NUTRITIONAL VALUE AND USE OF DISTILLER'S DRIED GRAINS WITH SOLUBLES IN THE FEEDING OF POULTRY

by

BRETT STEPHEN LUMPKINS

(under the direction of Amy B. Batal)

ABSTRACT

Recently, policies encouraging the production of fuel ethanol have resulted in an enormous increase in the production of "new generation" distiller's dried grains with solubles (NG-DDGS). "New generation" distiller's dried grains with solubles refers to DDGS from modern non-beverage fuel ethanol plants, which exclusively use corn in the fermentation process. The present studies were conducted to evaluate the use of NG-DDGS in poultry diets and to determine the lysine and phosphorus bioavailability of NG-DDGS. Based on the data, 6% NG-DDGS can safely be used in starter broiler diets, and can be increased to a 12% level during the grower and finisher periods. Six to 8% NG-DDGS can be fed in layer diets during peak production, and once body weight and feed intake have stabilized the NG-DDGS level can be increased to 10 or 12%. The lysine and phosphorus availability of NG- DDGS was estimated to be 80% and 61%, respectively.

INDEX WORDS: distiller's dried grains with solubles, broilers, laying hens, lysine, phosphorus, bioavailability

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Brett Stephen Lumpkins

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Brett Stephen Lumpkins

Major Professor: Amy B. Batal

Committee: Nick M. Dale
Adam J. Davis

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
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TABLE OF CONTENTS

Page

INTRODUCTION

Distiller's dried grains with solubles (DDGS) is the material recovered after the condensing and drying of stillage from dry mill ethanol production. For the production of ethanol several cereal grains can be used in the fermentative process to produce alcohol for human consumption or as a fuel source. Since the 1930's, the majority of DDGS available has come from the beverage industry and consisted of a variety of grains. However, by the mid 1990's the majority of DDGS being supplied to feed producers was coming from the production of fuel ethanol. The modern fuel ethanol plants mainly use corn as the substrate for fermentation, which differs from the variety of grains used for fermentation by the beverage industry. The DDGS from modern fuel ethanol plants also undergoes a drying process at a lower temperature than DDGS from the beverage industry. Thus, the by-product from these modern fuel ethanol plants has been referred to as "new generation" DDGS (NG-DDGS) or corn DDGS.

Distiller's dried grains with solubles is by no means a new feed ingredient. In the late 1930's D'Ercole (1939) reported that DDGS contained "unidentified growth factors," which led to extensive research on the use of DDGS in poultry diets. Due to its "unidentified growth factors" and low cost, DDGS became a common feed ingredient in livestock and poultry diets. However, by the early 1980's the interest in feeding DDGS began to fade as this feed ingredient became more expensive and provided no economical benefit (Reilly, 1979). The decreased interest in feeding DDGS in poultry diets may have also been due to the ease of using wet distiller's grains instead of DDGS as a feed ingredient for ruminants and the inconsistent nutrient

composition of DDGS. Therefore, DDGS slowly disappeared from poultry diets, and was instead incorporated into pet food diets.

Recently, the United States government has placed a major emphasis on the production of fuel ethanol. Ethanol producers responded by increasing fuel ethanol output and building new fuel ethanol plants, which resulted in an enormous increase in the production of DDGS. In 2002, it was estimated that approximately 2 to 3 million metric tons of DDGS were produced in North America (Shurson, 2003), and it is predicted that in the year 2005 there will be any where from 5 to 7 million metric tons produced. The massive volume of DDGS available, combined with the possibility of an economical benefit has sparked an interest with nutritionists and feed producers to reintroduced DDGS into poultry diets.

The majority of research reported has been conducted using DDGS from the beverage industry, which can be an inconsistent product mainly due to the variety of grains used in the fermentation process. A limited amount of research on the nutrient composition and feeding of NG-DDGS in poultry diets is available. The poultry industry has also changed dramatically due to the advances in genetics, nutrition, and management from when much of the early research with DDGS was conducted (Sloan, 1941; Matterson, 1949; Scott, 1951; Couch, 1962; Combs and Bossard, 1968). Thus, the objective of the research conducted herein was to examine the effects of feeding NG-DDGS in broiler and laying hen diets, and to determine the lysine and phosphorus bioavailability of NG-DDGS.

LITERATURE REVIEW

Distiller's Dried Grains with Solubles

Distiller's dried grains with solubles (DDGS) is a by-product of dry mill ethanol production. Before the 1990's a majority of the DDGS available to feed producers came from the beverage industry which uses various grains such as wheat, barley, and hops for the fermentation of alcohol. However, a sharp peak in the production of non-beverage ethanol has recently taken place in the United States and approximately 98% of the DDGS in North America comes from plants that produce ethanol for oxygenated fuel (Shurson, 2003). Modern non-beverage ethanol plants mainly use corn for the fermentation of ethanol, and the DDGS is dried under a less severe temperature than what was used in previous decades. During the production of ethanol 3 equal products are formed: 1) ethanol, 2) carbon dioxide, and 3) DDGS (Reilly, 1979). The recovered DDGS contains all the nutrients from corn or the other cereal grains used in the fermentation process minus the starch, which is utilized during the fermentation process. The nutrient content of DDGS is concentrated approximately three fold over that of corn or other cereal grains as a result of ethanol production. The distillers dried grains with solubles produced from the modern non-beverage ethanol plants that solely use corn during the fermentation process will be referred to as "new generation" DDGS (NG-DDGS). Unless otherwise specified it will be assumed that the research cited used DDGS or distillery by-products from the beverage industry, in which a variety of grains could have been used during the fermentation process.

Production of DDGS - Corn Dry Milling

Recently, the United States has placed a major emphasis on increasing non-beverage ethanol production. The government's reasoning for this increase in fuel ethanol production is due mainly to the fact that ethanol burns cleaner and supplies more energy than crude oil (Reilly, 1979). Due to this emphasis the production of non-beverage ethanol has climbed to over 2 million gallons per year, and additional modern fuel ethanol producing plants are currently being built which will further increase production. These policies encouraging the production of fuel ethanol have resulted in an enormous increase in the production of NG-DDGS. Currently in North America, there are approximately 3 million metric tons of DDGS available to feed producers (Shurson, 2003) and by the year 2005 it is estimated that there will be 5 to 7 million metric tons available.

The corn or cereal grain used for fermentation can undergo dry or wet milling to produce fuel ethanol. However, the two procedures differ in steps and by-products produced. The dry milling process produces DDGS, and wet milling produces corn gluten feed, corn gluten meal, corn fermentation solubles (CFS) and corn germ meal. Dry milling produces 40% of the fuel ethanol, and wet milling produces 60% of the fuel ethanol available. The following is a step by step procedure of the dry milling process of ethanol and DDGS production (refer to Figure 1.1). The initial step in the procedure is the harvesting of corn. Once the corn is harvested, the hull is removed, and then ground by a hammer mill, which exposes the starch and increases the surface area for enzymatic digestion and other fermentative processes. The ground corn is mixed with alpha amylase, the first enzyme in the fermentative process, for the initiation of hydrolysis of cornstarch to dextrin. This mixture is then placed in a cooker where lactic acid producing bacteria is killed. After cooking, the mixture is then introduced with yeast and glucoamylase and

transported to a fermentation tank where the mixture stays for approximately 40 to 50 h. The fermentation tank is where the ethanol, carbon dioxide and distillery products are produced. A distillation process occurs, which results in the separation of the ethanol from the distillery by-products. The wet by-product, whole stillage, is centrifuge to pull off the liquid fraction, leaving behind coarse solids. The liquid fraction is placed in an evaporator to produce distillers dried solubles (DDS). The coarse solids can be left alone and considered distillers wet grains or placed in a rotary dryer to produce distillers dried grains (DDG). The distiller's wet grains can also be combined with DDS and then put through a rotary dryer to produce distiller's dried grains with solubles (DDGS). The overall output of each product per bushel of corn is 2.7 gal of ethanol, 18 lbs of DDGS, and 18 lbs of carbon dioxide.

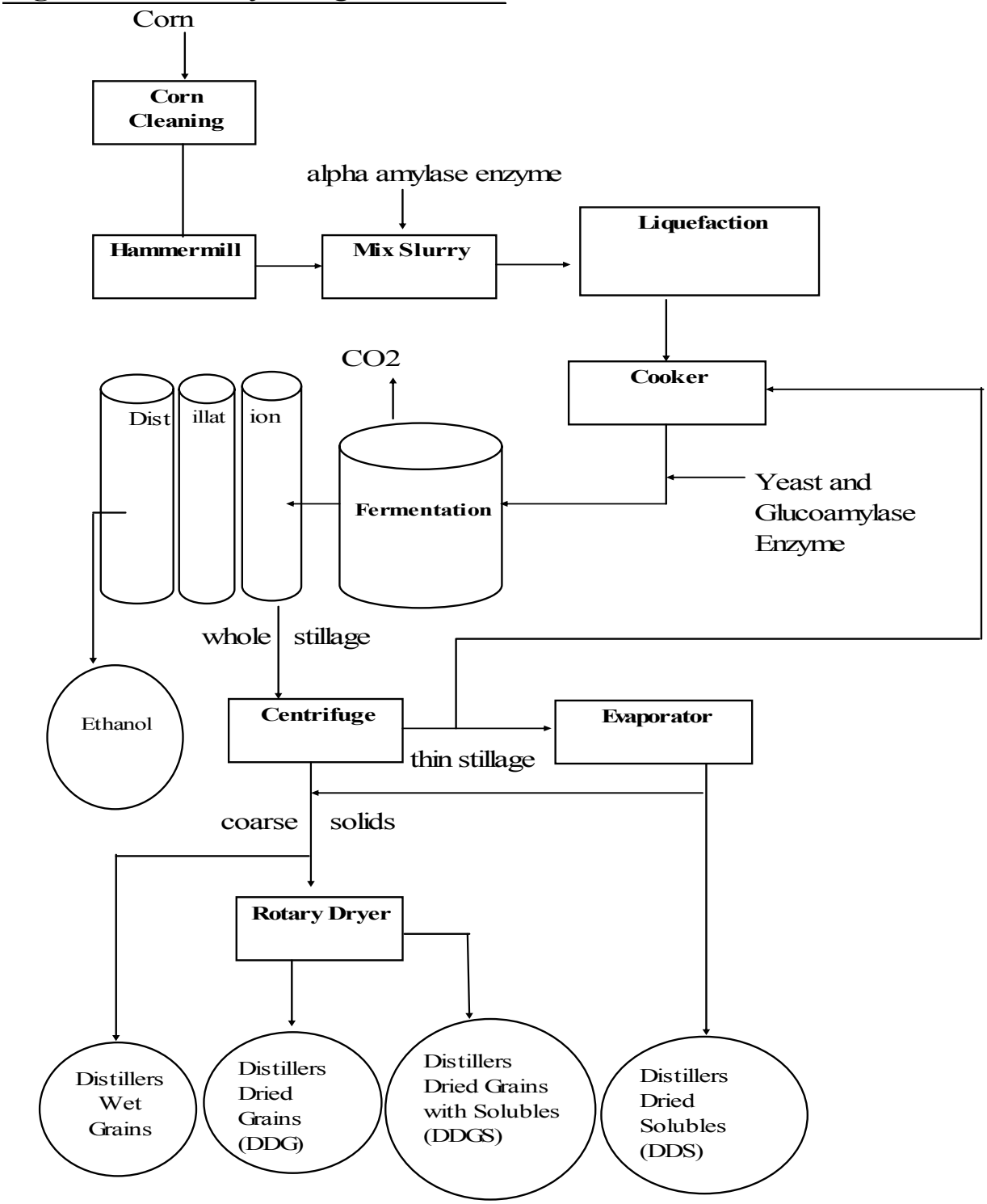
Composition of distiller's dried grains with solubles

The nutrient concentration of NG-DDGS has an approximate three fold increase over corn in all nutrients except for carbohydrates, which are consumed in the fermentation process. The following sections will provide an in-depth description of previous and current findings pertaining to DDGS' composition.

Amino Acid Composition, Availability and Digestibility

The crude protein level in old and NG-DDGS is greatly improved over the value for corn. Distiller's dried grains with solubles is estimated to be approximately 28% crude protein, while corn is recorded to have 8.5% crude protein (NRC, 1994). The elevated protein level in DDGS allows for the replacement of some soybean meal or other protein sources when DDGS is included in poultry diets.

Figure 1.1. Corn Dry Milling Overview



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The first limiting amino acid (AA) in corn is lysine, and since NG-DDGS is a by-product of corn fermentation, it stands to reason that lysine is the first limiting AA in DDGS. Hughes and Hauge (1945) experimented with rats and determined DDGS to be deficient in lysine and tryptophan, and Scott (1970) and Parsons et al. (1983) confirmed that lysine is the first limiting AA in DDGS.

Reported amino acid concentrations of DDGS are presented in Table 1.1. The variation in AA concentration between old and NG-DDGS is considerable. The AA concentrations of the NG-DDGS are generally higher for some of the essential AA, such as methionine, lysine, cysteine, tryptophan, and arginine as compared to the reported values for DDGS from the beverage industry.

Table 1.1. Amino Acid composition of distiller's dried grains with solubles

Amino Acids	Parsons et al. (1983)	NRC (1994)	Batal and Dale (unpublished data) "New generation" DDGS
	----------(%)----------		
Aspartic acid	2.10	---	1.73
Threonine	1.12	0.92	1.05
Serinie	1.57	1.61	1.14
Proline	1.58	---	1.86
Alanine	2.16	---	1.86
Cysteine	---	0.40	0.62
Valine	1.34	1.30	1.44
Methionine	0.44	0.60	0.56
Isoleucine	0.99	1.00	1.03
Leucine	3.78	2.20	3.10
Tyrosine	0.94	0.74	1.05
Phenylalanine	1.36	1.20	1.34
Histidine	0.72	0.66	0.74
Lysine	0.72	0.75	0.85
Arginine	0.98	0.98	1.25
Tryptophan	---	0.19	0.28

The color of NG-DDGS is often used as a quick guide to indicate the AA availability of this product (Cromwell et al., 1993; Ergul et al., 2003; Noll et al., 2003). The drying process, which DDGS undergoes, is thought to have an adverse affect on AA availability. Cromwell et al. (1993) reported that darker DDGS samples were usually a result of excessive heating during the drying procedure. It has been reported that excessive heating leads to a decrease in the AA availability of DDGS, specifically Lys digestibility (McGinnis and Evans, 1947; Warnick and Anderson, 1968), which is similar to the findings with soybean meal (Fernandez and Parson, 1996). Thus, it is assumed that darker DDGS samples have reduced AA availability. Little research has been conducted to determine the availability of the other AA besides lysine in DDGS. There is a heavy emphasis on lysine since it is the first limiting AA in DDGS and is the second limiting AA in a standard corn-soybean meal poultry diet.

One of the earliest procedures used for determining the bioavailability of an AA was a chick growth assay. A chick growth assay was originally described by Runnels (1966) and then further modified by Combs et al. (1968) and Combs and Bossard (1968). In a chick growth assay a basal diet is formulated that is deficient in the AA being tested. The basal diet is then supplemented with increasing levels of a synthetic source of the AA to give a known concentration and availability of the AA. As the levels of the synthetic AA are increased there should be an increase in growth performance producing a desired standard growth curve. The test growth curve is created through the incorporation of the test ingredient at graded levels to the basal diet, and any improvement in a selected parameter (i.e. body weight gain or feed efficiency) should only be due to the test ingredient supplying the limiting AA. The slope of the test growth curve is divided by the slope of the standard growth curve to estimate bioavailability.

The estimated bioavailability value is then divided by the total concentration of the AA in the test feed ingredient to determine an availability estimate.

Combs and Bossard (1969) performed a chick growth assay and determined that DDGS has a lysine availability ranging from 74 to 90%. Using similar methodology, Parson et al. (1983) estimated the lysine bioavailability of DDGS to be 66%. A recent study by Ergul et al. (2003) reported a lysine bioavailability of 71% for NG-DDGS.

Estimating the true digestibility of a feed ingredient is a much quicker method than conducting a chick growth assay to determine the AA availability of an ingredient. The common procedure described by Likuski and Dorrell (1978) and Sibbald (1986) was based on a total fecal collection after feeding a known amount of the tested feed ingredient. In this process, cecectomized roosters are allowed *ad libitium* access to feed and water prior to the true digestibility experiment. Then all the birds are fasted for a 24 h period and approximately five cecectomized roosters are crop intubated with a fixed amount (usually 30 to 35 g) of a test ingredient. Additional roosters are fasted throughout the experimental period allowing for the measuring of endogenous AA excretion. Excreta is collected quantitatively for 48 h post feeding. The feed and dried excreta samples are tested for AA concentration. Parsons et al. (1983) was the first to use this method to determine the true digestibility of several AA in DDGS (Table 1.2). The estimated lysine digestibility of DDGS was 82%, which was the lowest compared to the other determined AA digestibility values. These AA digestibility values were the only reported true digestibility values for DDGS, until Batal and Dale (2004) recently reported the AA digestibility values for NG-DDGS (Table 1.2). Ergul et al. (2003) determined lysine digestibility values from different samples of NG-DDGS, and reported a lower lysine digestibility average of 65%.

Table 1.2. True digestibility of several amino acids of distiller's dried grains with solubles

Amino Acids	Parsons et al. (1983)	Batal and Dale (2004) "New generation" DDGS
Lysine	82	75
Threonine	84	76
Alanine	88	85
Valine	86	83
Methionine	95	89
Isoleucine	89	83
Leucine	91	86
Phenylalanine	90	89
Arginine	90	84

Energy

The fermentation process during ethanol production is credited for concentrating the nutrients in DDGS and making them approximately three times greater than the levels of corn. However, the carbohydrate value of DDGS is decreased because the starch in the corn is consumed during fermentation. The metabolizable energy value of DDGS is lower than that of corn due to the decrease in carbohydrates and the dilution from the increase in crude fiber content of DDGS by approximately 4 to 6%. Research to determine the metabolizable energy value of DDGS is limited. The true metabolizable energy (TME_n) value of NG-DDGS was tested with conventional roosters using the total fecal collection procedure (Sibbald, 1976, 1979; Ostrowski-Meissner, 1984). The TME_n value for DDGS has been reported at 2,480 kcal ME_n/kg in the NRC (1994) and 2,755 kcal ME_n/kg by Dale and Batal (2003), which are lower than the recently estimated TME_n value of 2,830 kcal/kg for NG-DDGS (Batal and Dale, 2004). The intermediate energy value of NG-DDGS to corn and soybean meal allows small quantities of

corn (3,350 kcal ME_n/kg) and soybean meal (2,230 kcal ME_n/kg) to be replaced by NG-DDGS in poultry diets.

Vitamins

Research in the late 1930's opened the door to the thought that DDGS possessed "unidentified growth factors." Researchers believed that DDGS contained unknown vitamins needed for optimal poultry performance. Extensive research was conducted to identify the composition of DDGS. Much of this research was conducted prior to the use of vitamin premixes making the vitamins supplemented by feed ingredients an integral part of feed formulation. Researchers observed that when DDGS was supplemented to a vitamin deficient diet there was a significant improvement in growth performance, but the vitamins responsible for the improvement in performance could not be identified (Schumacher et al., 1940; Hill et al., 1944). Much of the research in attempting to identify the vitamin composition of DDGS was done mainly with the DDS fraction, where most of the vitamins are contained. Additional research demonstrated that DDS could be used as a vitamin supplement when incorporated into chick diets and could replace dried skimmilk in some of the broiler starter diets allowing for a diet to be composed of non- animal products (Marvel et al., 1944, 1945a, 1945b, and 1945c).

Many researchers identified possible vitamins that were believed to be the cause of the "unidentified growth factors," but it took some time before a full list could be compiled. The earliest research demonstrated that DDGS contained a source of vitamin B_1 and what was deemed as vitamin G, which today refers to a B vitamin that prevents skin lesions and weight loss (D'Ercole et al., 1939). It was reported that DDGS was an adequate source of riboflavin and thiamine, and could be used to replace riboflavin supplements as well as some of the protein source in broiler starter and laying hen diets (D'Ercole et al., 1939; Shea et al., 1941; Dickens et

al., 1941; Parkhurst et al., 1942, 1945; and Nelson et al., 1944). In a series of experiments conducted by various researchers, it was confirmed that the DDGS provided an adequate source of several B complex vitamins (Sloan, 1941; Shea et al., 1941; Halpin et al. 1942; Nelson et al. 1944). However, Novak et al. (1947) later determined that DDGS contained a vitamin that was not similar to any of the known B vitamins, and it was later determined that the unknown factor was vitamin B_{13} also know as orotic acid (Novak and Hauge, 1948; Austin and Boruff, 1949). Further research allowed for the determination that when distillers dried solubles was incorporated at a level of 2.5% it was a good source of vitamins except for vitamin B_{12} (Matterson, 1949 and 1950), which is only found in animal products.

The diets in the 1940's usually consisted of an animal protein factor (APF), whether it be meat scraps or dried skimmilk, as a way of supplying additional nutrients (vitamin B_{12}) that could not be found in cereal grains. Researchers conducted experiments in an attempt to completely replace APF with DDS or DDGS, and observed a decrease in growth rate (Couch et al., 1951; Schlamb and Winter, 1948; Sloan, 1941; Shea et al., 1941). Researchers were still determined to formulate a diet that would replace APF with DDS and not cause a decrease in growth rate. Marvel et al. (1945c) and Cline et al. (1947) reported that it is possible to obtain improved growth when feeding 5% DDS with out APF, as long as the diet was supplemented with riboflavin, pantothenic acid, niacin, and choline. It was possible to formulate a diet containing DDS and no APF, but it was not economically feasible for feed producers. Matterson (1950) experimented with the combination of DDS and APF and reported that an adequate amount of vitamins would be supplied to chickens by using APF in combination with a 2% level of corn DDS.

The vitamin composition of DDGS and DDS is recorded in the NRC (1994) (Table 1.3) and Feedstuffs annual reference issue (Dale and Batal, 2003). Similar to the other nutrient components of DDGS variation exists between reported vitamin concentrations.

Table 1.3. Vitamin composition of distiller's dried grains with solubles and distiller's dried solubles (NRC, 1994)

Vitamins	DDGS	DDS
Pyridoxine (mg/kg)	2.2	10.0
Vitamin E (mg/kg)	40.0	55.0
Thiamin (mg/kg)	2.9	6.9
Riboflavin (mg/kg)	8.6	17.0
Pantothenic acid (mg/kg)	11.0	21.0
Biotin (µg/kg)	780.0	1100.0
Folic acid (µg/kg)	900.0	1100.0
Choline (mg/kg)	2637.0	4842.0
Niacin (mg/kg)	71.0	116.0

Minerals

In addition to the vitamins contained in DDGS or DDS, it was also believed that the mineral content of these feed ingredients may be responsible for the "unidentified growth factors" (Norris, 1955 and Couch et al., 1955). The "unidentified growth factor" of DDGS was not associated with the mineral content during the early research in the 1940's due to the emphasis on vitamins, but in the 1950's this view changed and the mineral content of DDS and DDGS was examined. Morrison et al. (1955) recognized that various minerals provided by DDGS were also responsible in part for the unexplained chick growth. The authors observed an improvement in chick growth when the diets were incorporated with the ash of five "unidentified growth factor" supplements including distillers dried solubles. Researchers began trying to identify the specific minerals in DDGS that resulted in the improved chick performance. O'Dell and Savage (1957) observed that the addition of zinc produced a growth response similar to that of DDS in poultry diets. Distillers dried solubles was also thought to contain molybdenum due

to the similar growth improvements that were observed with the supplementation of molybdenum instead of DDGS (Kurnick et al., 1957; Reid et al., 1956). The interest in the minerals contained in DDS slowly began to dwindle due to reports stating that natural feedstuffs would supply sufficient amounts of trace minerals (Mehring et al., 1956; Norris et al. 1958; and Scott, 1958), and with the development and use of trace mineral premixes. The mineral composition of DDGS is listed in Table 1.4 and contains values from two sources of NG-DDGS as well as reported values (NRC, 1994). The differences in composition between Batal and Dale (2003) and the University of Minnesota (2003) are likely due to the variation between modern ethanol plants.

Table 1.4. Mineral composition of distiller's dried grains with solubles

		"New generation" distiller's dried grains with solubles	
Minerals	NRC (1994)	University of Minnesota (2003)	Batal and Dale (2003)
	----------(%)----------		
Sodium	0.48	0.13	0.25
Potassium	0.65	1.03	0.91
Phosphorous	0.72	0.78	0.68
Calcium	0.17	0.07	0.29
Magnesium	0.19	0.32	0.28
Sulfur	0.30	0.66	0.84
	----------(ppm)----------		
Manganese	24	20	22
Iron	280	120	149
Aluminum	---	---	56
Copper	57	6	10
Zinc	80	67	61

The sodium value reported in the NRC (1994) for DDGS is much higher than that reported by Batal and Dale (2003) and the University of Minnesota (2003), and is more than

three times higher than the sodium value of corn (0.02%). The high sodium value reported in the NRC (1994) for DDGS is unclear, considering that no sodium is added during the fermentation process. It is believed that the high levels of sodium may be due to the residue of the products that are used to clean the fermenting tanks.

Phosphorus (P) utilization has recently become the main focal point of many animal nutritionists due to the high levels of P pollution being found in the environment (Ryden et al., 1973; Simons et al., 1990; DeLaune et al., 2001; Applegate et al., 2003; Dhandu and Angel, 2003). Many common feed ingredients in poultry diets have a low P availability due to high contents of phytin P. The phytin P in these feed ingredients binds to P making it unavailable to the animal. Before P was an environmental issue, Singsen (1948) performed a chemical analysis of DDGS and reported that it contained no phytin P. The fermentation is believed to produce phytase, which breaks up phytate making the P more available. Singsen et al. (1962) conducted a biological availability study and reported that the P in DDGS was 100% available. However, Amezcua et al. (2003) reported that the average P bioavailability of NG-DDGS was about 54%, which is better than that of corn, but is not the 100% reported in earlier research. As stated previously, the availability of AA in DDGS could be assessed based on the color of the DDGS, interestingly the same can be assumed for mineral availability. It has been suggested that the darker the DDGS sample the more available the P is in NG-DDGS (Amezcua et al., 2003; Ergul al., 2003; Noll et al. 2003). The fermentation allows for the production of phytase, which is used to break up phytate P.

Distiller's Dried Grains with Solubles in Non-Ruminant Diets

The research pertaining to the use of distillery by-products in poultry diets is very old and the majority was conducted with DDS and not DDGS. There is limited amount of research

available today pertaining to the use of NG-DDGS in non- ruminant diets. Insko et al. (1937) observed that 80% of the corn in a poultry diet could be replaced with the thick syrup produced from the fermentation of such grains as wheat, sorghum, and barley and this introduced the idea of using distiller's by-products as a feed ingredient. The first record of the actual use of distiller's dried grains in poultry diets was by Allman and Branion (1938) who demonstrated that the feed ingredient was economical and improved chick performance and feathering, when compared to a diet containing 5% alfalfa, fish meal, and buttermilk. D'Ercole (1939) mixed DDS with DDG to produce distiller's dried grains with solubles (DDGS) and reported that DDGS incorporated into a standard broiler diet would provide adequate nutrients to support optimal growth performance.

Laying Hens

1. Egg Production

Egg production is one of the most important parameters when evaluating laying hen performance. Thus, the effect of a feed ingredient on egg production is vital. Matterson et al. (1966) fed 10 and 20% DDGS in a 1962 New England College Conference laying hen diet, which consisted of corn, wheat middlings, and soybean meal to 35 Leghorns for a 40 wk period. It was reported that DDGS could compromise approximately 1/3 of the laying hen diet without any negative effects on egg production. Harms et al. (1969) conducted an experiment to evaluate the incorporation of 10% DDGS with graded levels of methionine supplemented in a corn-soybean meal laying hen diet. Ten experimental diets were formulated and fed to 28 wk old Hy-Line 934-H pullets for 280 d. The incorporation of 10% DDGS did not effect egg production regardless of the level of methionine supplemented. Jensen (1973) experimented with DDGS incorporated at 2.5, 5, and 10% into a wheat-soybean meal laying hen diet, which was fed to 24

wk old White Leghorns for ten 28 d periods. No difference in egg production was reported when 2.5 and 5% DDGS was incorporated into the wheat-soybean meal diet. However, when feeding a level of 10% DDGS there was a decrease in egg production and it was believed that this decrease was due to a lysine deficiency. Jensen (1973) suggests that when levels of 10% DDGS or greater were incorporated into laying hen diets, L-lysine should be supplemented. Roberson et al. (2004) conducted the most recent research feeding NG-DDGS at levels of 5, 10, and 15% in a corn-soybean meal laying diet to Hy-Line W36 laying hens from 47 to 67 wk of age. During post-peak production, no differences in egg production were observed at any of the NG-DDGS inclusion levels tested.

2. Egg Weights

Research has shown that the linoleic acid contained in vegetable oils is a factor in increasing egg weights (Jensen et al., 1957; Hopkins and Nesheim, 1962; Shutze and Jensen, 1963). The distiller's dried solubles from corn fermentation were observed to be a good source of linoleic acid compared to other poultry feedstuffs common at the time (Scott, 1965). Scott (1965) conducted an experiment to test the effects of incorporating 2.5 to 5% corn based DDS on body growth and egg size of hens fed an isocaloric and isonitrogenous corn-soybean meal laying hen diet. The incorporation of corn DDS at 2.5 and 5% level resulted in an increase in egg size and improved feed efficiency during peak production. Scott (1965) reported that the feeding of corn based DDS is a way for nutritionists to meet the linoleic acid requirement in poultry diets. Lilburn and Jensen (1984) incorporated corn fermentation solubles (CFS) at 2.5, 5, 10, and 20% in a corn-SBM diet that was fed to 24 wk old Babcock White Leghorn hens. No difference in egg weights was observed at any of the inclusion levels tested.

Jensen et al. (1974) fed levels of 2.5, 5, and 10% DDGS in both a wheat-soybean meal and corn-soybean meal diet to 24 wk old Single Comb White Leghorns for ten 28 d periods. The hens fed the diets containing 2.5 and 5% DDGS in both the corn and wheat diets had a significant increase in egg weights. Roberson et al. (2004) also measured egg weights in Hy-Line W36 hens (47 to 67 wk of age) and reported that the inclusion NG-DDGS at 5, 10, and 15% in a corn-soybean meal diet had no effect on egg weights.

3. Interior Egg Quality

One methodology of determining interior egg quality was described by Haugh (1937). Measuring interior quality by this method involves breaking the egg out on a flat surface without breaking the yolk. A tripod micrometer is placed on a plateau region of the albumin that is closest to the yolk. The measurement taken is then plugged into a standard equation, which yields a value referred to as a Haugh unit. The addition of 5, 10, or 20% brewers dried grains in a layer diet lead to an improvement in Haugh units when fed to White Leghorn hens for ten 28 d periods (Damron et al., 1976; Jensen et al., 1976). Damron et al. (1976) also reported improvements in interior egg quality when Babcock B-300 laying hens were fed diets containing 5 or 10% DDGS. Jensen et al. (1978) fed Babcock Leghorn hens a diet containing 2.5, 5, 10, and 20% DDGS supplemented with a 0.1% level of a trace mineral premix to a corn-soybean meal-alfalfa meal layer diet for an 8 wk period. It was reported that hens fed a diet containing levels as low as 2.5% DDGS could result in an improved interior egg quality

4. Egg Shell Quality

Shell quality is determined by shell deformities, shell thickness, shell breaking strength and specific gravity measurements. The non-destructive procedures used to measure shell strength or thickness is egg shell deformities (Schoorl and Boersma, 1962; Potts and Washburn,

1974) and specific gravity, which is a measure of buoyancy in various concentrations of salt water solution (Potts and Washburn, 1974). In the destructive method of testing for shell strength and thickness as described by Potts and Washburn (1974), the shell must be broken. Jensen et al. (1978) conducted an 8 wk experiment using Babcock Single Comb White Leghorn laying hens that were fed a corn-soybean meal laying hen diet with the incorporation of 10% brewer's dried grains or DDGS. No significant differences were observed between the control, 10% brewer dried grains, and 10% DDGS treatments for any of the shell parameters tested. Bolden and Jensen (1985) reported a significant improvement in egg shell quality with the incorporation of 5% DDGS in a corn-soybean meal diet compared to the control diet with 2% dietary calcium. However, the improvement in shell quality may have been due to the increased calcium levels (2.75 and 3.50%) and not from the incorporation of DDGS into the experimental diets.

5. Yolk Color

The degree of yellow color in an egg yolk plays a role in consumer preference (Jasper and Cray, 1953; Slocum and Swanson, 1954) thus, it is important to understand the effect a feed ingredient may have on the yolk color. The pigmentation of an egg yolk can be affected by carotenoids in the diet (Palmer and Kempster, 1919). Studies have demonstrated that xanthophylls from corn have a greater impact on yolk color than the pigments found in green plants when they are fed at equal amounts (Gillam and Heilbron, 1935; Peterson et al., 1939; and Day and Williams, 1958). Since, NG-DDGS is a by-product from corn ethanol processing the potential yellow yolk pigmentation is of interest. Roberson et al. (2003) tested 5, 10, and 15% NG-DDGS using 48 wk old Hy-Line W36 laying hens and noticed a statistical darkening in yolk color at all three levels of inclusion with the use of a colorimeter. The 5% level did not show an

impact until after 8 wk of testing, and the 10 and 15% DDGS levels displayed yolk color darkening from 48 to 67 wk of age. The colorimeter uses three axis (L*, a*, and b*) to pinpoint the exact color on a color sphere. The L* and b* are the more critical values than a* when considering the range of colors, which the human eye can differentiate. The slightest change in the axis value will result in a difference no matter how similar the color may appear to the consumer. Even though the colorimeter registered a statistical difference, it is likely that that the human eye would not be able to detect these differences.

6. Fatty Liver Syndrome

Fatty liver syndrome is a disease commonly seen in laying hens and was believed to result in decreased egg production. The first written report of fatty liver syndrome was by Couch (1956) who believed that liver fat accumulation was due to dietary and environmental factors. Jensen et al. (1974) conducted two experiments in which laying hens were fed diets containing 0, 2.5, 5, and 10% DDGS and observed a lower liver weight and a decrease in liver fat accumulation. Fatty liver syndrome may also increase a laying hen's susceptibility to liver hemorrhages. Jensen (1978) reported that when hens were fed a diet containing 10 to 20% DDGS there was a 0% occurrence of liver hemorrhages. Jensen (1981) concluded that diets containing 10 to 20% DDGS would aid in the prevention of fatty liver hemorrhagic syndrome.

Lilburn and Jensen (1984) conducted two experiments with corn fermentation solubles (CFS) to determine if the soluble fraction of DDGS was the result for the decrease in fatty liver syndrome. The first experiment confirmed the results of previous studies with DDGS, but it was suggested that the decrease in liver fat accumulation may be due to the increased levels of lysine that were supplemented. In the second experiment, Lilburn and Jensen (1984) speculated that

the CFS acts on an unidentified compound in the maintenance of normal lipid metabolism due to the lower liver weight and fat accumulation observed.

Broilers

Schlamb and Winter (1948) conducted the earliest experiment to determine the optimal dietary inclusion levels of DDS using one d old New Hampshire chicks. The high test levels of 15 and 20% DDS were reported to result in satisfactory growth performance as compared to the 0% DDS control diet when fed for a 20 wk period. The authors suggested that levels greater than 10% DDS may have a laxative effect even though no laxative effect was observed at the 10 or 15% level of DDS. Matterson (1949) conducted three experiments to test the affects of feeding DDS on broiler performance, but only incorporated a level of 5% DDS. No statistical difference in weight gains were observed throughout the experiments (0 to 8 wk of age) in birds fed the 5% DDS level compared to those fed diets with 0% DDS. Morgan (1951) conducted an experiment with straight run New Hampshire chicks that were fed a corn-soybean meal diet with graded levels of DDS from 2 to 10% from 0 to 10 wk of age. The objective was to determine if an economic gain could be achieved by incorporating a level greater than 5% DDS in a standard corn-soybean meal diet, while at the same time not hindering broiler performance. The diets were formulated to be isonitrogenous and DDS was added at the expensive of corn and soybean meal. An increase in growth rate was observed when 2, 4, and 5% DDS levels were fed. No improvements in growth rate were observed in diets containing a level greater than 5% DDS, which may have indicated the beginning of a possible AA limitation.

Early research with broilers was focused more on working with DDS, and it was not until the early 1980's when research with DDGS was reported. Waldroup et al. (1981) fed broilers isocaloric corn-soybean meal diets containing 5, 10, 15, 20, and 25% DDGS from 0 to 6 wk of

age. It was reported that DDGS could be fed at a level of 25% without any negative effects on growth. A significant improvement in feed efficiency was reported when 20% DDGS was fed compared to the 0, 5, 10 and 15% DDGS levels. However, a decrease in feed efficiency was observed in broilers fed the 25% DDGS level. Parsons et al. (1983) conducted an experiment to test the amount of soybean meal that can be replaced with DDGS. Male New Hampshire chicks were fed a corn-soybean meal diet that incorporated 10, 20, 30, 40, and 50% DDGS at the expense of soybean meal from 8 to 21 d of age. No negative effects on any performance parameter were observed when DDGS replaced 30% of the soybean meal in the diet as long as the diet was supplemented with lysine.

Turkeys

The majority of the research with DDGS in poultry diets has been conducted using chickens, but there are also reports of DDGS in turkey diets. Couch et al. (1954) observed no affects on fertility and hatchability when turkey hens were fed diets containing 5 and 10% DDS, but feeding DDGS resulted in increased body weights. Atkinson et al. (1955) reported a marked improvement in hatchability when turkey hens were fed 5% DDS in an alfalfa meal diet from the 12^{th} to the 17^{th} wk of egg production. Manley et al. (1978) incorporated 3% DDGS into a corn-soybean meal-alfalfa diet that was fed for 56 d to turkey hens that had been in egg production for 14 to 15 wk prior to the start of the experiment. A marked improvement in egg production and hatchability of fertile eggs was also reported in hens feed DDGS.

Ruf and Marvel (1950) conducted some of the earliest research on feeding distiller's by-products to turkeys, but once again the studies were conducted using DDS. Three, five, and eight percent levels of DDS were incorporated into high and low energy turkey diets for 12 wk. A significant improvement in feed efficiency and an increase in weight gain were observed in

turkeys fed diets containing DDS at any inclusion level. Research with distillery products in turkey diets shifted from working with DDS to DDGS. Potter (1966) examined DDGS by feeding levels of 10 and 20% DDGS in turkey diets with graded levels of corn gluten meal and with or without the addition of 0.30% lysine. There was a numerical, but not significant improvement in feed efficiency and weight gains when turkeys were fed the 10 and 20% level of DDGS without the supplementation of lysine in a diet containing no more than 15% corn gluten meal. Research on feeding DDGS to turkeys became almost non-existent after the late 1960's and early 1970's. Recently, Noll et al. (2002) conducted a study to determine the lysine digestibility of NG-DDGS, and to evaluate the performance of turkeys fed 12% NG-DDGS from 8 to 19 wk of age. The lysine digestibility was calculated to be 78%, which is similar to previous findings in chickens. No effect on body weight, feed efficiency, or carcass yield was reported when turkeys were fed diets with 12% NG-DDGS (Noll et al., 2002) as compared to the turkeys fed the 0% NG-DDGS control diet.

Swine

Distiller's dried grains with solubles has not only been fed to poultry, but also to beef and dairy cattle as well as swine. The research with swine is more relevant to poultry than research with cattle since swine are monogastrics and closer metabolically to poultry than cattle. The first research with the feeding of DDGS to swine was not reported until the late 1940's. Stewart (1949) fed 5% DDGS in a corn-soybean meal-skim milk solids diet to 30 d old nursery pigs until 8 wk of age. It was reported that feeding the 5% DDGS in the piglet diet resulted in a decrease in the time required for piglets to be on milk. Wahlstrom et al. (1968) fed three levels of DDGS (5, 10, and 20%) in a corn-soybean meal diet to weaned pigs. No observed differences in body gain or feed efficiency when DDGS was incorporated at a level lower than 20%. However,

when the weaned pigs were fed the 20% level of DDGS a negative effect only on feed efficiency was reported. Wahlstrom and Libal (1980) fed 10, 20, and 30% DDGS to nursery pigs and reported that growth performance was significantly decreased as the levels of DDGS in the diet increased.

Research with piglet diets was just the beginning of DDGS experimentation in swine diets. Combs and Wallace (1969) and Cromwell et al. (1985) observed positive growth performance in growing pigs over a 6 wk period with the feeding of 10 and 20% DDGS. Thong et al. (1978) experimented with gilts averaging 8 months of age and observed that feeding DDGS at a 17.7 to 44.2% level could replace soybean meal on an equivalent lysine basis in gestating sows. The most recent study with DDGS was conducted by Whitney and Shurson (2004) who experimented with NG-DDGS at 0, 5, 10, 15, 20, and 25% levels and the gender of the pigs were statistically blocked. The corn-soybean meal-dried whey diets were fed to nursery pigs 4 d following weaning in two phases from 0 to 14 d and then from 14 to 35 d. There was no negative affects on growth performance, feed intake, and feed conversion with the feeding of DDGS at any inclusion level for the 35 d period.

REFRENCES

Allman, R.T. and H.D. Branion. 1938. A preliminary investigation of the value of corn distillers dried grains in chick rations. Scientific Agr. 18:700

Amezcue, C.M., C.M. Parsons, and S.L. Noll. 2003. Content and bioavailability of phosphorus in distillers dried grains with solubles. Poult. Sci. 82 (Suppl. 1):36. (Abstr.)

Applegate, T.J., B.C. Joern, D.L. Nussbaum-Wagler, and R. Angel. 2003. Water-soluble phosphorus in fresh broiler litter is dependent upon phosphorus concentrations fed but not on fungal phytase supplementation. Poult. Sci. 82:1024-1029.

Atkinson, R.L., T.M. Ferguson, J.H. Quisenberry, and J.R. Couch. 1955. Dehydrated alfalfa meal, condensed fish solubles, distillers dried solubles and dried whey as supplements to an all vegetable protein turkey laying diet. Poult. Sci. 34: 730-735.

Austin, F.L. and C.S. Boruff. 1949. some observations on vitamin B_{13} in distillers dried grain solubles. Page 77-82 in Proc. Dist. Feed Res. Counc.

Batal, A.B. and N.M. Dale. 2003. Mineral composition of distillers dried grains with solubles. J. Appl. Poult. Res. 12: 400-403.

Batal, A.B. and N.M. Dale. 2004. True metabolizable energy and amino acid digestibility of distiller's dried grains with solubles. Poult. Sci. 83 (Suppl. 1):SW19.

Bolden, S.L. and L.S. Jensen. 1985. The effect of marginal levels of calcium, fish meal, torula yeast, and alfalfa meal on feed intake, hepatic lipid accumulation, plasma estradiol and egg shell quality among laying hens. Poult. Sci. 64: 937-946.

Cline, M.A., C.W. Carrick, R.E. Roberts, and S.M. Hauge. 1947. Distillers' dried solubles as a source of pantothenic acid in chick rations. Poult. Sci. 26: 315-322.

Combs, G.F. and E.H. Bossard. 1968. Available lysine content of corn distillers dried grains with solubles based on chick bioassay. Pages 58-63 in Proc. Dist. Feed Res. Counc.

Combs, G.F., E.H. Bossard, and G.R. Childs. Improved chick bioassay for available lysine and available methionine. Feedstuffs, March, 1968.

Combs, G.F. and E.H. Bossard. 1969. Further studies on available amino acid content of corn distillers dried grains with solubles. Pages 53-58 in Proc. Dist. Feed Res. Counc.

Combs, G.F. and H.D. Wallace. 1969. Dried distillers grains with solubles in pig starter diets. FL Animal Science Mimeo. Series No. 69-14.

Couch, J.R. 1956. Fatty livers in laying hens- a condition which may occur as a result of increased strain. Feedstuffs, 28: 46-54.

Couch, J.R. 1962. Corn distillers dried solubles- a source of phosphorus. Page 50-59 in Proc. Dist. Feed Res. Counc.

Couch, J.R., J.R. Reed, JR., R.L. Atkinson, and B.E. Welch. 1951. Distillers grain solubles and dried whey with an APF concentrate in broiler feeds. Pages 41-49 in Proc. Dist. Feed Res. Counc.

Couch, J.R., J.R. Reed, Jr., R.L. Atkinson, R.W. Perrett, B.E. Welch, and J.W. Dieckert. 1954. Distillers dried solubles for growth and hatchability. Page 38-48 in proc. Dist. Feed Res. Counc.

Couch, J.R., B.L. Reid, A.A. Camp, W.N. Dannenburg and E.E. Rozacky. 1955. Distillers dried solubles in the diets of chicks. Page 47-57 in Proc Dist. Feed Res.Conf.

Cromwell, G.L., T.S. Stahly, and H.J. Monegue. 1985. Distillers dried grains with solubles and antibiotics for weaning swine. Kentucky Agric. Exp. Stn., Lexington, Swine Research Report No. 292.

Cromwell, G.L., K.L. Herkelman, and T.S. Stahly. 1993. Physical, chemical, and nutritional characteristics of distillers dried grains with solubles for chicks and pigs. J. Anim. Sci. 71:679-686

Dale, N.M. and A.B. Batal. 2003. Ingredient analysis table: 2003-2004 edition. Feedstuffs vol. 75. 38:16.

Damron, B.L., A.R. Eldred, and R.H. Harms. 1976. An improvement in interior egg quality by the feeding of brewers dried grains. Poult. Sci. 55: 1365-1366.

Day, E.J. and W.P. Williams Jr. 1958. A study of certain factors that influence pigmentation in broilers. Poult. Sci. 37: 1373

DeLaune, P.B., P.A. Moore, Jr., D.C. Carman, T.C. Daniel, and A.N. Sharpley. 2001. Development and validation of a phosphorus index for pastures fertilized with animal manure. Proceedings in the International Symposium Addressing Animal Production and Environmental Issues. North Carolina State University, Raleigh, NC.

D'Ercole, A.D., W.B. Esselen, Jr., and C.R. Fellers. 1939. The nutritive value of distillers by-products. Poult. Sci. 18:89-95.

Dhandu, A.S. and R. Angel. 2003. Broiler nonphytin phosphorus requirement in the finisher and withdrawal phases of a commercial four-phase feeding system. Poult. Sci. 82:1257-1265.

Dickens, F.L., R.T. Parkhurst, and C.R. Fellers. 1941. Corn distillers' dried grains with solubles in poultry rations. II. Laying rations. Poult. Sci. 20: 536-542.

Ergul T., C. M. Amezcua, C.M. Parsons, D. Walters, J. Brannon, and S.L. Noll. 2003. Amino acid digestibility in corn distillers dried grains with solubles. Poult. Sci. 82 (Suppl. 1):70. (Abstr.)

Fernandez, S.R. and C.M. Parsons. 1996. Bioavailability of digestible lysine in heat-damaged soybean meal for chick growth. Poult. Sci. 75:224-231.

Gillam, A.D. and I.M. Heilbron. 1953. Vitamin A-active substances in egg yolk. Biochem. J. 29: 1064.

Harms, R.H., R.S. Moreno, and B.L. Damron. 1969. Evaluation of distillers dried grains with solubles in diets of laying hens. Poult. Sci. 48: 1652-1655.

Halpin, J.G., W.W. Cravens, and C.E. Holmes. 1942. Distillery residue not a good protein substitute. Wis. Agr. Exp Sta. Annual Rpt., Bul. 455: 4.

Hill, F.W., M.L. Scott, L.C. Norris, and G.F. Heuser. 1944. Deficiency of unidentified vitamins in practical chick rations. Poult. Sci. 23:253.

Hopkins, D.T. and M.C. Nesheim. 1962. Further studies on linoleic acid deficiency in hens and chicks. Proc Cornell Nutr. Conf. pp. 104.

Haugh, R.R. 1937. The haugh unit for measuring egg quality. U.S. Egg Poultry Mag. 43:552.

Hughes, E.W. and S.M. Hauge. 1945. Nutritional value of distillers dried solubles as a source of protein. J. Nutrition 30:245-258.

Insko, W.M., G.D. Buckner, H. Martin, and Amanda Harms. 1937. Distillery slop in chick rations. Ky. Agr. Exp Sta. Cir. 46.

Jasper, A.W. and R.E. Cray. 1953. Consumer preferences, practices and demands on purchasing eggs and poultry in Columbus, Ohio. Research Bull. 736, Ohio Agr. Expt. Sta., Wooster, Ohio.

Jensen, L.S., J.B. Allred, R.E. Fry, and J. McGinnis. 1957. Studies on an unidentified factor necessary for maximum egg weight. Poult. Sci. 36: 1130.

Jenson, L.S. 1973. The evaluation of distillers dried grains with solubles in layer rations. Pages 43-49 in Proc. Dist. Feed Res. Counc.

Jensen, L.S., L. Falen, and C.H. Chang. 1974. Effect of distillers dried grain with solubles on reproduction and liver fat accumulation in laying hens. Poult. Sci. 53: 586-592.

Jensen, L.S., C.H. Chang, and D.V. Maurice. 1976. Improvements in interior egg quality and reduction in liver fat in hens fed brewers dried grains. Poult. Sci. 55: 1841-1847.

Jensen, L.S. 1978. Distillers feed as sources of unidentified factors for laying hens. Pages 17-22 in Proc. Dist. Feed Counc.

Jensen, L.S., C.H. Chang, and S.P. Wilson. 1978. Interior egg quality: improvement by distillers feeds and trace elements. Poult. Sci. 57: 648-654.

Jensen, L.S. 1981. Value of distillers dried grains with solubles in poultry feeds. Pages 87-93 in Proc. Dist. Feed Res. Counc.

Kurnick, A.A., B.L. Reid, R.N. Burroughs, H.D. Stelzner, and J.R. Couch. 1957. Effect of distillers dried solubles and Molybdenum on the growing chick. Proc. Soc. Expt. Biol. Med. 95: 353-356.

Likuski, H.J.A. and H.G. Dorrell. 1978. A rapid bioassay for determinations of amino acid availability. Poult. Sci. 57: 1658-1660.

Lilburn, M.S. and L.S. Jensen. 1984. Evaluation of corn fermentation solubles as a feed ingredient for laying hens. Poult. Sci. 63: 542-547.

Manley, J.M., R.A. Voitle, and R.H. Harms. 1978. Influence of distillers dried grains with solubles (DDGS) in diet of turkey breeder hens. Poult. Sci. 57: 726-728.

Marvel, J.A., C.W. Carrick, R.E. Roberts, and S.M. Hauge. 1944. The supplementary value of choline and methionine in a corn and soybean oil meal chick rations. Poult. Sci. 23: 294-297.

Marvel, J.A., C.W. Carrick, R.E. Roberts, and S.M. Hauge. 1945a. A comparison of soybean oil meals in chick rations containing distillers dried solubles. Poult. Sci. 24: 46-52.

Marvel, J.A., C.W. Carrick, R.E. Roberts, and S.M. Hauge. 1945b. The value of choline additions to corn and soybean oil meal chick ration containing distillers dried solubles. Poult. Sci. 24: 181-186.

Marvel, J.A., C.W. Carrick, R.E. Roberts, and S.M. Hauge. 1945c. Distillers' dried solubles in chick rations containing corn and vegetable protein supplements. Poult. Sci. 24: 252-258.

Matterson, L.D. 1949. Distillers grain solubles in high energy, low fiber broiler rations. Pages 54-57 in Proc. Dist. Feed Res. Counc.

Matterson, L.D. 1950. Distillers solubles for rapidly growing broilers. Pages 26-31 in Proc. Dist. Feed Res. Counc.

Matterson, L.D., J. Tlustohowicz, and E.P. Singsen. 1966. Corn Distillers dried grains with solubles in rations for high producing hens. Poult. Sci. 45: 147-150.

McGinnis, J. and R.J. Evans. 1947. Amino acid deficiencies of raw and over-heated soybean oil meal for chicks. J. Nutr. 34: 725-732.

Mehring, A.L., Jr., J.H. Brumbaugh, and H.W. Titus. 1956. A comparison of the growth of chicks fed diets containing different quantities of zinc. Poult. Sci. 35: 956-958.

Morgan, C.L. 1951. The effect of various levels of distillers grain soluble in a broiler mash upon chick growth, feathering and litter condition. Pages 61-66 in Proc. Dist. Feed Res. Counc.

Morrison, A.B., M.L. Scott and L.C. Norris. 1955. Evidence for an unidentified mineral required by the chick. Poult. Sci. 34: 738-740.

National Research Council. 1994. Nutrient requirements of poultry. 9th rev. ed. National Academy Press, Washington, DC.

Nelson, W.L., F.E. Volz, R.T. Parkhurst, and L.R. Parkinson. 1944. Corn distillers' by-products in poultry rations. I. Chick rations. Poult. Sci 23: 278-286.

Noll, S.L., V. Stangeland, G. Speers, C. Parsons, and J. Brannon. 2002. Utilization of canola meal and distillers grains with solubles in market turkey diets. Poultry Sci. 81 (Suppl. 1): 92 (Abstr.)

Noll, S.L., C. Abe, and J. Brannon. 2003. Nutrient composition of corn distiller dried grains with solubles. Poult. Sci. 82 (Suppl. 1):71. (Abstr.)

Norris, L.C. 1955. Recent progression in unidentified growth factors in distillers dried solubles and other feed supplements. Pages 39-42 in Proc Dist. Feed Res. Counc.

Norris, L.C., R.M. Leach, Jr. and T.R. Zeigler. 1958. Recent research on the mineral requirements of poultry. Pages 63-73 in Proc. Dist. Feed Res. Counc.

Novak, A.F., S.M. Hauge, and C.W. Carrick. 1947. An unidentified growth factor in distillers dried solubles essential for the chick growth. Poult. Sci. 26: 604- 609.

Novak, A.F. and S.M. Hauge. 1948. Isolation of the unidentified growth factor (vitamin B13) in distillers dried solubles. J. Bio. Chem. 174:647-651.

O'Dell, B.L. and J.E. Savage. 1957. Potassium, zinc and distillers dried solubles as a supplement to a purified diet. Poult. Sci. 36: 459-460.

Ostrowski- Meissner, H.T. 1984. A method for simultaneous measurement of apparent (AME) and true (TME) metabolizable energy with ducks and comparisons of data obtained with drakes and cockerels. Nutr. Reports International 5:1239-1248.

Palmer, L.S. and H.L. Kempster. 1919. The influence of specific feeds and certain pigmentation the color of the egg yolk and body fat of fowls. J. Biol. Chem. 39:331.

Parkhurst, R.T., C.R. Fellers, and J.W. Kuzmeski. 1942. Corn dried distillers' by-products in laying rations. Poult. Sci. 21: 475.

Parkhurst, R.T., C.R. Fellers, and J.W. Kuzmeski. 1945. Corn distiller's by-products in poultry rations. II. Laying and breeding rations. Poult. Sci. 24: 8-19.

Parsons, C.M., D.H. Baker, and J.M. Harter. 1983. Distillers dried grains with solubles as a protein source for the chick. Poult. Sci. 62: 2445-2451.

Peterson, W.J., J.S. Hughes, and L.F. Payne. 1939. Avian carotenoids. Kansas State Agr. Bulletin 46.

Potter, L.M. 1966. Studies with distillers feeds in turkey rations. Page 47-51 in Proc. Dist. Feed Res. Counc.

Potts, P.L. and K.W. Washburn. 1974. Shell evaluation of white and brown egg strains by specific gravity, breaking strength, shell thickness and specific gravity. I. Relationship to egg characteristics. Poult. Sci. 53: 1123-1128

Reid, B.L., A.A. Kurnick, R.L. Svacha, and J.R. Couch. 1956. The effects of molybdenum on chick and poult growth. Proc. Soc. Expt. Biol. Med. 93: 245-248.

Roberson, K.D., J.L. Kalbfleisch, W. Pan, and R.A. Chabeneau. 2004. Dried distillers grains with solubles changes egg yolk color without affecting egg production when included at 5 to 15 percent of a corn soybean meal diet. Southern Poultry Science Meeting, January 2004.

Reilly, P.J. 1979. Gasohol-future prospects. Pages 4-14 in Proc. Dist. Feed Res. Counc.

Ruff, E.W. and J.A. Marvel. 1950. Turkey feeds containing distillers grain solubles. Page 41-45 in Proc. Dist. Feed Res. Counc.

Runnels, T.D. 1966. The biological nutrient availability of corn distillers dried grains with solubles in broiler feeds. Pages 11-15 in Proc. Dist. Feed Res. Counc.

Ryden, J.C., J.K. Syers, and R.F. Harris. 1973. Pages 1-44 in: Advances in Agronomy. Vol. 25. Academic Press, New York, NY.

Schlamb, K.F. and Winter, A.R. 1948. An evaluation of dried distillers feedstuffs fed to chickens throughout their life cycle. Poult. Sci. 27:492-497.

Schoorl, P. and H.Y. Boersma. 1962. Research on quality of the egg shell. 12th World's Poult. Congr., Sydnet: 432-435.

Schumacher, A.E., G.F. Heuser, and L.C. Norris. 1940. The complex nature of the alcohol precipitate factor required by the chick. J. Biol. Chem. 135:13.

Scott, M.L. 1951. Studies on the enlarged hock disorder in turkeys. III. Evidence of a detrimental effect of fish liver oil and the beneficial effect of brewers' yeast and other materials. Poult. Sci. 30: 846-855.

Scott, M.L. 1958. Selenium as a required trace mineral in animal nutrition. Pages 111-117 in Proc. Cornell Nutrition Conf.

Scott, M.L. 1965. Distillers dried solubles for maximum broiler growth and maximum early egg size. Page 55-57 in Proc. Dist. Feed Counc.

Scott, M.L. 1970. Twenty-five years of research on distillers feeds for broilers. Pages 19-24 in Proc. Dist. Feed Res. Counc.

Shea, K.G., C.R. Fellers, and R.T. Parkhurst. 1941. Corn distillers' dried grains with solubles in poultry rations. I. Chick rations. Poult. Sci. 20: 527-535.

Shurson, J. 2003. Subject: The value and Use of Distillers Dried Grains with Solubles (DDGS) in Livestock and Poultry Rations. http://www.ddgs.umn.edu/. Accessed Nov. 2003.

Shutze, J.V. and L.S. Jensen. 1963. Influence of linoleic acid on egg weight. Poult. Sci. 42: 921.

Sibbald, I.R. 1976. A bioassay for true metabolizable energy in feedstuffs. Poult. Sci. 55:303-308.

Sibbald, I.R. 1979. The effect of the duration of the excreta collection period on the true metabolizable energy values in feedstuffs with slow rates of passage. Poult. Sci. 58: 896-899.

Sibbald, I.R. 1986. The T.M.E. system of feed evaluation: methodology, feed consumption data and bibliography. Technical Bulletin 1986-4E. Agriculture Canada, Ottawa, ON, Canada

Simons, P.C.M., H.A.J. Versteegh, A.W. Jongbloed, P.A. Kemme, P. Slump, K.D. Bos, M.G.E. Wolters, R.F. Beudeker, and G.J. Vershoor. 1990. Improvement of phosphorus availability by microbial phytase in broilers and pigs. Br. J. Nutr. 64:525-540.

Singsen, E.P. 1948. The phosphorus requirements of the chicken with special reference to the availability of phytin phosphorus. Storrs Agr. Expt. Sta. Bull. 260.

Singsen, E.P., A.H. Spandorf, L.D. Matterson, J.A. Serafin, and J.J.Tlustohowicz. 1962. Phosphorus in the nutrition of the adult hen. 1. Minimum phosphorus requirements. Poul. Sci. 41: 1401.

Sloan, H.J. 1941. The use of distillers' by-products in poultry rations. Poult. Sci. 20: 83-96.

Slocum, W.L. and H.S. Swanson. 1954. Egg consumption habits. Purchasing patterns and preferences of Seattle consumers. Bull. 556. Was. Agr. Expt. Sta., Pullman, Wash.

Stewart, H.A. 1949. Distillers grain solubles in diets for young pigs. Page 131-133 in Proc. Dist. Feed Res. Counc.

Thong, L.A., A.H. Jensen, B.G. Harmon, and S.G. Cornelius. 1978. distillers dried grains with solubles as a supplemental protein source in diets for gestating swine. J Anim. Sci. 46: 674-677.

University of Minnesota. 2003. Subject: Nutrient profile comparison table. http://www.ddgs.umn.edu/. Accessed Nov. 2003.

Wahlstrom, R.C., C.S. German, and O.E. Olson. 1968. Effect of distillers dried grains with solubles on ration digestibility and growth of swine. J. Anim. Sci. 27:1780-1781.

Wahlstrom, R.C. and G.W. Libal. 1980. Effect of distillers dried grains with solubles in pig starter diets. Series for Swine. No. 80-6 South Dakota Agric. Exp. Stn., Brookings.

Waldroup, P.W., J.A. Owen, B.E. Ramsey, and D.L. Whelcel. 1981. The use of high levels of distillers dried grains plus solubles in broiler diets. Poult. Sci. 60: 1479-1484.

Warnick, R.E. and J.O. Anderson. 1968. Limiting essential amino acids in soybean meal for growing chickens and effects of heat upon availability of essential amino acids. Poult. Sci. 47: 281.

Whitney, M.H. and G.C. Shurson. 2004. Growth performance of nursery pigs fed diets containing increasing levels of corn distillers dried grains with solubles originating from a modern Midwestern ethanol plant. J. Anim. Sci. 82: 122-128.

CHAPTER 2

EVALUATION OF DISTILLER'S DRIED GRAINS WITH SOLUBLES AS A FEED INGREDIENT FOR BROILER CHICKENS[1]

[1] Lumpkins, B. S., A.B. Batal, and N. M. Dale. Accepted for publication in *Poultry Science.*

ABSTRACT Two experiments were conducted to evaluate the use of distiller's dried grains with solubles (DDGS) from modern ethanol plants in broiler diets. Experiment 1 was a 2 x 2 factorial design with diets containing two levels of DDGS (0 and 15%) and two diet densities (high and low). The high and low density diets were formulated to contain 22% CP and 3,050 kcal ME_n/kg and 20% CP and 3,000 kcal ME_n/kg, respectively. Eight pens of six chicks were fed each experimental diet from 0 to 18 d of age. Weight gain and feed efficiency (gain:feed) of the chicks receiving the high density diets were significantly ($P < 0.05$) better than the chicks fed the low density diets. However, within the two density levels there was no difference in performance of chicks fed diets with 0 or 15% DDGS. In Experiment 2, 6 replications of 50 chicks were fed one of four dietary treatments for 42 d. The diets were formulated to be isocaloric and isonitrogenous and contained 0, 6, 12, or 18% DDGS. There was no significant difference in performance or carcass yield throughout the 42 d experiment except for a depression in body weight gain and feed conversion when chicks were fed diets with 18% DDGS during the starter period (0 to 16 d). These studies indicate that DDGS from modern ethanol plants is an acceptable feed ingredient for broiler diets and can be safely used at 6% in the starter period and 12% in the grower and finisher periods.

(Key words: Distiller's dried grains with solubles, DDGS, broilers, feed ingredients, carcass yield)

INTRODUCTION

Historically, the majority of distiller's dried grains with solubles (DDGS) have been a by-product of the beverage industry, with several different grains employed in the fermentation process. However, the beverage industry was not the only source of DDGS, as ethanol plants also produced this ingredient. Recently, non-beverage fuel ethanol production has been encouraged in the United States, as ethanol is cleaner burning, provides more energy than petroleum, and is a partially renewable resource. Ethanol producers responded to this emphasis in the mid to late 1990's by building new plants. The DDGS from these modern ethanol plants is derived almost entirely from corn and is dried under less severe temperatures than the DDGS produced in the past.

The production of DDGS continues to increase and it is predicted by the year 2005 there will be approximately 5 to 7 million metric tons available to feed producers in North America (Shurson, 2003). Distiller's dried grains with solubles have been used in commercial poultry diets at a level of 5% or less for many years. Incorporation of DDGS at higher levels may provide an additional outlet for the growing amounts available (Noll *et al*., 2001). Researchers have observed positive results when DDGS was incorporated in broiler diets. Day *et al.* (1972) observed an increase in weight gain when broilers were fed diets containing low levels of DDGS (2.5 and 5%). Insko *et al.* (1937) suggested that "distillery slop", DDGS before it undergoes drying, can replace four-fifths of corn in a standard poultry diet. Other researchers have concluded that up to 25% DDGS can be incorporated in broiler diets if dietary energy is held constant (Waldroup *et al*., 1981). However, it is presumed that most of the DDGS used in these studies came from the beverage industry and DDGS from modern fuel ethanol plants may differ in nutrient composition. As very little research has been published pertaining to the use of

DDGS from modern fuel ethanol plants, and limited nutritional information is available, our objective was to evaluate the use of this "new generation" distiller's dried grains with solubles in broiler diets.

MATERIALS AND METHODS

General Procedures

Two experiments were performed to test the level at which distiller's dried grains with solubles from modern fuel ethanol plants can be successfully incorporated into broiler diets. The distiller's dried grains with solubles used in both experiments was completely derived from corn and came from a modern fuel ethanol plant in Aurora, Nebraska that was built in the early 1990's. The sample had a golden yellow color, a coarse appearance, and a distinctively sweet smell. The diets for both experiments were formulated on a total amino acid basis using the Brill® least cost feed formulation program. The nutrient levels of DDGS used for the diet formulation were estimated based on previous analysis of various samples (unpublished data) and book values (Table 2.1). Lysine and methionine were supplemented to the diets when needed to maintain consistent total amino acid levels between experimental diets.

A sample of the DDGS used in both studies was sent for proximate analysis[1]. Ten conventional and cecectomized Single Comb White Leghorn roosters were fasted for 24 h and then crop intubated with 30 g of the DDGS sample for the determination of TME_n and true amino acid digestibility, respectively (Sibbald, 1976, 1979). Excreta were collected for a 48 h period, dried, and weighed. The distiller's dried grains with solubles and excreta samples were sent for analysis[1] (Table 1).

[1] UGA Nutrition Lab, University of Georgia, Poultry Science Bldg. Athens, GA 30602 and Experiment Station Chemical Laboratories, University of Missouri-Columbia, room 4, Agriculture Bldg, Columbia, MO 65211

Experiment 1

All procedures were approved by the University of Georgia Animal Use and Care Committee. Experiment 1 was a preliminary experiment to test a 15% level of DDGS in starter diets for broilers. Chicks were housed in an environmentally controlled building and placed into thermostatically controlled starter batteries[2] with raised wire floors. Cobb X Cobb-500 straight run chicks were divided into 8 replicate pens per treatment of 6 chicks and fed one of the four dietary treatments *ad libitum* from 0 to 18 d of age. A 2 x 2 factorial design was employed, with two high density diets containing 0 or 15% DDGS and two low density diets also containing 0 or 15% DDGS (Table 2.2). The high density diets were formulated to contain 22% crude protein and 3,050 kcal ME_n/kg and the low density diets contained 20% crude protein and 3,000 kcal ME_n/kg. The purpose for including the low density diet was to allow for the evaluation of DDGS under limiting nutritional conditions. Weight gain and feed efficiency (gain:feed) were determined for each pen at 7, 14, and 18 d of age.

Experiment 2

Results from Experiment 1 indicated that 15% DDGS could be used in practical broiler starter diets. Thus, the objective of Experiment 2 was to examine the effects of DDGS on broiler performance and carcass yield through market weight. Graded levels of DDGS leading up to and surpassing 15% were evaluated in a 42 d broiler growth study. Six replicate pens per treatment of 50 straight run Cobb X Cobb-500 chicks per pen were housed in a curtain sided building, which used natural ventilation. The house had litter floors and the pens were separated by wire mesh to create 2.5 x 3.6 meter pens. Each pen contained two bell waterers and two galvanized steel feeders. Feed and water were provided *ad libitum* throughout the study. Four experimental diets containing 0, 6, 12, or 18% DDGS were formulated for the starter (0 to16 d), grower (17 to

31 d), and finisher (32 to 42 d) periods (Table 2.3). Diets were formulated to be isonitrogenous and isocaloric with constant total lysine and methionine levels for each treatment within each of the three periods. The same parameters as in Experiment 1 (weight gain, feed intake and feed efficiency) were examined in Experiment 2, at 16, 31, and 42 d of age. To investigate a possible effect of DDGS on processing characteristics, ten birds (5 females and 5 males) from each pen were randomly selected for processing at 42 d of age. Feed was removed 10 hours prior to processing. After processing, carcasses were chilled for 12 hours and yield was determined for breast, wings, and front and back halves. The entire carcass was weighed and the back half, which consists of the leg quarters joined to the lower back, was removed leaving the white meat front half. Both wings and the pectoralis major and minor were removed from the front half.

Statistical Analysis

Data from both experiments were subjected to analysis of variance procedure for completely randomized design (Steel and Torrie, 1980) by using the general linear model procedures of SAS® software (SAS Institute, 1990). Statistical significance of differences among treatments were assessed using the least significant difference test (Steel and Torrie, 1980). Data from Experiment 1 was analyzed by ANOVA to determine significance of main effects (density and DDGS) and interactions (density x DDGS). A probability level of $P < 0.05$ was used to determine statistical differences.

RESULTS

Experiment 1

There was no difference in the weight gain of chicks fed the high and low density diets containing either 0 or 15% DDGS at 7 d of age (Table 2.4). At 14 and 18 d of age, differences in

[2] Petersime Incubator Co., Gettysburg OH 45328

weight gain were observed between the high and low density diets. Body weight gain of chicks receiving the high density diets were significantly better than chicks fed the low density diets. However, within each diet density, there was no difference in the weight gain of chicks fed diets containing either 0 or 15% DDGS.

No differences in feed intake between chicks fed the high or low density diets or the 0 or 15% levels of DDGS were observed. At 7 d of age there was a significant difference in feed efficiency (gain:feed) between chicks fed all four of the dietary treatments, with the lowest feed efficiency observed when chicks were fed the low density diet with 15% DDGS (Table 4). There was no difference in feed efficiency at 14 d of age when the chicks were fed the high density diet with 0 or 15% DDGS. However, chicks fed the low density diet with 15% DDGS had reduced feed efficiency as compared to chicks fed the low density diet with 0% DDGS or the high density diets. At 18 d of age feed efficiencies of chicks fed the high density diets were improved over chicks fed the low density diets, but within each diet density there was no difference in feed efficiency between chicks fed 0 or 15% DDGS (Table 2.4). No interactions between density x DDGS were observed.

Experiment 2

The inclusion of 18% DDGS in the diet significantly depressed ($P < 0.05$) chick weight gain during the starter (0 to 16) period (Table 2.5). There was also a slight numerical decrease in weight gain with the inclusion of 12% DDGS. During the grower and finisher periods there was no difference in the weight gain of broilers fed any of the dietary treatments. However, the overall weight gain (42 d) of chicks fed diets with 18% DDGS was depressed, principally due to the reduced gain during the starter period.

No differences in feed intake were observed between any of the dietary treatments throughout the experiment. Feed efficiency (gain:feed) was depressed during the starter period when chicks were fed diets with 18% DDGS and there was also a numeric decrease in feed efficiency due to the inclusion of 12% DDGS (Table 2.5). No differences in feed efficiency were observed between any of the dietary treatments during the grower and finisher period or throughout the 42 d experiment. Feeding 0, 6, 12, or 18% DDGS to broiler chicks had no effect on carcass yield when observing the selected carcass parts: front and back halves (white and dark meat areas), wings, and breasts (Table 2.6).

The color of the DDGS was quantified with a Minolta colorimeter[3] and had a recorded value of L*(white and black) =58.52, a*(red and green) =6.38, b*(yellow and blue) =20.48. Testing the color of our DDGS sample will allow for future comparisons with other DDGS samples.

DISCUSSION

Based on the body weight gain results from Experiment 1, it could be concluded that 15% DDGS may be used safely in commercial (high density) broiler diets. However, the lower feed efficiency (gain:feed) observed during the first seven d and the numeric reduction thereafter suggest that an inclusion level of 15% DDGS may be excessive during the starter period. These assumptions were confirmed by the results of Experiment 2, in which 12 and 18% DDGS depressed chick performance during the starter period.

Soybean protein is known to have a more favorable amino acid pattern for chick growth than corn. When 18% DDGS (protein is of corn origin) was incorporated into the diet the percent protein from corn origin doubled (4.6 to 8.6%) while the percent protein from soybean meal (SBM) decreased. It is believed that at 18% DDGS, the high level of dietary protein of

corn origin and the corresponding decrease in soybean protein may have contributed to the depressed performance due to a marginal lysine deficiency. The estimated lysine value (0.94%) of DDGS used in diet formulation was higher than the analyzed value (0.85%). The depressed performance observed at the higher inclusion levels was likely due to the overestimation of lysine in DDGS and decreases in the level of soybean protein, the main lysine source in the diet, which resulted in a marginal lysine deficiency. At lower inclusion levels of DDGS there appeared to be sufficient lysine from the soybean protein and thus no negative effect due to the overestimation of the lysine concentration was observed. Our results seem to agree with those of Hughes and Hauge (1945) who observed that when DDGS was used as the sole source of protein in a broiler diet there was a marginal deficiency of lysine, causing a slight decrease in performance.

Waldroup *et al.* (1981) found that up to 25% DDGS could be used in broiler starter diets when the energy level was constant. In their study, the inclusion of 25% DDGS was substituted for both corn and soybean meal without lysine supplementation. Based on the results herein it would be expected that a depression in performance would be observed with the higher incorporation levels of DDGS and no supplementation of lysine. However, this was not observed, which is likely due to a lower estimated lysine value used in the diet formulation. Parsons *et al.* (1983) reported that at least 20% of the dietary SBM could be replaced by DDGS in the absence of lysine supplementation and up to 30% of the SBM could be replaced with DDGS in the presence of supplemental lysine. In our studies, diets were formulated for a constant energy level and supplemented with lysine to keep the total lysine in all dietary treatments constant. However, depressed performance was observed during the starter period with the inclusion of 18% DDGS even with the supplementation of lysine. Diets used by

[3]Minolta CR300 colorimeter. Minolta Corporation, 101williams drive, Ramsey, New Jersey 07446, USA

Waldroup *et al.* (1981) had higher fat levels than the diets used herein (5.5-8.4 vs. 1.8 to 2.2%) and were formulated to a higher ME (3,200 vs. 3,030 kcal/kg) values. Thus, the fiber or energy content of the diets may further explain the differences observed between the reported maximal inclusion levels. The diets used herein were also formulated to be isonitrogenous, in contrast to Waldroup *et al.* (1981), in which the minimum protein level was 23%, but was not kept constant and increased as the inclusion level of DDGS increased. This may be another explanation for the differences between experiments.

At an early age chick performance was depressed when the diet contained 18% DDGS. It appeared that the younger birds (up to 16 d) were less able to tolerate the high levels of DDGS, but this was not the case during the grower and finisher stages. It appears that increased inclusion levels of DDGS resulted in a marginal lysine deficiency, which was most limiting when the birds were young and had the highest amino acid requirements. During the grower and finisher period no significant differences were observed at any level of inclusion, which suggested that once past the starter period, higher levels of DDGS can efficiently be incorporated in broiler diets. Distiller's dried grains with solubles from modern ethanol plants appears to be a highly acceptable feed ingredient in commercial broiler diets. A conservative maximum level of DDGS to use in the starter diet is 6% and it could be speculated based on previous research that higher values of 9% can be used. However, in the grower and finisher period it appears feasible to increase DDGS in the diet to as high as 12%.

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REFERENCES

Day, E.J., B.C. Dilworth, and J. McNaughton. 1972. Unidentified growth factor source in poultry diets. In "Proceedings Distillers Feed Research Council Conference". pp 40-45.

Hughes, C.W. and S.M. Hauge. 1945. Nutritive value of distillers' dried solubles as a source of protein. J. Nutr. 30: 245-258.

Insko, W.M, G.D. Buckner, H. Martin, and A. Harms, 1937. Distillery slop in chick rations. Ky. Agr. Expt. Sta. Cir 46, Jan.

Noll S., V. Stangeland, G. Speers, and J. Brannon. 2001. Distillers grains in poultry diets. In "Proceedings Minnesota Nutrition Conference". pp. 53-61.

Parsons, C.M. and D.H. Bake. 1983. Distillers dried grains with solubles as a protein source for the chick. Poult. Sci. 62: 2445-2451.

SAS Institute Inc. 1990. SAS STAT User's Guide Release 6.08. SAS Institute Inc., Cary NC.

Shurson, J. 2003. Subject: The value and Use of Distillers Dried Grains with Solubles (DDGS) in Livestock and Poultry Rations. http://www.ddgs.umn.edu/. Accessed Nov. 2003.

Sibbald, I.R. 1976. A bioassay for true metabolizable energy in feedstuffs. Poult. Sci. 55:303-308.

Sibbald, I.R. 1979. The effect of the dureation of the excreta collection period on the true metabolizable energy values in feedstuffs with slow rates of passage. Poult. Sci. 58: 896-899.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics. A Biometrical Approach. 2nd ed. McGraw-Hill Book Co., Inc., New York, NY.

Waldroup, P.W., J.A. Owen, B.E. Ramsey, and D.L.Whelchel. 1981. The use of high levels of distillers dried grains with solubles in broiler diets. Poult. Sci. 60: 1479-1484.

Table 2.1. Nutritional composition of distiller's dried grains with solubles (as-fed basis) used in Experiments 1 and 2

	Distiller's dried grains with solubles	
	Estimated[1]	Analyzed
TME_n, kcal/kg	2800	2905[2]
Dry matter, %	87	86
CP, %	27	29.1
Lysine, %	0.94	0.85 (75)[3]
Methionine, %	0.60	0.56 (89)
TSAA, %	1.00	1.18 (82)
Threonine, %	0.95	1.05 (76)
Arginine, %	1.00	1.25 (84)
Tryptophan, %	0.20	0.28 (84)
Fat, %	10.00	9.80
Ash, %	4.50	3.90
Sodium, %	0.13	0.11

[1] Values used for diet formulation.
[2] TME_n for DDGS was determined in ten conventional roosters.
[3] Values in parentheses are the percent availability determined in cecectomized roosters.

TABLE 2. 2. Composition of dietary treatments (as-fed basis), Experiment 1

Ingredients	High density		Low density	
	Control	DDGS	Control	DDGS
	(%)			
Corn, yellow, ground	56.48	48.83	63.77	56.24
Soybean meal (48)	36.79	29.22	31.36	23.78
DDGS[1]	---	15.00	---	15.00
Fat, poultry	2.69	3.03	0.77	1.01
Dicalcium phosphate	1.74	1.38	1.77	1.39
Limestone	1.25	1.36	1.26	1.38
Salt	0.50	0.47	0.50	0.47
Vitamin premix[2]	0.25	0.25	0.25	0.25
DL-methionine	0.22	0.20	0.20	0.18
L-lysine	---	0.18	0.04	0.22
Trace mineral premix[3]	0.08	0.08	0.08	0.08
Contents by calculation				
TME_n, kcal/kg	3050	3050	3001	3001
Protein, %	22	22	20	20
Lysine, %	1.23	1.23	1.12	1.12
Methionine, %	0.58	0.59	0.54	0.54

[1]DDGS= distiller's dried grains with solubles.

[2]Vitamin mix provided the following (per kg of diet): thiamin•mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B_{12} (cobalamin), 12.0 µg; pyridoxine•HCL, 2.7 mg; D-biotin, 0.11 mg; folic acid, 0.55 mg; menadione sodium bisulfate complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 1,100 IU; trans-retinyl acetate, 5,500 IU; all-rac-tocopherol acetate, 11 IU; ethoxyquin, 150 mg.

[3] Trace mineral mix provides the following (per kg of diet): manganese ($MnSO_4•H_2O$), 60 mg; iron ($FeSO_4•7H_2O$), 30 mg; zinc (ZnO), 50 mg; copper ($CuSO_4•5H_2O$), 5 mg; iodine (ethylene diamine dihydroiodide), 1.5 mg.

TABLE 2.3. Composition of dietary treatments (as-fed basis), Experiment 2

Ingredients	Starter				Grower				Finisher			
	Control	6% DDGS	12% DDGS	18% DDGS	Control	6% DDGS	12% DDGS	18% DDGS	Control	6% DDGS	12% DDGS	18% DDGS
	(%)											
Corn, yellow, ground	58.39	55.16	51.97	48.69	62.83	59.62	56.41	53.13	68.52	65.31	60.77	55.47
Soybean meal (48)	36.47	33.49	30.49	27.50	31.50	28.49	25.50	22.51	26.48	23.48	21.67	20.53
DDGS[1]	---	6.00	12.00	18.00	---	6.00	12.00	18.00	---	6.00	12.00	18.00
Fat, poultry	1.82	2.02	2.22	2.49	2.50	2.70	2.91	3.17	2.12	2.32	2.74	3.27
Defluorinated phosphate	1.78	1.63	1.47	1.32	1.54	1.39	1.23	1.07	1.29	1.14	0.97	0.81
Limestone	0.62	0.72	0.81	0.90	0.69	0.79	0.88	0.97	0.72	0.81	0.90	0.99
Salt	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.33	0.35	0.36	0.36	0.36
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
DL- methionine	0.22	0.22	0.21	0.20	0.23	0.22	0.21	0.21	0.15	0.14	0.12	0.10
L-lysine	---	0.06	0.13	0.20	0.01	0.09	0.16	0.23	0.04	0.11	0.14	0.14
Trace 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
Coccidiostat[4]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	---	---	---	---
Contents by calculation												
TME_n, kcal/kg	3031	3031	3031	3034	3120	3120	3120	3123	3159	3159	3159	3159
Protein, %	22	22	22	22	20	20	20	20	18	18	18	19
Lysine, %	1.23	1.22	1.22	1.22	1.10	1.10	1.10	1.10	0.98	0.98	0.98	0.98
Methionine, %	0.59	0.59	0.60	0.60	0.57	0.57	0.57	0.58	0.46	0.47	0.46	0.46

[1] DDGS= distiller's dried grains with solubles.

[2]Vitamin mix provided the following (per kg of diet): thiamin•mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B_{12} (cobalamin), 12.0 µg; pyridoxine•HCL, 2.7 mg; D-biotin, 0.11 mg; folic acid, 0.55 mg; menadione sodium bisulfate complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 1,100 IU; trans-retinyl acetate, 5,500 IU; all-rac-tocopherol acetate, 11 IU; ethoxyquin, 150 mg.

[3] Trace mineral mix provides the following (per kg of diet): manganese ($MnSO_4•H_2O$), 60 mg; iron ($FeSO_4•7H_2O$), 30 mg; zinc (ZnO), 50 mg; copper ($CuSO_4•5H_2O$), 5 mg; iodine (ethylene diamine dihydroiodide), 1.5 mg.

[4] Coccidostat= Coban 60®, Elanco Animal Health, Indianapolis, IN 46285.

TABLE 2.4. Effects of feeding DDGS[1] to broilers on weight gain and feed efficiency, Experiment 1[2]

	Weight gain (g/chick)			Gain:feed (g:kg)		
Treatment	Day 7	Day 14	Day 18	Day 7	Day 14	Day18
High density, 0% DDGS	133	401[a]	556[a]	956[a]	938[a]	782[a]
High density, 15% DDGS	134	399[a]	555[a]	931[b]	936[a]	772[a]
Low density, 0% DDGS	130	376[b]	523[b]	898[c]	874[b]	712[b]
Low density, 15% DDGS	124	362[b]	518[b]	854[d]	847[c]	705[b]
Pooled SEM	3.6	7.2	8.2	8.5	8.7	8.6
Density						
High	134	400[a]	555[a]	944[a]	938[a]	777[a]
Low	127	369[b]	521[b]	876[b]	861[b]	709[b]
Pooled SEM	2.5	5.1	5.8	6.0	6.1	6.1
DDGS						
0%	132	388	540	928[a]	906	747
15%	129	380	536	893[b]	892	738
Pooled SEM	2.5	5.1	5.8	6.0	6.1	6.1
Sources of Variation	(P)					
Density	0.06	0.01	0.01	0.01	0.01	0.01
DDGS	0.46	0.29	0.71	0.01	0.12	0.31
Density x DDGS	0.34	0.47	0.83	0.06	0.14	0.82

[a-d] Means within a column and section with no common superscript differ significantly ($P < 0.05$).

[1] DDGS= distiller's dried grains with solubles.

[2] Means represent eight pens per treatment, six chicks per pen.

TABLE 2.5. Effects of feeding DDGS[1] to broilers on weight gain and feed efficiency, Experiment 2[2]

	Weight gain (g/chick)			Gain:feed (g:kg)		
DDGS %	Day 0-16	Day 17-31	Day 0-42	Day 0-16	Day 17-31	Day 0- 42
0	414[a]	1052	2314[a]	746[a]	597	566
6	416[a]	1055	2289[a]	739[a]	600	554
12	399[ab]	1049	2291[a]	715[ab]	604	565
18	387[b]	1039	2243[b]	702[b]	599	554
Pooled SEM	7.2	7.2	14.4	11.2	5.7	6.7

[a-b] Means within a column with no common superscript differ significantly *(P* < 0.05).

[1] DDGS= distiller's dried grains with solubles.

[2] Means represent six pens per treatment, 50 chicks per pen.

TABLE 2. 6. Effect of feeding DDGS[1] to broilers on carcass weights and yields, Experiment 2[2]

DDGS%	Carcass	Breast meat	Wings	Front half[3]	Back Half[4]
	----------(g)----------				
0	1673	284	193	719	761
6	1662	274	194	713	755
12	1653	278	193	713	747
18	1639	272	193	705	741
Pooled SEM	22.7	7.5	2.7	11.8	10.9
	----------(%)[5]----------				
0	71.2	16.9	11.5	43.0	45.5
6	70.9	16.5	11.7	42.9	45.4
12	70.3	16.8	11.7	43.2	45.2
18	70.8	16.6	11.8	43.0	45.2
Pooled SEM	0.80	0.29	0.09	0.29	0.33

[1] DDGS= distiller's dried grains with solubles.
[2] Means represent six pens per treatment, 10 birds per pen.
[3]Front half= the half of the carcass containing the breast, wings, and back (white meat).
[4]Back half= the half of the carcass containing the leg quarters joined at the lower back (dark meat).
[5]Yields = % of chilled carcass weights, carcass yield = % of live weight.

CHAPTER 3

THE USE OF DISTILLER'S DRIED GRAINS PLUS SOLUBLES IN LAYING HEN DIETS[1]

[1] Lumpkins, B. S., A.B. Batal, and N. M. Dale. Submitted to *Journal of Applied Poultry Research.*

ABSTRACT A major emphasis on ethanol production in the U.S. has led to the construction of new ethanol plants and an increased production of distiller's dried grains plus solubles (DDGS). In the past DDGS has come largely from the beverage industry, and consisted of several grains used during fermentation. Recently, a majority of the DDGS produced is from corn fermentation for fuel ethanol production. Little research has been conducted to test the use of this DDGS from modern ethanol plants in laying hen diets. Hy-line W-36 laying hens were used to test the effects of feeding an elevated inclusion level of DDGS in layer diets. Hens were fed a commercial or low density diet formulated to contain 0 or 15% DDGS from 25 to 43 wk of age. No differences were observed in the majority of parameters evaluated between hens fed 0 or 15% DDGS. However, there was a significant ($P < 0.05$) reduction in hen-day egg production through 35 wk of age when hens were fed the low density diet with 15% DDGS. Hens fed the commercial diet with 15% DDGS had numerically lower egg production from 25 to 35 wk of age, but it was not statistically different than the hens fed the commercial 0% DDGS diet. Distiller's dried grains plus solubles proved to be an acceptable feed ingredient for laying hen diets. Based on a conservative recommendation, 6 to 8% DDGS can be safely incorporated into layer diets during peak production, and once body weight and feed intake have stabilized the DDGS level can be increased to 10 or 12%.

(*Key Words*: Distiller's dried grains plus solubles, DDGS, laying hens, egg quality, egg production)

INTRODUCTION

Recently, the United States has placed a major emphasis on increasing fuel ethanol production. The government's reasoning for this increase in ethanol production is due mainly to environmental issues; ethanol burns cleaner and supplies more energy than crude oil (Reilly, 1979). Due to this emphasis the production of non-beverage ethanol has climbed to over 2 million gallons per year, and additional modern ethanol production plants are currently being built that will further increase this quantity. In the production of ethanol three approximately equal components are formed: 1/3 is ethanol, 1/3 is released as carbon dioxide, and the final 1/3 is distiller's dried grains plus solubles (DDGS). Currently in the North America, there are approximately 3 million metric tons of DDGS available to feed producers and by the year 2005 it is estimated that there will be 5 to 7 million metric tons available.

In past decades, distillers dried grains plus solubles was used as a feed ingredient in poultry diets partially due to its unidentified growth factors. It was later determined that these unidentified growth factors were vitamins synthesized during fermentation. Thus, feeding DDGS resulted in improved overall performance. By the 1950's synthesis of these vitamins and availability of trace minerals was common, and DDGS was largely removed from poultry diets and used more in ruminant and pet food diets. The distiller's dried grains plus solubles available in the past was from the fermentation of a variety of different grains used by the beverage industry. Today a majority of the DDGS available is from the production of fuel ethanol, which mainly uses corn during the fermentation process.

Although, DDGS has been extensively incorporated into dairy and beef cattle diets, the levels utilized will not fully deplete the increasing quantities available. Distiller's dried grains plus solubles from modern ethanol plants may be an attractive alternative ingredient for layer

diets. Thus, our primary objective was to evaluate the affects of feeding an elevated quantity of DDGS in laying hen diets.

MATERIALS AND METHODS

Experimental Procedures

All procedures were approved by the University of Georgia Animal Use and Care Committee. Hy-line W-36 White Leghorn hens were housed in a completely enclosed fan ventilated building with elevated wire cages, and the hens were exposed to a 16 L: 8 D daily lighting schedule. The experiment was conducted for a 22 wk period from June to October. The hens were provided feed and water *ad libitum* throughout the study. A total of four diets were formulated for the experiment, two were commercial diets to observe how DDGS would perform at industry standards, and two were low density diets to test any nutritional limitations of DDGS. Prior to formulating the diets it was determined that the DDGS sample had a TME_n of 2,805 kcal/kg, 27% crude protein and 0.94% lysine (unpublished data). For the first 4 wk of the study hens were divided into two groups and only fed the commercial grade diets, which contained 0 or 15% DDGS (Table 3.1). The 15% DDGS level was selected as a level higher than what may actually be fed as a means for observing any performance limitations that may occur. These diets were each fed from 21 to 25 wk of age to 16 replicate groups of 16 hens (two hens per (12" x 18") cage, 8 cages per replicate group), 256 hens per treatment. The commercial grade diets were fed to insure that the hens would reach the recommended body weight at 25 wk of age before being placed on a more sensitive low density diet, due to the hot summer conditions and the pullets being slightly underweight at the start of the experiment.

At 25 wk of age two additional diets were incorporated into the experiment. The two additional diets were low density diets that were formulated to be lower in protein and energy

than that of the commercial grade diets. The commercial grade diets were formulated to contain 18.5 % protein and a TME_n of 2,871 kcal/kg, and the lower density diets contained 17.0% protein and a TME_n of 2,805 kcal/kg (Table 3.1). Half of the hens being fed the commercial grade diet with 0% DDGS were switched to the low density diet containing 0% DDGS and half the hens being fed the commercial grade diet with 15% DDGS were then fed the low density diet with 15% DDGS. Therefore, at 25 wk of age all four diets were each fed to 8 replicate groups of 16 hens until 43 wk of age. The low density diets were designed to be more sensitive then the commercial grade by allowing any nutritional limitations of DDGS to become evident. At the occurrence of a mortality the hen was weighed, and hen-day egg production and feed intake were adjusted accordingly.

Egg production was measured daily (hen-day production), and egg weights were measured on a weekly basis after all eggs were collected for that d. Feed consumption, feed efficiency and hen body weight were measured at 25, 31, and 43 wk of age. Shell quality was tested using two methods. The two tests performed were specific gravity (Schoorl and Boersma, 1962) and shell breaking strength (Potts and Washburn, 1974), and these tests were conducted on eggs produced at 25, 35, and 43 wk of age. Shell breaking strength was measured on each individual egg using a texture analyzer[1] with a 5 kg load cell. The test speed was set at 2 mm/s with a 1g trigger. The eggs were placed in a cradle underneath the load cell with the air cell pointing up. The load cell applied pressure to the top of the egg until it cracked, and the force required to crack the egg was recorded in newtons. Eggs were also evaluated for interior quality by determining Haugh units and yolk color. Haugh units were measured using the QCD super

[1] TA.XT. plus texture analyzer. Texture Technologies Corp., 18 Fairview rd. Scarsdale NY 10583.

system[2]. Yolk color (L* (lightness), a* (redness), and b* (yellowness)) was measured using a Minolta colorimeter[3].

Statistical Analysis

Data from all parameters for both the commercial and low density diets were subjected to analysis of variance procedures for completely randomized designs (Steel and Torrie, 1980) and statistical differences were determined through the use of SAS® software (SAS Institute, 2001). Least significant difference test was used to assess any statistical significance of differences among the dietary treatments (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

No statistical differences ($P > 0.05$) in hen-day egg production or cumulative egg production were observed when hens were fed the commercial grade diets with 0 or 15% DDGS throughout the 22 wk experiment (Table 3.2). However, egg production of hens fed the diet with 15% DDGS was consistently lower through 32 wk of age (Table 3.2 and Figure 3.1). When hens were fed the low density diets there was a significant depression ($P < 0.05$) in egg production and cumulative egg production from 26 to 35 wk of age due to the 15% level of DDGS (Table 3.2 and Figure 3.2). However, after 35 wk of age there was no difference in egg production between the low density diets with 0 or 15% DDGS (Figure 3.2). There was no difference in egg weights or cumulative mass throughout the duration of the experiment when hens were fed the commercial or low density diets containing either 0 or 15% DDGS (Table 3.3).

At the three test periods (25, 31, and 43 wk of age) there was no statistical difference ($P > 0.05$) in feed intake between the commercial and low density diets with 0 or 15% DDGS (Table 3.4). Hens fed the low density diets were expected to have a greater feed intake than hens fed

[2] TSS QCD System. Technical Services and Supplies, Chessingham Park, Dunnington, York Y019 5SE, England.
[3] Minolta CR300 colorimeter. Minolta Corporation, 101 Williams Drive, Ramsey, NJ 07446, USA.

the commercial diet, but this was not observed. This could be partially due to the small difference of only 66 kcal TME/kg between the commercial and low density diets. In addition, the experiment was initiated during hot summer conditions, which appeared to depress feed intake for all the hens. Under these conditions the hens were not consuming as much feed as was expected, and it was observed that feed intake did not approach the recommended intake of 95g/bird/d until later in the study. The early depression in feed intake may have resulted in hens not acquiring the appropriate amount of nutrients, which would allow for differences in performance that would not normally be observed in a commercial setting. Feed efficiency (kg/dozen) was slightly better when diets did not contain DDGS. However, there was no statistical difference ($P < 0.05$) in feed efficiency between the commercial grade diets with 0 or 15% DDGS and the low density control (0% DDGS) during the 22 wk period (Table 3.5). The depression in egg production when the low density diet with 15% DDGS was fed appears to have resulted in the higher feed efficiency value observed at 31 and 43 wk of age. Body weights were measured throughout the experiment and no difference ($P > 0.05$) was observed between the four treatments. The inclusion of 15% DDGS in the commercial or low density diets had no affect on hen mortality.

There was no difference ($P < 0.05$) between the four treatments for specific gravity and shell breaking strength (results not shown). A specific gravity value of 1.08 or above is used by the laying hen industry as an indicator of good shell quality. The hens fed the commercial or low density diet with 0 or 15% DDGS did not lay an egg with a specific gravity value lower than 1.08. When testing the interior quality of the eggs, there was no statistical difference in Haugh units at 25, 35, and 43 wk of age between any four of the dietary treatments (Table 3.6). However, hens fed the commercial diet with 15% DDGS had a numerically higher Haugh unit

value at 43 wk of age compared to the commercial control diet. Hughes and Hauge (1945) observed improvements in Haugh units when hens were fed diets consisting of 5 and 10% brewers dried grains. Jensen *et al*. (1978) and Lilburn and Jensen (1984) reported that the incorporation of 20 % corn fermentation solubles into laying hen diets resulted in a significant improvement of Haugh units. Waldroup and Hazen (1979) reported a similar response in Haugh units with the use of corn dried steep liquor concentrate. Based on previous studies we expected to see improved Haugh units due to the incorporation of DDGS into laying hen diets. The trend towards improved interior egg quality may have been more pronounced if the experiment was carried out beyond 43 wk of age, when albumen quality usually declines.

A possible effect of DDGS on yolk color is of interest to researchers and producers considering the fact that DDGS is from corn origin and the xanthophylls in corn are a main contributor of yolk pigmentation. Researchers and producers are concerned that DDGS may supply additional pigment and create a darker yolk than what is desired by the consumer. At the three periods tested there was no observable difference in yolk color between 0 and 15% DDGS for both diet densities (Table 3.7). The L*a*b* values allow for the exact pinpoint of a color in a color sphere. The L* and b* values are the critical color indicators and are the colors that the human eye can differentiate. At 43 wk of age there was a statistical difference ($P < 0.05$) for the a* value only. However, the differences detected were so minor that the human eye would not be able to detect any difference in yolk color. The DDGS used in these diets had a color value of L*= 58.52, a*= 6.38, b*=20.48. The color testing of our DDGS sample will allow for future comparisons of other DDGS samples.

Matterson *et al.* (1966) performed two 40 wk experiments with Leghorn –type birds on litter floors. The laying hens were fed a corn-soybean (SBM) meal diet with the incorporation of

0, 10, and 20% DDGS. The distiller's dried grains plus solubles used came from the beverage industry, and the diets were formulated to contain an energy value of approximately 2,900 kcal ME_n/kg. No differences in egg production were observed due to the inclusion of 10 or 20% DDGS. Harms *et al.* (1969) incorporated 0 and 10% DDGS (beverage industry) into laying hen rations to which various amounts of methionine were supplemented. The treatments were fed to 28 wk old Hy-line 934-H pullets for 280 days. No significant difference in egg production was observed regardless of the level of sulfur amino acids supplemented. Considering that the experiment reported herein was conducted during summer conditions with initially low feed intake and lower energy diets most likely resulted in the early depression in egg production. It can be speculated that the hens were not fully meeting their caloric intake during this period.

Another explanation for the initial depression in egg production may be due to the amino acid profile of DDGS. Hughes and Hauges (1945) observed that when DDGS was used as the sole source of protein in a corn-wheat broiler diet there was a slight deficiency in lysine and tryptophan causing a decrease in male rat growth performance during an 18 d period. The diets herein were formulated on a total amino acid basis, which could have resulted in a lysine or amino acid deficiency. Also, SBM has a more preferable amino acid pattern for poultry production than corn. In a normal corn-SBM diet, SBM contributes 75% protein. However, when using 15% DDGS (whose protein is of corn origin) SBM only contributes 50% of the total protein. The differences in amino acid levels and its availability could have affected production performance.

An early numeric depression in egg production was observed when 15% DDGS was included in both the commercial and low density diets. Based on egg production, it could be concluded that the inclusion of 15% DDGS in a standard layer diet may be above a

recommended maximum inclusion level especially during peak production. The feeding of 15% DDGS to laying hens had no effect on egg weight, yolk color, and exterior or interior egg quality. Six to 8% DDGS is a conservative recommendation that can be safely incorporated into layer diets during peak production. Once body weight and feed intake have stabilized the level of DDGS in laying hen diets can be increased to 10 or 12%. Distiller's dried grains plus solubles has proven to be an acceptable feed ingredient in laying hen diets and might be advantageous to nutritionist in formulating a laying hen diet at a lower cost.

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REFERENCES

Harms, R.H., R.S. Moreno, and B.L. Damron. 1969. Evaluation of distiller's dried grain with solubles in diets of laying hens. Poult. Sci. 48:1652-1654.

Hughes, C.W. and S.M. Hauge. 1945. Nutritive Value of Distillers' Dried Solubles as a Source of Protein. J. Nutr. 30: 245-258.

Jensen, L.S., C.H. Chang, and S.P. Wilson. 1978. Interior egg quality : improvement by distillers feeds and trace elements. Poult. Sci. 57 :648-654.

Lilburn, M.S. and L.S. Jensen. 1984. Evaluation of corn fermentation solubles as a feed ingredient for laying hens. Poult. Sci. 63:542-547.

Matterson, L.D., J. Tlustohowicz, and E.P. Singsen. 1966. Corn distillers dried grains with solubles in rations for high-producing hens. Poult. Sci. 45:147-151.

Potts, P.L. and K.W. Washburn. 1974. Shell evaluation of white and brown egg strains by specific gravity, breaking strength, shell thickness and Specific gravity. I. Relationship to egg characteristics. Poult. Sci. 53: 1123-1128

Reilly, P.J. 1979. Gashol-future prospects. Distillers Feed Conference 34 :4-14.

SAS Institute. 2001. SAS® User's guide: Statistics. Version 8 Edition. SAS Institute Inc., Cary, NC.

Schoorl, P. and H.Y. Boersma. 1962. Research on quality of the egg shell. 12th World's Poult. Congr., Sydnet: 432-435.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics. A Biometrical Approach. 2nd ed. McGraw-Hill Book Co., Inc., New York, NY.

Waldroup, P.W. and K.R. Hazen. 1979. Examination of corn dried steep liquor concentrate and various feed additives as potential sources of a Haugh unit improvement factor for laying hens. Poult. Sci. 58 : 580-586.

TABLE 3.1. Composition of layer diets (as fed basis)

Ingredients	Commercial		Low density	
	Control	DDGS[1]	Control	DDGS[1]
	(%)			
Corn, yellow, ground	54.944	48.082	61.415	54.554
Soybean meal (48)	29.659	21.585	25.450	17.375
DDGS[1]	---	15.000	---	15.000
Limestone	9.358	9.484	9.432	9.557
Fat, poultry	3.430	3.447	1.180	1.197
Dicalcium phosphate	1.666	1.289	1.574	1.197
Salt	0.417	0.386	0.418	0.387
Egg layer premium[2]	0.250	0.250	0.250	0.250
DL-methionine	0.211	0.199	0.176	0.164
Trace mineral premix[3]	0.060	0.060	0.060	0.060
L-lysine	0.005	0.219	0.045	0.259
Contents by calculation				
ME, kcal/kg	2871	2871	2805	2805
Protein, %	18.5	18.5	17.0	17.0
Lysine, %	1.02	1.02	0.94	0.94
Methionine, %	0.52	0.53	0.47	0.48

[1]DDGS= Distiller's dried grains plus solubles.

[2]Vitamin mix provided the following (per kg of diet): thiamin•mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B12 (cobalamin), 12.0 µg; pyridoxine•HCL, 2.7 mg; D-biotin, 0.11 mg; folic acid, 0.55 mg; menadione sodium bisulfate complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 1,100 IU; trans-retinyl acetate, 5,500 IU; all-rac-tocopherol acetate, 11 IU; ethoxyquin, 150 mg.

[3]Trace mineral mix provides the following (per kg of diet): manganese ($MnSO_4 \cdot H_2O$), 60 mg; iron ($FeSO_4 \cdot 7H_2O$), 30 mg; zinc (ZnO), 50 mg; copper ($CuSO_4 \cdot 5H_2O$), 5 mg; iodine (ethylene diamine dihydroiodide), 1.5 mg.

TABLE 3.2. Effect of feeding DDGS[1] in a commercial and low density diet to laying hens on hen-day egg production[2]

	Commercial Diets			Low Density Diets		
Weeks of age	0% DDGS	15% DDGS	Pooled SEM	0% DDGS	15% DDGS	Pooled SEM
	——————(%)——————			——————(%)——————		
22	62.9	64.2	2.29	----	----	----
24	94.2	92.3	1.42	----	----	----
26	95.2	94.3	0.99	95.4[a]	91.1[b]	0.84
28	95.5	92.3	1.02	94.9	91.6	1.29
30	96.2[a]	92.2[b]	1.14	95.3[a]	89.9[b]	1.29
32	94.2	91.7	1.03	93.7[a]	90.2[b]	1.04
34	92.7	92.4	0.96	90.3	87.6	1.43
36	90.0	92.3	0.96	89.6	88.1	2.97
38	91.0	91.3	1.04	89.0	88.4	0.84
40	90.7	91.7	0.79	88.9	87.2	0.96
42	89.5	90.8	1.14	88.9	88.9	1.09

[a-b] Means within a row and diet with no common superscript differ significantly ($P < 0.05$).
[1]DDGS= Distiller's dried grains plus solubles.
[2]Means represent 8 replications per treatment (16 hens/replication).

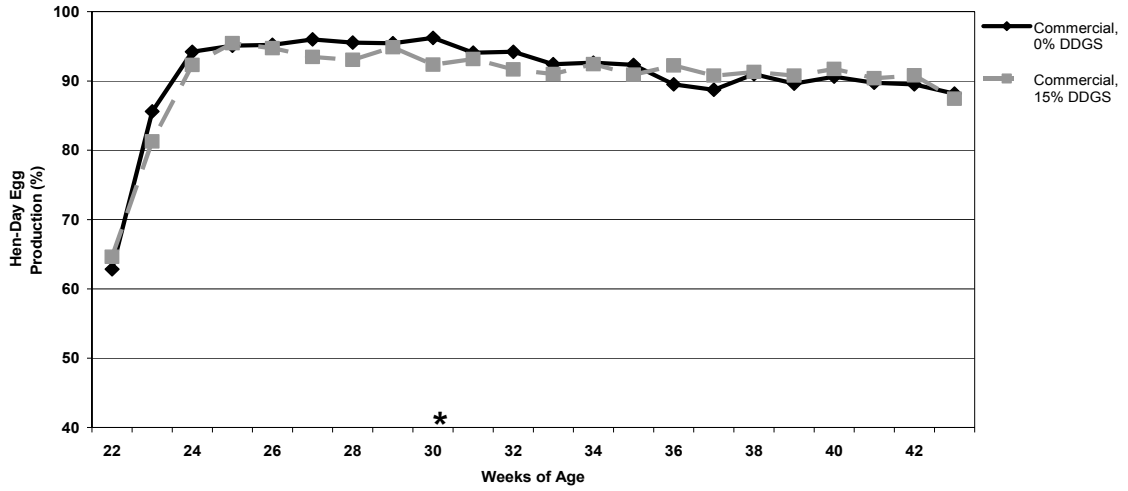

FIGURE 3.1. Effects of feeding distiller's dried grains plus solubles in commercial grade diets to laying hens on hen-day egg production. *Asterick denotes a significant ($P < 0.05$) difference between the two treatments.

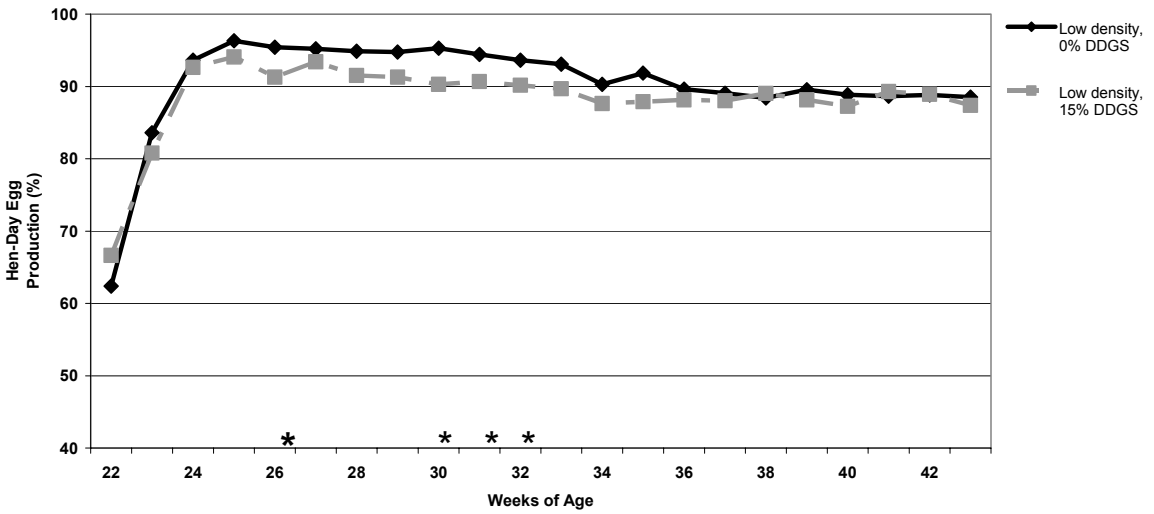

FIGURE 3.2. Effects of feeding distiller's dried grains plus solubles in low density diets to laying hens on hen-day egg production. *Asterick denotes a significant ($P < 0.05$) difference between the two treatments.

TABLE 3.3. Effects of feeding DDGS[1] to laying hens on egg weights[2]

	Commercial Diets		Low density Diets		
Weeks of age	0 % DDGS	15% DDGS	0% DDGS	15% DDGS	Pooled SEM
	(g)				
22	37.6	37.1	------	------	2.06
24	49.5	49.9	------	------	0.19
26	52.8	52.6	51.9	52.4	0.42
28	51.8[b]	53.1[a]	51.4[b]	52.4[ab]	0.47
30	54.6	54.7	53.5	54.6	0.41
32	56.2	56.0	55.2	55.9	0.33
34	57.1	56.8	56.1	56.8	0.31
36	57.9[a]	58.3[a]	56.8[b]	57.6[a]	0.28
38	59.4	59.3	58.4	58.7	0.34
40	60.3	60.2	59.6	59.6	0.35
42	61.3	60.0	60.0	61.2	0.65
Cumulative	52.6	51.5	51.6	51.3	0.72

[a-b] Means within a row with no common superscript differ significantly ($P < 0.05$).
[1] DDGS= Distiller's dried grains plus solubles.
[2] Means represent 8 replications per treatment (16 hens/replication).

TABLE 3.4. Effects of DDGS[1] on feed intake of laying hens[2]

Treatments	Week 25	Week 31	Week 43
	g/hen/day		
Commercial, 0% DDGS	83	91	94
Commercial, 15% DDGS	84	91	94
Low density, 0% DDGS	------	90	95
Low density, 15% DDGS	------	92	95
Pooled SEM	0.65	0.73	0.68

[1] DDGS= Distiller's dried grains plus solubles.
[2] Means represent 8 replications per treatment (16 hens/replication).

TABLE 3.5. Effects of DDGS[1] on feed efficiency of laying hens[2]

Treatments	Week 25	Week 31	Week 43
	kg/dozen[3]		
Commercial, 0% DDGS	1.18	1.15[b]	1.21[b]
Commercial, 15% DDGS	1.20	1.18[ab]	1.22[b]
Low density, 0% DDGS	------	1.14[b]	1.23[b]
Low density, 15% DDGS	------	1.21[a]	1.26[a]
Pooled SEM	1.369	0.013	0.008

[1] DDGS= Distiller's dried grains plus solubles.
[2] Means represent 8 replications per treatment (16 hens/replication).
[3] kg/dozen= kg of feed consumed per hen/dozen eggs produced per hen.

TABLE 3.6. Effects of feeding DDGS[1] to laying hens on egg Haugh units[2]

Treatments	Week 25	Week 35	Week 43
	Haugh units		
Commercial, 0% DDGS	95.2	91.6	85.4[ab]
Commercial, 15% DDGS	96.4	94.5	87.2[a]
Low density, 0% DDGS	------	95.3	85.9[ab]
Low density, 15% DDGS	------	93.8	84.3[b]
Pooled SEM	0.89	1.66	0.66

[a-b] Means within a column with no common superscript differ significantly ($P < 0.05$).
[1] DDGS= Distiller's dried grains plus solubles.
[2] Means represent 8 replications per treatment (16 hens/replication).

TABLE 3.7. Effect of feeding DDGS[1] to laying hens on yolk color at 43[3] weeks of age[2]

Treatments	L*	a*	b*
Commercial, 0% DDGS	55.16	-2.01[b]	45.46
Commercial, 15% DDGS	54.34	-0.11[a]	47.62
Low density, 0% DDGS	55.13	-1.75[b]	46.14
Low density, 15% DDGS	54.15	-0.19[a]	48.20
Pooled SEM	0.19	0.24	0.45

[a-b] Means within a column with no common superscript differ significantly ($P < 0.05$).
[1] DDGS= Distiller's dried grains plus solubles.
[2] Means represent 8 replications per treatment (16 hens/replication).
[3] Color (L* (lightness), a* (redness), and b* (yellowness)) was measured with a Minolta CR300 colorimeter.

CHAPTER 4

THE BIOAVAILABILITY OF LYSINE AND PHOSPHORUS IN DISTILLER'S DRIED GRAINS WITH SOLUBLES [1]

[1] Lumpkins, B. S., A.B. Batal, and N. M. Dale. Will be submitted to *Poultry Science.*

ABSTRACT Five experiments were conducted to determine the Lys and phosphorus (P) bioavailability of distiller's dried grains with solubles (DDGS), which was derived from corn fermentation in a modern non-beverage ethanol plant. In Experiment 1, using the precision-fed cecectomized rooster assay the true digestibility of Lys in DDGS was estimated to be 75%. In Experiments 2, 3, 4, and 5 the bioavailability of Lys and P were assessed using slope-ratio chick growth experiments. In Experiments 2 and 3, Lys deficient basal diets containing 0.40 or 0.60% digestible Lys respectively, were formulated. A linear growth response ($P < 0.05$) was observed from the addition of 0.10 and 0.20% L-Lys from L-Lys•HCl and DDGS (10 and 20%) to the basal diets. Body weight gain was regressed on Lys intake from L-Lys•HCl and DDGS, and the ratio of the slopes indicated the bioavailable Lys in DDGS. The values as a percent of total Lys (0.83) in DDGS, yielded availability estimates of 80% for Experiment 2 and 100% for Experiment 3. In Experiments 4 and 5, a P deficient basal diet containing 0.12% non-phytate phosphorus was formulated. A linear growth and tibia ash (%) response ($P < 0.05$) was observed from the addition of 0.05 and 0.10% P from K_2HPO_4 and two levels of DDGS (5 and 10% for Experiment 4, and 7 and 14% for Experiment 5). Tibia ash (%) was regressed on P intake from K_2HPO_4 or DDGS, and the ratio of slopes indicated the bioavailability of P in DDGS. The values as a percent of total P (0.74%) in DDGS, yielded availability estimate of 68% for Experiment 4 and 54% for Experiment 5.

(Key words: Distiller's dried grains with solubles, lysine, bioavailability, phosphorus)

INTRODUCTION

The majority of distiller's dried grains with solubles (DDGS) produced has traditionally been derived from the beverage industry based on a mixture of several grains used during the fermentation process. Recently, the United States has encouraged non-beverage ethanol production as ethanol is cleaner burning, provides more energy than petroleum and is a renewable resource. Ethanol producers responded to government encouragement in the mid to late 1990's by building new plants. Large quantities of DDGS from these new non-beverage ethanol plants have become available to the feed industry (Shurson, 2003), which has renewed interest in using DDGS in poultry diets. The DDGS coming from these modern plants is almost exclusively from corn fermentation and is dried under lower temperatures, all of which allows DDGS to be a more consistent product (Noll *et al*. 2003).

The bioavailability of Lys in DDGS has been questioned. In the process of drying DDGS the material is exposed to temperatures of approximately 600°F. Similar to soybean meal (Fernandez and Parsons, 1996), it has been reported that excessive heating leads to a decrease in amino acid (AA) availability, specifically Lys (McGinnis and Evans, 1947; Warnick and Anderson, 1968). Research in the past has been conducted to determine AA availability of DDGS, but much of the DDGS used was a by-product of the beverage industry with several grains employed during the fermentation. Combs and Bossard (1969) performed a chick growth assay and reported Lys bioavailability values ranging from 74 to 90%. Parsons *et al.* (1983) estimated a lower bioavailability of 66% using similar methodology, and also determined the true digestibility of Lys in DDGS to be 82% using the total fecal collection assay. The variation in reported availability values and recorded estimates (NRC, 1994) may be due to the differences in the drying process and the grain composition of DDGS.

In recent years environmental concerns have been directed towards the poultry industry. Poultry manure has become a concern due to its phosphorus (P) content present, which may contribute to environmental contamination. Thus, efficient P utilization (i.e. reduced excretion) is of great concern. In an effort to reduce P in poultry waste, diets for commercial broilers have been formulated with reduced levels of both inorganic P and supplemented with phytase. As P is an expensive component of poultry diets, knowledge of the availability of P in DDGS will allow feed producers to more accurately formulate diets so as to meet the bird's P needs while reducing environmental contamination. Research conducted to determine the P bioavailability of DDGS is limited.

Due to the increased interest and availability of this feedstuff, the present studies were conducted to determine the Lys and P bioavailability of DDGS from modern non-beverage fuel ethanol plants.

MATERIALS AND METHODS

Analytical and Digestibility Evaluation of DDGS

The distiller's dried grains with solubles used in these experiments was produced in a non- beverage fuel ethanol plant in Aurora, Nebraska, built in the early 1990's using corn as the fermentation substrate. The sample had a golden yellow color, a coarse appearance, and a distinctively sweet smell. The distiller's dried grains with solubles used in these experiments was analyzed for dry matter, crude protein, ether extract, crude fiber, ash, sodium and P (Table 4.1) by the methods of the Association of Official Analytical Chemists (1984). In addition, nine samples of DDGS were analyzed for total P and phytate P concentration[1] as described by Latta and Eskin (1980).

[1] UGA Nutritional Lab, University of Georgia, Poultrys Science Bldg. Athens, GA 30602

Experiment 1

The true digestibility of Lys in DDGS was determined using the precision-fed cecectomized rooster assay. Single Comb White Leghorn roosters were cecectomized at 20 wk of age as described by Parsons (1985) and not used for digestibility trials for at least 2 months after surgery. The roosters were allowed *ad libitium* access to feed and water prior to the true digestibility experiment. All birds were fasted for a 24 h period and five roosters were crop intubated with 30 g of DDGS. The crop intubation procedure has been described by Sibbald (1986). An additional five roosters were fasted throughout the experimental period, which allowed for the measuring of endogenous AA excretion. Excreta were collected quantitatively for 48 h post feeding (Likuski and Dorrell, 1978). Excreta samples were dried at 75ºC for 48 h, weighed, and ground. The distiller's dried grains with solubles and excreta samples were then sent to the Experiment Station Chemical Laboratories at the University of Missouri[2] for the determination of AA concentrations. The true digestibility experiment was performed twice with a month interval period and the calculated digestibility values from each experiment were averaged.

Chick Bioavailability Experiments 2, 3, 4, and 5- General Procedures

Four experiments were conducted to determine the bioavailability of Lys and P in DDGS using multiple regression slope-ratio methodology. The basal diets for the Lys and P experiments provided vitamins, minerals except P (for Experiments 4 and 5) and all indispensable AA except Lys (for Experiments 2 and 3), in amounts adequate to meet or exceed NRC (1994) nutrient recommendations for maximal chick growth. Male Cobb 500 chicks were

[2] Experiment Station Chemical Laboratories, University of Missouri-Columbia, room 4, Agriculture Bldg, Columbia, MO 65211

housed in environmentally controlled rooms in thermostatically controlled starter batteries[3] with raised wire floors and were allowed *ad libitum* access to water and feed. Uniform light was provided 24 h daily. Chicks received a standard starter broiler diet (3,200 kcal ME_n/kg, 23% crude protein, and 0.2% supplemental methionine) from 0 to 7 d of age. On day 8, after an overnight period of feed withdrawal, chicks were weighed and randomly allotted to pens such that each pen had similar initial weights. Each of the diets were fed to six replicate pens of six chicks. Body weight and feed intake for all the groups were measured, and weight gain and feed efficiency (gain:feed) were calculated.

Experiments 2 and 3

The bioavailability of Lys was determined by slope-ratio assay using a semi-purified cornstarch-dextrose-corn gluten meal basal diet (Table 4.2), which was formulated to contain 0.40 and 0.60% digestible Lys, for Experiments 2 and 3, respectively. The true digestibility of Lys in the corn gluten meal was estimated to be 0.88% by the total fecal collection method using cecectomized roosters. A linear standard growth curve was constructed by the addition of 0.10 and 0.20% L-Lys from L-Lys•HCl to the basal diets to achieve digestible Lys levels of 0.50 and 0.60% in Experiment 2, and 0.70 and 0.80% in Experiment 3. In addition, two levels of DDGS (10 and 20%) were added to the basal diets for Experiments 2 and 3, at the expense of cornstarch, to provide levels of digestible Lys that would be expected to fall within the boundaries of the standard curve. The chicks were fed the experimental diets from 8 to 19 d posthatching in Experiment 2, and 8 to 17 d posthatching for Experiment 3.

Experiments 4 and 5

The bioavailability of P in DDGS was determined in two chick growth experiments (4 and 5). A corn-soybean meal basal diet containing 0.12% non-phytate P (Table 4.3) was

[3] Petersime Incubator Co., Gettyburg, OH 45328

supplemented with 0.05 and 0.10% P from K_2HPO_4 to create conditions projected to result in a linear standard growth curve. Two levels of DDGS in Experiment 4 (5 and 10%) and Experiment 5 (7 and 14%) were added to the basal diet at the expense of cornstarch to provide a linear test growth curve. In Experiments 4 and 5, the chicks were fed each of the five experimental diets from 8 to 21 d posthatching. At the end of each experiment left tibias were collected from every bird. The muscle and tissue were removed from the tibia leaving only the cartilage cap and bone. The bones then underwent fat extraction as described by the Association of Official Analytical Chemists (1984) and were ashed at 600ºC in a muffle furnace for 24 hr to allow for the determination tibia ash percent.

Statistical Analysis

Bioavailability of Lys and P were calculated using slope-ratio methodology (Finney, 1978). Multiple regressions were computed with mg of supplemental digestible Lys and P intake from L-Lys•HCl or K_2HPO_4 (standards) or DDGS as the independent variables and total body weight gain, feed efficiency, and tibia ash (%) as the dependent variable. The digestibility of L-Lys•HCl (Chung and Baker, 1992; Zhang and Parsons, 1993) and K_2HPO_4 was assumed to be 100%. The calculated ratio of the slope of the DDGS response lines to the L-Lys•HCl or P (K_2HPO_4) standard lines yielded the amount of bioavailable Lys or P, which was then expressed as a proportion of total Lys or P in the DDGS to estimate availability. Prior to computing the multiple regression equations, all response lines were tested for linearity and intersection effects as described by Finney (1978). After the multiple regression coefficients or slopes were tested for statistical differences as outlined by Steel and Torrie (1980) the slope values were then tested for statistical differences as outlined by Finney (1978). All data were analyzed using algorithms generated by SAS Institute (1990).

RESULTS AND DISCUSSION

Experiment 1, 2, and 3; Lysine Bioavailability

The total fecal collection assay using adult cecectomized roosters yielded a true digestibility estimated of 75% for the Lys in DDGS. The growth performance and feed efficiency (gain: feed) results for Experiments 2 and 3 are summarized in Table 4.4. A linear growth response ($P < 0.05$) was observed from the addition of supplemental L-Lys•HCl and DDGS to the basal diet in both experiments. Multiple regression methodology was used in both experiments. The equation developed for Experiment 2 based on gain was: gain (g) = 14.4 + 0.15 Lys intake (mg) + 0.10 DDGS intake (g); R^2= 0.98. The bioavailability of Lys was then estimated using the slope-ratio methodology were growth rate was regressed on Lys intake from L-Lys•HCl or DDGS. The ratio of slopes indicated a bioavailable Lys concentration of 0.67% in DDGS. The determination of available Lys in DDGS was calculated by dividing the bioavailability value, which was determined by slope-ratio, by the total Lys concentration value (0.83%) to yield an availability estimate of 80%. In Experiment 3, the model developed was gain (g) = 114.7 + 0.12 Lys intake (mg) + 0.10 DDGS intake (g); R^2=0.85. The ratio of slopes indicated a bioavailability Lys concentration of 0.83% in DDGS. This value expressed as a percentage of 0.83% total Lys in DDGS yielded an availability estimate of 100%.

The values obtained based on the chick growth assays varied between Experiments 2 and 3. When the multiple regression model was graphed there was an overlap of the standard and test (DDGS) curves, which confirmed the 100% availability of Lys estimated for Experiment 3. However, it is unlikely for a nutrient to be 100% available, and this value was deemed questionable. The 80% available Lys determined in Experiment 2 is felt to be the more accurate estimated value and was similar to the 75% true Lys digestibility findings in Experiment 1.

The Lys bioavailability estimate of 80% obtained with the chick growth experiment was similar and slightly higher than that of Ergul *et al*. (2003) who determined an average Lys digestibility of 71% for DDGS. Combs and Bossard (1969) observed similar values of 74 to 90% bioavailable Lys even though the DDGS used was a by product of the beverage industry. However, Parsons *et al*. (1983) also conducted a chick growth study using DDGS from the beverage industry and observed a lower Lys bioavailability value of 66%. The Lys digestibility of DDGS (75-80%) from modern non-beverage ethanol plants is higher than reported values from past experiments using DDGS fermented with several grains (Parsons *et al*., 1983) and the value of 65% reported in the NRC (1994). These results also indicate that the Lys digestibility of DDGS (75-80%) from modern non-beverage ethanol plants is not extremely different from the Lys digestibility of corn (81%). Thus, the Lys digestibility of DDGS from modern non-beverage ethanol plants does not appear to be greatly hindered during the drying process.

Experiment 4 and 5; Phosphorous Bioavailability

The results of the growth performance and tibia ash (%) for Experiments 4 and 5 are summarized in Table 4.5. The addition of P at levels of 0.05 and 0.10% from K_2HPO_4 to the basal diet resulted in a linear growth and tibia ash (%) response ($P < 0.05$). The addition of DDGS to the basal diet at a level of 5 and 10% for Experiment 4, and 7 and 14% for Experiment 5 also resulted in a linear increase in growth and tibia ash (%) ($P < 0.05$). A significant difference ($P < 0.05$) was observed between the various levels of P that were supplemented to the basal diet in either the form of K_2HPO_4 and DDGS. The results were tested for linearity and a multiple regression analysis was performed to develop the following models. In Experiment 4, the model was tibia ash (%) = 25.09 + 0.01 P intake (mg) + 0.005 DDGS intake (g); R^2= 0.81 and Experiment 5 using tibia ash (%) = 26.11 + 0.01 P intake (mg) + 0.004 DDGS intake (g);

R^2= 0.88. Through slope ratio methodology the bioavailability of P based on tibia ash (%) for Experiments 4 and 5 were 0.50 and 0.40%, respectively. Phosphorus availability was calculated to be 68% for Experiment 4, and 54 % for Experiment 5 based on the total P value of 0.74% in DDGS.

The P bioavailability estimate of 68 and 54% for Experiments 4 and 5 is similar to the average value (54%) reported by Amezcua *et al*. (2003) for 22 DDGS samples from various non-beverage ethanol plants in Minnesota. Whitney and Shurson (2001) conducted an experiment using swine and reported a higher P availability estimate of 88% for DDGS. The calculated 64% available P in DDGS (Table 4.6) was similar to our findings based on tibia ash (%) (61%, average of Experiments 4 and 5) and appears to be much higher than corn (29%). Thus, it can be speculated that the fermentation process, which the corn undergoes improves P availability in the by-product, DDGS, possibly through the synthesis of microbial phytase.

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REFERENCES

Amezcua, C.M., C.M. Parsons, and S.L. Noll. 2003. Content and bioavailability of phosphorus in distillers dried grains with solubles. Poult. Sci. 82 (Suppl. 1):36 (Abstr.).

Association of Official Analytical Chemists. 1984. Official Methods of Analysis. 14th ed. Association of Official Analytical Chemists, Washington, D.C.

Chung, T.K. and D.H. Baker. 1992. Apparent and true amino acid digestibility of a crystalline amino acid mixture and of casein: comparison of values obtained with ileal cannulated pigs and cecectomized cockerels. J. Anim. Sci. 70:3781-3790.

Combs, G.F. and E.H. Bossard. 1969. Further studies on available amino acid content of corn distillers dried grains with solubles. Pages 53-58 in Proc. Dist. Feed Res. Counc.

Ergul T., C.M. Amezcua, C.M. Parsons, D. Walters, J. Brannon, and S.L. Noll. 2003. Amino acid digestibility in corn distillers dried grains with solubles. Poult. Sci. 82 (Suppl. 1):70 (Abstr.).

Fernandez, S.R. and C.M. Parsons. 1996. Bioavailability of digestible lysine in heat-damaged soybean meal for chick growth. Poult. Sci. 75:224-231.

Finney, D.J. 1978. Statistical Method in Biological Assay. 3rd ed. Charles Griffin and CO. Ltd., High Wycombe, Buckinghamshire, UK.

Latta, M. and M. Eskin. 1980. A simple and rapid colorimetric method for phytate determination. J. Agric Food Chem. 28: 1313-1315.

Likuski, H.J.A. and H.G. Dorrell. 1978. A rapid bioassay for determinations of amino acid availability. Poult. Sci. 57: 1658-1660.

McGinnis, J. and R.J. Evans. 1947. Amino acid deficiencies of raw and over-heated soybean oil meal for chicks. J. Nutr. 34: 725-732.

National Research Council. 1994. Nutrient Requirements for Poultry. 9th rev. ed. National Academy Press, Washington, DC.

Noll, S.L., C. Abe, and J. Brannon. 2003. Nutrient composition of corn distiller dried grains with solubles. Poult. Sci. 82 (Suppl. 1):71. (Abstr.)

Parson, C.M. 1985. Influences of caecectomy on digestibility of amino acids by roosters fed distillers' dried grains with solubles. J. Agric. Sci Camb. 104:469-472.

Parsons, C.M., D.H. Baker, and J.M. Harter. 1983. Distillers dried grains with solubles as a protein source for the chick. Poult. Sci. 62:2297-2572.

SAS Institute Inc. 1990. SAS STAT User's Guide Release 6.08. SAS Institute Inc., Cary NC.

Sibbald, I.R. 1986. The T.M.E. system of feed evaluation: methodology, feed consumption data and bibliography. Technical Bulletin 1986-4E. Agriculture Canada, Ottawa, ON, Canada

Shurson, J. 2003. Subject: The value and Use of Distillers Dried Grains with Solubles (DDGS) in Livestock and Poultry Rations. http://www.ddgs.umn.edu/. Accessed Nov. 2003.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics. A Biometrical Approach. 2nd ed. McGraw-Hill Book Co., Inc., New York, NY.

Warnick, R.E. and J.O. Anderson. 1968. Limiting essential amino acids in soybean meal for growing chickens and effects of heat upon availability of essential amino acids. Poult. Sci. 47: 281.

Whitney, M.H. and G.C. Shurson. 2001. Availability of phosphorus in distiller's dried grains with solubles for growing swine. J. Anim. Sci. 79: 108 (Suppl. 1).

Zhang, Y. and C.M. Parsons. 1993. Effect of crystalline lysine and methionine intake on amino acid excretion by precision-fed cockerels. Poult. Sci. 72:1180-1183.

TABLE 4.1. Nutritional composition of distiller's dried grains with solubles (as-fed basis)

Component	%
TME_n, kcal/kg	2905[1]
Dry matter	86.00
Crude protein	30.00
Ether extract	9.80
Crude fiber	5.34
Phosphorus	0.74
Ash	3.90
Sodium	0.11
Amino Acids	
Lysine	0.83
Methionine	0.56
TSAA	1.18
Threonine	1.05
Arginine	1.25
Tryptophan	0.28

[1] TME_n for DDGS was determined in ten conventional roosters.

TABLE 4.2. Composition of the lysine-deficient basal diets (as-fed basis)

Ingredients	Experiment 2[1]	Experiment 3[2]
	----------(%)----------	
Cornstarch	to 100.00	to 100.00
Corn gluten meal[3]	25.00	25.00
Dextrose	29.98	30.56
Fat, poultry	3.00	3.00
Limestone	1.32	1.32
Dicalcium phosphorus	2.25	2.25
Salt	0.40	0.40
Vitamin mix[4]	0.50	0.50
Mineral mix[5]	0.08	0.08
L-Lysine•HCl	0.22	0.47
DL-Methionine	0.30	0.30
Gylcine	2.00	2.00
L-Glutamic acid	5.50	4.92
L-Threonine	0.30	0.30
L-Tryptophan	0.12	0.12
L-Isoleucine	0.22	0.22
L-Arginine	0.77	0.77
L-Valine	0.22	0.22
L-Histidine	0.05	0.05
Zinc bacitracin[6]	0.05	0.05
$MgSO_4•7H_2O$	0.30	0.30
K_2HPO_4	0.51	0.51
$NaHCO_3$	0.50	0.50
Coccidostat[7]	0.08	---

[1]The diet contained (by calculation): 22.5% crude protein, 3,613 kcal ME_n/kg, and 0.40% digestible Lys.

[2] The diet contained (by calculation): 22.5% crude protein, 3,532 kcal ME_n/kg, and 0.60% digestible Lys.

[3]Corn gluten meal contained 1.05% total Lys, 0.88% digestible Lys.

[4]Vitamin mix provided the following (per kg of diet): thiamin•mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B_{12} (cobalamin), 12.0 µg; pyridoxine•HCL, 2.7 mg; D-biotin, 0.11 mg; folic acid, 0.55 mg; menadione sodium bisulfate complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 1,100 IU; trans-retinyl acetate, 5,500 IU; all-rac-tocopherol acetate, 11 IU; ethoxyquin, 150 mg.

[5]Trace mineral mix provides the following (per kg of diet): manganese ($MnSO_4•H_2O$), 60 mg; iron ($FeSO_4•7H_2O$), 30 mg; zinc (ZnO), 50 mg; copper ($CuSO_4•5H_2O$), 5 mg; iodine (ethylene diamine dihydroiodide), 1.5 mg.

[6] Contributed 27.5 mg bacitracin methylene disalicylate/kg.

[7] Coccidostat= Coban 60®, Elanco Animal Health, Indianapolis, IN 46285.

TABLE 4.3. Composition of basal diets used in Experiments 4 and 5 (as-fed basis)

Ingredients	Experiment 4[1]	Experiment 5[2]
	----------(%)----------	
Cornstarch	to 100.00	to 100.00
Corn	47.55	41.63
Soybean meal	38.00	40.00
Fat, poultry	2.00	2.00
Limestone	1.42	1.42
Salt	0.30	0.30
Vitamin mix[3]	0.25	0.25
Mineral mix[4]	0.08	0.08
Zinc bacitracin[5]	0.05	0.05
DL-Methionine	0.28	0.28
Coccidostat[6]	0.08	---

[1]The diet contained (by calculation): 22% crude protein, 3,172 kcal ME_n/kg, and 0.12% non-phytate P.

[2] The diet contained (by calculation): 22.5% crude protein, 3,172 kcal ME_n/kg, and 0.12% non-phytate P.

[3]Vitamin mix provided the following (per kg of diet): thiamin•mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B_{12} (cobalamin), 12.0 µg; pyridoxine•HCL, 2.7 mg; D-biotin, 0.11 mg; folic acid, 0.55 mg; menadione sodium bisulfate complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 1,100 IU; trans-retinyl acetate, 5,500 IU; all-rac-tocopherol acetate, 11 IU; ethoxyquin, 150 mg.

[4]Trace mineral mix provides the following (per kg of diet): manganese ($MnSO_4•H_2O$), 60 mg; iron ($FeSO_4•7H_2O$), 30 mg; zinc (ZnO), 50 mg; copper ($CuSO_4•5H_2O$), 5 mg; iodine (ethylene diamine dihydroiodide), 1.5 mg.

[5] Contributed 27.5 mg bacitracin methylene disalicylate/kg.

[6] Coccidostat= Coban 60®, Elanco Animal Health, Indianapolis, IN 46285.

TABLE 4.4. Determination of lysine availability in DDGS[1] using a slope-ratio bioassay, Experiments 2 and 3[2]

Treatment	Body weight gain (g/chick)	Gain:Feed (g:kg)
Experiment 2[3]		
Basal (0.40% avail. Lys)	15.7[d]	144.8[e]
Basal + 0.10% L-Lys[4]	37.4[c]	270.8[c]
Basal + 0.20% L-Lys	62.0[a]	378.5[a]
Basal + 10% DDGS	30.0[c]	231.7[d]
Basal + 20% DDGS	46.8[b]	334.0[b]
Pooled SEM	2.77	12.8
Experiment 3[5]		
Basal (0.60% avail. Lys)	116.1[c]	505.9[d]
Basal + 0.10% L-Lys	141.3[b]	578.5[b]
Basal + 0.20% L-Lys	186.0[a]	641.3[a]
Basal + 10% DDGS	146.1[b]	546.5[c]
Basal + 20% DDGS	175.1[a]	601.6[b]
Pooled SEM	5.81	8.10

[a-d] Means within a column and experiment with no common superscript differ significantly ($P < 0.05$).

[1] DDGS= distiller's dried grains with solubles.

[2] Means represent six pens per treatment, six chicks per pen.

[3] Multiple linear regression of weight gain (Y in g) as a function of supplemental Lys intake (mg) from L-Lys • HCl (X_1) or DDGS (X_2) was: Y = 14.4 + 0.15 Lys intake (mg) + 0.10 DDGS intake (g) (R^2= 0.98).

[4] Lysine added from L-lysine•HCl (79% lysine).

[5] Multiple linear regression of weight gain (Y in g) as a function of supplemental Lys intake (mg) from L-Lys • HCl (X_1) or DDGS (X_2) was: Y = 114.7 + 0.12 Lys intake (mg) + 0.10 DDGS intake (g) (R^2 = 0.85).

TABLE 4.5. Determination of phosphorus availability in DDGS[1] using a slope-ratio bioassay, Experiment 4 and 5[2]

Treatment	Body weight gain (g/chick)	Tibia ash (%)
Experiment 4[3]		
Corn-SBM basal diet (0.12% non-phytate P)	329.9^{c}	24.8^{d}
Basal + 0.05% P from K_2HPO_4	425.3^{b}	28.9^{b}
Basal + 0.10% P from K_2HPO_4	498.4^{a}	32.7^{a}
Basal + 5% DDGS	386.6^{b}	26.5^{cd}
Basal + 10% DDGS	409.1^{b}	27.4^{bc}
Pooled SEM	12.7	0.61
Experiment 5[4]		
Corn-SBM basal diet (0.12% non-phytate P)	471.7^{b}	25.2^{d}
Basal + 0.05% P from K_2HPO_4	504.7^{b}	31.1^{b}
Basal + 0.10% P from K_2HPO_4	546.1^{a}	34.4^{a}
Basal + 7% DDGS	497.4^{b}	29.0^{c}
Basal + 14% DDGS	585.8^{a}	30.1^{bc}
Pooled SEM	13.8	0.58

[a-b] Means within a column and experiment with no common superscript differ significantly ($P < 0.05$).

[1] DDGS= distiller's dried grains with solubles.

[2] Means represent six pens per treatment, six chicks per pen.

[3] Multiple linear regression of tibia ash (Y in %) on supplemental P intake (mg) from K_2HPO_4 (X_1) or DDGS (X_2) was: Y = 25.09 + 0.01 P intake (mg) + 0.005DDGS intake (g) (R^2= 0.81).

[4] Multiple linear regression of tibia ash (Y in %) on supplemental P intake (mg) from K_2HPO_4 (X_1) or DDGS (X_2) was: Y = 26.11 + 0.01 P intake (mg) + 0.004 DDGS intake (g) (R^2 = 0.88).

TABLE 4.6. Percent phytate phosphorus in DDGS[1]

Feed ingredient	% Total P	% Phytate P	% Available P
Corn (NRC, 1994)	0.28	0.20	29
DDGS[1,2]	0.74	0.27	64

[1] DDGS= distiller's dried grains with solubles.
[2]Average of 9 DDGS samples.

CONCLUSION

Since the late 1930's, distiller's dried grains with solubles (DDGS) has been a common feed ingredient found in poultry diets, but DDGS was slowly phased out of poultry diets by the 1980's. The mass quantities available and possible economical benefit "new generation" DDGS (NG-DDGS) possess has rekindled the torch for nutritionist and feed producers to reintroduce this feed ingredient into poultry diets.

In an initial 18 d battery study no differences were observed for any of the performance parameters measured when 15% NG-DDGS was fed to broiler chicks. This initial experiment only tested one level of NG-DDGS and only during the starter period. Therefore, a 42 d experiment was conducted to test the maximal inclusion level of NG-DDGS in a standard corn-soybean meal broiler diet by feeding levels of 0, 6, 12, and 18%. There were no significant differences throughout the experiment for any of the measured performance parameters when the 6 and 12% levels of NG-DDGS were fed. A decrease in broiler weight gain and feed efficiency was observed when the 18% level of NG-DDGS was fed during the starter period (0 to 16 d). However, during the grower (17 to 31 d) and finisher (32 to 42 d) periods no differences in any performance parameters measured were observed at any of the inclusion levels.

"New generation" DDGS appears to be an adequate feeding ingredient when feed at a level of 15% in a commercial laying hen diet. However, it is suggested that that such an excessive level of NG-DDGS not be used until post peak production, due to the numerically fewer eggs that were laid from 21 to 32 wk of age. Feeding a 15% level of NG-DDGS in a low

density laying hen diet also proved to be excessive as a significant decrease in egg production was observed from 21 to 35 wk of age. Mortality and body weight of laying hens were not affected by the feeding of NG-DDGS. No differences in egg weight, shell quality, or yolk color were observed due to the feeding of diets containing 15% NG-DDGS. However, an improvement in interior egg quality (Haugh units) was becoming evident from laying hens fed the commercial grade diet with 15% NG-DDGS.

The lysine digestibility of NG-DDGS was determined using the precision-fed cecectomized rooster assay and found to be 75% digestible. Chick growth experiments were also conducted to determine the lysine bioavailability of NG-DDGS using slope-ratio methodology. The available lysine in NG-DDGS was estimated to be 80%, which is similar to the lysine availability found in yellow corn grain (81%). The results suggest that the lysine availability of NG-DDGS is not greatly hindered by the heat used during the drying process. Several samples of NG-DDGS were evaluated for total and phytate phosphorus (P) content. The phytate P in NG-DDGS was analyzed to comprise 37% of the total P, which indicates a P availability in excess of 60%. The analyzed P availability was confirmed by the results of two chick growth experiments using slope-ratio methodology in which the P availability of NG-DDGS was estimated to be 61%. The fermentation process appears to have improved the P availability of NG-DDGS over that of its substrate, corn (29% P availability).

"New generation" DDGS is a highly acceptable feed ingredient for both broilers and layers. Based on a conservative recommendation relating to the data, 6% NG-DDGS can safely be used in starter (0 to16 d) broiler diets, and can be increased to a 12% level during the grower (17 to 31 d) and finisher (32 to 42 d) periods. A practical recommendation of 6 to 8% NG-

DDGS can be employed in layer diets during peak production. Once body weight and feed intake have stabilized the level of NG-DDGS in laying hen diets can be increased to 10 or 12%.