.90±0.84	58.16±0.62
Week 21 – 41	0.068	52.25±0.44	51.60±0.70	52.82±0.40	52.59±0.51	50.98±0.30
Feed efficiency,[3]						
Week 21 – 26	0.873	1.73±0.04	1.72±0.04	1.70±0.04	1.68±0.04	1.73±0.04
Week 26 – 31	0.777	1.81±0.05	1.87±0.05	1.80±0.04	1.78±0.05	1.84±0.08
Week 31 – 36	0.979	1.72±0.04	1.72±0.04	1.75±0.04	1.73±0.03	1.73±0.03
Week 36 – 41	0.103	1.83±0.04	1.72±0.02	1.82±0.03	1.80±0.03	1.76±0.03
Week 21 – 41	0.942	1.77±0.02	1.76±0.02	1.77±0.02	1.75±0.02	1.76±0.03

[1]Probability that differences did not occur by chance. Based on one-way ANOVA with 4 degrees of freedom for treatment and 10 replications per treatment
[2]Egg mass = hen-day egg production * egg weight/100.
[3]Feed efficiency = feed intake / egg mass

Table 5.4 Analysis of variance (Two-way ANOVA) for feed intake, egg mass, and feed efficiency

Variable	Two-way ANOVA	Source	Level	Source*level	Error	R^2
	df	1	1	1	43	
Feed Intake						
Week 21 – 26		0.335	0.917	0.622		0.029
Week 26 – 31		0.208	0.994	0.034		0.140
Week 31 – 36		0.688	0.924	0.293		0.036
Week 36 – 41		1.000	0.337	0.236		0.065
Week 21 – 41		0.418	0.794	0.050		0.112
Egg mass,[1] g						
Week 21 – 26		0.090	0.446	0.297		0.136
Week 26 – 31		0.055	0.965	0.001		0.642
Week 31 – 36		0.210	0.278	0.202		0.137
Week 36 – 41		0.665	0.726	0.230		0.057
Week 21 – 41		0.388	0.690	0.006		0.180
Feed efficiency,[2]						
Week 21 – 26		0.915	0.795	0.352		0.028
Week 26 – 31		0.662	0.959	0.221		0.040
Week 31 – 36		0.815	0.686	0.699		0.010
Week 36 – 41		0.797	0.430	0.026		0.161
Week 21 – 41		0.720	0.582	0.979		0.017

[1]Egg mass = hen-day egg production * egg weight/100.
[2]Feed efficiency = feed intake / egg mass

Table 5.5 Effect of diets with different DDGS samples varying in oil content (%) to laying hens on hen-day egg production, BW, body weight gain (BWG), and egg weight

Variable	P<[1]	Control	10% DDGS	20% DDGS	10% LO-DDGS	20% LO-DDGS
Hen-day egg production,[2] %						
Week 21 – 26	0.421	92.67±1.88	94.48±1.30	95.24±1.45	94.10±1.27	91.49±1.45
Week 26 – 31	0.277	82.48±3.15	76.45±3.61	84.67±4.57	84.95±3.59	76.26±3.29
Week 31 – 36	0.982	84.47±3.07	81.38±6.29	81.14±5.30	83.81±4.72	81.38±5.23
Week 36 – 41	0.130	88.10±1.03	91.23±1.14	89.81±1.50	90.76±0.59	92.12±0.92
Week 21 – 41	0.015	86.93±0.72	85.89±0.86	87.72±0.45	88.40±0.50	85.31±0.55
BW,[2] kg						
Week 21	0.802	1.39±0.02	1.37±0.02	1.36±0.02	1.39±0.02	1.38±0.02
Week 26	0.468	1.59±0.02	1.56±0.03	1.58±0.02	1.56±0.02	1.53±0.02
Week 31	0.450	1.63±0.03	1.59±0.03	1.63±0.02	1.62±0.03	1.57±0.03
Week 36	0.155	1.63±0.02	1.60±0.03	1.64±0.02	1.64±0.03	1.56±0.03
Week 41	0.245	1.71±0.03	1.65±0.03	1.72±0.03	1.71±0.03	1.64±0.04
BWG,[2] kg						
Week 21 – 26	0.033	0.20±0.02	0.18±0.01	0.21±0.01	0.17±0.01	0.15±0.01
Week 26 – 31	0.877	0.04±0.02	0.03±0.02	0.06±0.02	0.06±0.02	0.06±0.04
Week 31 – 36	0.745	0.00±0.02	0.01±0.02	0.01±0.02	0.02±0.01	-0.01±0.01
Week 36 – 41	0.376	0.09±0.01	0.06±0.01	0.07±0.01	0.07±0.01	0.08±0.01
Average	0.063	0.08±0.01	0.07±0.01	0.09±0.01	0.08±0.01	0.06±0.01
Egg weight,[3] g						
Week 26	0.888	55.07±0.64	55.56±0.71	55.71±0.62	55.22±0.53	55.81±0.47
Week 31	0.688	58.20±0.58	57.38±0.79	57.86±0.62	57.78±0.70	56.88±0.70
Week 36	0.561	61.68±0.57	62.77±0.86	62.37±0.65	61.43±0.67	62.49±0.50
Week 41	0.667	64.18±0.88	63.93±0.78	64.09±0.68	62.75±0.78	63.63±0.56
Average	0.780	59.49±0.56	60.03±0.66	59.79±0.49	59.09±0.53	59.64±0.39

[1]Probability that differences did not occur by chance. Based on one-way ANOVA with 4 degrees of freedom for treatment and 10 replications per treatment
[2]Means represent 10 replications per treatment (3 hens per replication)
[3]Means represent 10 replications per treatment (3 eggs per replication)

Table 5.6 Analysis of variance (Two-way ANOVA) for hen-day egg production, BW, body weight gain (BWG), and egg weight

Variable	Two-way ANOVA	Source	Level	Source*level	Error	R^2
	df	1	1	1	20	
Hen-day egg production,[1] %						
Week 21 – 26		0.180	0.542	0.272		0.169
Week 26 – 31		0.991	0.948	0.032		0.216
Week 31 – 36		0.794	0.794	0.830		0.019
Week 36 – 41		0.405	0.977	0.213		0.288
Week 21 – 41		0.930	0.330	0.001		0.447
	df	1	1	1	143	
BW,[1] kg						
Week 21		0.398	0.513	0.987		0.011
Week 26		0.346	0.746	0.259		0.024
Week 31		0.554	0.867	0.103		0.025
Week 36		0.441	0.478	0.021		0.045
Week 41		0.698	0.867	0.038		0.037
BWG,[1] kg						
Week 21 – 26		0.010	0.725	0.081		0.070
Week 26 – 31		0.893	0.942	0.279		0.008
Week 31 – 36		0.873	0.389	0.367		0.013
Week 36 – 41		0.477	0.213	0.749		0.029
Week 21 – 41		0.218	0.794	0.008		0.060
Egg weight,[2] g						
Week 26		0.845	0.532	0.713		0.008
Week 31		0.669	0.757	0.309		0.017
Week 36		0.360	0.616	0.273		0.022
Week 41		0.271	0.483	0.625		0.019
Average		0.310	0.769	0.457		0.012

[1]Means represent 10 replications per treatment (3 hens per replication)
[2]Means represent 10 replications per treatment (3 eggs per replication)

Table 5.7 Effect of diets with different DDGS samples varying in oil content (%) to laying hens on egg specific gravity, and yolk color measures (lightness, redness, and yellowness)

Variable	P<[1]	Control	10% DDGS	20% DDGS	10% LO-DDGS	20% LO-DDGS
Specific gravity[2]						
Week 25	0.001	1.0917±0.0011	1.0862±0.0008	1.0870±0.0012	1.0878±0.0012	1.0852±0.0013
Week 29	0.001	1.0859±0.0013	1.0788±0.0012	1.0840±0.0012	1.0823±0.0015	1.0793±0.0014
Week 33	0.034	1.0817±0.0014	1.0759±0.0019	1.0788±0.0015	1.0781±0.0014	1.0752±0.0017
Week 37	0.868	1.0888±0.0007	1.0894±0.0008	1.0888±0.0007	1.0892±0.0008	1.0882±0.0010
Week 41	0.027	1.0852±0.0009	1.0850±0.0007	1.0863±0.0010	1.0860±0.0008	1.0827±0.0008
Average	0.001	1.0869±0.0008	1.0836±0.0006	1.0851±0.0006	1.0847±0.0007	1.0822±0.0006
Color score[2,3]						
Lightness (L*)						
Week 25	0.001	57.46±0.36	56.21±0.40	55.14±0.34	56.09±0.36	55.74±0.41
Week 29	0.001	59.33±0.31	58.69±0.47	57.76±0.23	57.78±0.35	57.05±0.39
Week 33	0.006	58.09±0.49	57.73±0.52	56.59±0.47	56.82±0.45	55.84±0.41
Week 37	0.001	61.09±0.28	59.68±0.34	58.84±0.36	59.68±0.23	59.19±0.25
Week 41	0.001	56.90±0.33	56.54±0.26	55.17±0.28	56.25±0.20	55.19±0.26
Average	0.001	58.57±0.24	57.67±0.27	56.74±0.18	57.31±0.22	56.55±0.22
Redness (a*)						
Week 25	0.001	-3.72±0.09	-2.90±0.11	-1.82±0.14	-3.22±0.11	-2.45±0.15
Week 29	0.001	-4.53±0.10	-3.99±0.19	-2.44±0.14	-3.65±0.13	-3.07±0.15
Week 33	0.001	-5.20±0.19	-4.62±0.20	-3.32±0.21	-4.47±0.20	-3.54±0.19
Week 37	0.001	-2.59±0.12	-1.27±0.17	-0.18±0.11	-1.77±0.09	-0.92±0.12
Week 41	0.001	-5.47±0.09	-4.51±0.14	-3.16±0.09	-4.49±0.19	-3.63±0.10
Average	0.001	-4.27±0.07	-3.44±0.11	-2.11±0.08	-3.53±0.10	-2.74±0.09
Yellowness (b*)						
Week 25	0.001	39.96±0.91	43.02±0.79	44.05±0.68	41.67±0.53	42.86±0.62
Week 29	0.001	39.46±0.70	43.46±0.75	44.59±0.55	42.67±0.41	44.14±0.62
Week 33	0.001	40.21±0.66	44.69±0.69	47.07±0.93	42.42±1.08	46.45±0.56
Week 37	0.300	46.66±0.64	47.46±0.82	48.76±0.91	47.02±0.51	47.92±0.81
Week 41	0.001	46.01±0.48	48.65±0.57	48.50±0.44	47.60±0.51	47.13±0.40
Average	0.001	42.36±0.35	45.34±0.43	46.47±0.42	44.17±0.35	45.54±0.30

[1]Probability that differences did not occur by chance. Based on one-way ANOVA with 4 degrees of freedom for treatment and 10 replications per treatment

[2]Means represent 10 replications per treatment (3 eggs per replication)

[3]Measured using a Minolta colorimeter (Minolta Corporation, Ramsey, NJ). Higher values for a* and b* indicate a greater degrees of redness and yellowness, respectively; L*= lightness of egg yolk, where
0 = black to 100 = white.

Table 5.8 Analysis of variance (Two-way ANOVA) for egg specific gravity, and yolk color measures (lightness, redness, and yellowness)

Variable	Two-way ANOVA	Source	Level	Source*level	Error	R^2
	df	1	1	1	143	
Specific gravity[1]						
Week 25		0.929	0.410	0.129		0.120
Week 29		0.653	0.423	0.003		0.136
Week 33		0.666	0.989	0.077		0.083
Week 37		0.643	0.321	0.797		0.010
Week 41		0.120	0.249	0.007		0.084
Average		0.175	0.454	0.002		0.169
Color score[1,2]						
Lightness (L*)						
Week 25		0.524	0.060	0.339		0.128
Week 29		0.023	0.021	0.789		0.165
Week 33		0.081	0.027	0.869		0.113
Week 37		0.563	0.029	0.558		0.213
Week 41		0.620	0.001	0.554		0.212
Average		0.221	0.001	0.704		0.262
Redness (a*)						
Week 25		0.001	0.001	0.195		0.501
Week 29		0.324	0.001	0.001		0.510
Week 33		0.859	0.001	0.346		0.348
Week 37		0.001	0.001	0.332		0.640
Week 41		0.090	0.001	0.067		0.594
Average		0.001	0.001	0.004		0.698
Yellowness (b*)						
Week 25		0.081	0.126	0.914		0.118
Week 29		0.326	0.040	0.783		0.261
Week 33		0.080	0.001	0.315		0.300
Week 37		0.405	0.151	0.794		0.037
Week 41		0.014	0.524	0.747		0.135
Average		0.006	0.001	0.748		0.337

[1]Means represent 10 replications per treatment (3 eggs per replication)

[2]Measured using a Minolta colorimeter (Minolta Corporation, Ramsey, NJ). Higher values for a* and b* indicate a greater degrees of redness and yellowness, respectively; L*= lightness of egg yolk, where 0 = black to 100 = white.