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Use of Maize Distiller's Dried Grains with Solubles (DDGS) in Laying Hen Diets: Trends and Advances

[1]Mohamed Ezzat Abd El-Hack, [1]Mahmoud Alagawany, [2]Mayada Ragab Farag and [3]Kuldeep Dhama

[1]Department of Poultry, Faculty of Agriculture, Zagazig University, Zagazig, 44111, Egypt
[2]Department of Forensic Medicine and Toxicology, Veterinary Medicine, Zagazig University, Zagazig, 44111, Egypt
[3]Division of Pathology, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, 243122, Uttar Pradesh, India

Corresponding Author: Mohamed Ezzat Abd El-Hack, Department of Poultry, Faculty of Agriculture, Zagazig University, Zagazig, 44111, Egypt

ABSTRACT

Distiller's Dried Grains with Solubles (DDGS) as untraditional feedstuff has been available for feed industry for many years and became a nutritional and economical feed ingredient. According to recent studies, DDGS is usually used at low concentrations (10 or 15%) as a feed ingredient in laying hen diets without adverse effects on laying performance, feed utilization, nutrient digestibility, egg quality criteria and economics. Because DDGS became available in feed market in large amounts, the ability of using higher DDGS inclusion rate in poultry feed has become an interest for several researchers and poultry producers. Using such untraditional feedstuffs aims mainly to decrease the feed costs. Researchers assured that feeding higher levels of DDGS could have a significant effect on the cost of feed for poultry producers because of higher availability of DDGS and the current price fluctuations of feed ingredients. On the other hand, beneficial effects of DDGS on the environment have also been reported. These beneficial effects could be represented through mitigating harmful emissions and pollution from manure which provides production within clean atmosphere. Findings from different researches on the use of DDGS as feed ingredient for laying hens are illustrated in this review. Moreover, this study describes advanced information regarding the use of corn DDGS as untraditional feedstuff for laying hens involving its production process and nutritive value along with its useful effects on laying hens production traits, egg quality, apparent digestibility, economics and the impact on the surrounding environment in poultry house.

Key words: DDGS, maize, layers, performance, production, egg quality, digestibility, environmental pollution, economics

INTRODUCTION

Distillers Dried Grains with Solubles (DDGS) is a by-product of the ethanol alcohol industry which produced by the fermentation process of some cereal grains such as maize, barley, wheat, sorghum and rye in dry mill ethanol plants, as described by Aines *et al*. (1986) and Abd El-Hack (2015). Feed costs have sharply increased may be due to increase in the feed ingredient prices. However, DDGS has been recognized as a good source of protein, energy, water soluble vitamins and minerals, amino acids for poultry (Potter, 1966; Runnels, 1966; Jensen, 1978, 1981;

Waldroup *et al*., 1981; Parsons *et al*., 1983; Wang *et al*., 2007; Purdum *et al*., 2014) and a valuable source of xanthophylls (Runnels, 1957) and linoleic acid as well (Scott, 1965). Youssef *et al*. (2009) evaluated DDGS as feed ingredient in poultry rations and noted that DDGS could be considered a conventional feed stuff as alternative of energy and protein in poultry diets with other feed components. However, previous studied had reported that DDGS could be incorporated into laying hen diets at levels up to 15% to maintain egg production and egg output had no negative impact (Swiatkiwicz and Koreleski, 2006).

Several steps are needed to produce DDGS, corn is ground, mixed with water and cooked. To produce ethanol and CO_2, the liquefied starch from this process is hydrolysed and fermented (Rosentrater, 2006). Consequently, the non-fermentable components of this process are recovered in a highly concentrated form as distillers dried grains with solubles (NRC., 1994; Weigel *et al*., 1997; AAFCO., 2002).

Because of the rapid increase of ethanol production from yellow corn in recent years, huge amounts of DDGS have been generated. The United States of America is the first place in the world in producing ethanol from corn and consequently DDGS. Total distiller grains production in the United States reached approximately 22 million Mt in the year of 2008 and 30.5 million Mt in 2009/2010 as reported by the Renewable Fuel Association. The DDGS produced has been used in livestock and poultry feeding and about 20% of total amount has been exported to other countries over the world (Salim *et al*., 2010; Sun *et al*., 2015). With the increase in DDGS production and based on its nutritional value, DDGS could be an attractive low cost ingredient to replace soybean meal and corn in poultry rations (Adam, 2008; Masa'deh *et al*., 2012; Swiatkiewicz *et al*., 2014).

So, the aim of this study is to provide advanced information about the use of corn DDGS as untraditional feedstuff for laying hens involving DDGS production process, nutritive value, as well as its effect on laying hens production traits, egg quality, apparent digestibility, economics and the impact on surrounding environment in poultry farms.

PRODUCTION OF DDGS

Dry grind-milling or wet-milling are two distinguished methods for processing corn to produce ethanol as described by Davis (2001) and Dooley (2008). The shape 1 provides a summary for the DDGS production steps. The most of corn based ethanol (approximately 60%) is produced by the methods of dry grind-milling. The primary by-products from the wet milling plants are wet or dried corn gluten feed, corn germ meal and corn gluten meal. While, wet and dried distillers grains with solubles and condensed distillers are the by-products from the dry grind-milling process (University of Minnesota, 2008).

Generally, cleaning of the corn grain is the first step to reduce foreign materials and contamination. Then, corn grain is ground by using a hammer mill. Thereafter, water is added to make slurry, then enzymes of alpha-amylase are added, in order to break the alpha 1-4-glucosidic linkages to release dextrin, maltose, glucose, tetroses and maltotriose; this process is called "Liquefaction". Therefore, the pH (5-6 pH) is adjusted. Cooking is the next step, in which the slurry is jet-cooked using temperatures grading from 90-165°C to eliminate microorganisms and remove lactic acid bacteria from the kernel. After that the jet-cooked slurry is cooled down to 32°C to be ready for the addition of glucoamlyase enzyme which is needed to convert dextrin into the simple sugar dextrose.

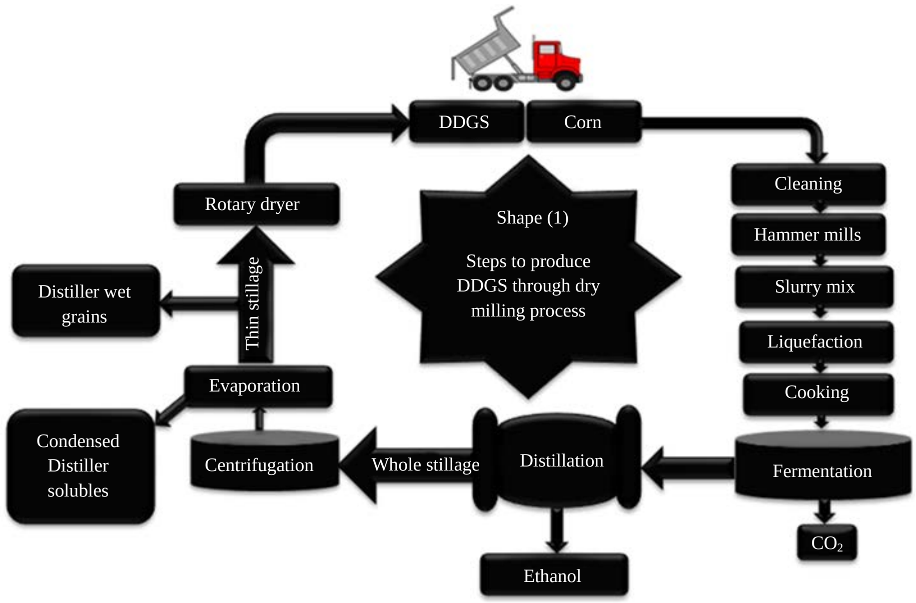

Fig. 1: Steps to produce DDGS through dry milling process

In the fermentation step, amylase and dextrose are fermented into ethyl alcohol (ethanol) and carbon dioxide using a molecular sieves and yeast (*Saccharomyces cerevisiae*). The next step is distillation, in which ethanol is removed from the fermented mash. This process needs about 40-60 h to be completed. After the distillation process, the whole stillage which contains water, protein, fat and fiber is centrifuged. Centrifugation leads to the separation of the wet grains from the thin stillage. The thin stillage then evaporated and condensed to form corn condensed distillers solubles. Finally, corn DDGS is produced in the last step by adding a portion or all of the solubles to the distillers wet grains, then drying in a ring drier or a rotary-kiln at temperatures ranging from 127-621°C (Wright, 1987; Davis, 2001; Kelsall and Lyons, 2003; Power, 2003). One bushel of corn (25.4 kg in average) fermented in a dry grind-milling, ethanol plant; produce 10.22 L approximately of ethanol, 8.16 kg of DDGS and 8.16 kg of carbon dioxide as reported by Davis (2001) (Fig. 1).

NUTRITIONAL VALUE AND BIOAVAILABILITY OF DDGS

Distillers dried grains with solubles contain concentrated amounts of all the nutrients from grains (Babcock *et al*., 2008) excepting starch, because it has been utilized in the process of fermentation. So, it provides a good source of crude protein, amino acids and other nutrients in poultry rations (Swiatkiewicz and Koreleski, 2008).

Many factors influence the physical and nutritional characteristics of DDGS and making the variability. The aforementioned variability includes, levels of nutrient in the corn sources, proportion of added distiller's soluble to DDG before drying process (Martinez-Amezcua *et al*., 2007), the efficiency of obtaining ethanol from starch, as well as temperature and duration of drying.

The main problem in using DDGS as a feedstuff in poultry diets is the high variability of nutrient amounts and quality among the different sources of DDGS, although the content of nutrients in DDGS is relatively equal within the same processing source (Noll *et al*., 2007). So, nutritionists should perform a complete analysis of each source of DDGS using a standardized method before formulating poultry diets (Spiehs *et al*., 2002).

DDGS content of crude protein and amino acid: Many researchers reported a good content of Crude Protein (CP) in DDGS. Dale and Batal (2005) stated that corn DDGS content of CP can range from 24-29%. Salim *et al*. (2010) reported that the average CP content in DDGS from different samples was 27.15% with 3.72% coefficient of variation. Furthermore, Batal and Dale (2006) and Fastinger *et al*. (2006) reported similar results (CP ranged from 23-32%). Using 10 new ethanol plants in Minnesota and South Dakota, Spiehs *et al*. (2002) have evaluated nutrient level of DDGS originating from these plants. They found that the CP accounted for 30.2% while and lysine and methionine for 0.85 and 0.55%, respectively.

Several factors are affecting the high variability among DDGS sources such as differences in the protein content of the corn grown in various geographical locations that are used to produce DDGS, percentage of grain vs. soluble during the production process, as well as the differences in residual starch content caused by differences in fermentation efficiency and processing techniques (Belyea *et al*., 2004; Martinez-Amezcua *et al*., 2007; Babcock *et al*., 2008). Parsons *et al*. (1983) used five treatments to evaluate the protein quality of DDGS. Authors observed that when DDGS is fed to growing chicks as the main source of dietary protein, after lysine, tryptophan closely followed by arginine are the second and third limiting amino acids, respectively.

Parsons *et al*. (1983) reported that the overall protein quality of DDGS could be greatly improved by lysine supplementation for growing chicks, in spit of its limiting tryptophan and arginine. Nutritionist should have enough information about total amino acid content in DDGS to know its' digestibility by the particular species when formulating diets (Salim *et al*., 2010). The differences in manufacturing processes could be responsible for a substantial amount of the variability in the nutritional value of DDGS (Cromwell *et al*., 1993), also temperature is one of the most crucial factor that can impact amino acid digestibility. This harmful effect of heat on amino acid biavailability generally and lysine especially has been well recognized (Warnick and Anderson, 1968), so lysine level and digestibility should take the main concern in using DDGS as a feed component for poultry. Lysine digestibility can range between 59 and 84% (Parsons *et al*., 2006). Pahm *et al*. (2009) evaluated the standardized digestibility (SDD) value for lysine by using 45 week old cecectomized Single Comb White Leghorn roosters. Authors used seven different sources of corn DDGS. Results showed that the mean digestibility was 61.4%, consistent with that reported by Parsons *et al*. (2006). Ergul *et al*. (2003) stated that the mean digestible lysine content for DDGS at 0.53% (ranged from 0.38-0.65%) based using 22 samples.

Lumpkins *et al*. (2005) found that lysine digestibility value for DDGS determined with caecectomised White Leghorn roosters have been reported at 75%. Batal and Dale (2006) determined amino acid digestibility of DDGS by using cecectomized Single Comb White Leghorn roosters. Data showed digestibility coefficient for all amino acids was 81.7% across all samples. Authors also found that digestibility was lowest for threonine, lysine and cystine (73.9, 74.5, 69.6%, respectively) and digestible lysine ranged at 0.51% and broadly averaged from 0.18 to 0.66%.

Cromwell *et al*. (1993) demonstrated that dark DDGS has a lower lysine digestibility than golden DDGS. So, analysis of color may be a quick and reliable indicator for the amino acid digestibility, especially of lysine, in DDGS for poultry (Batal and Dale, 2006). Yellow or golden color of DDGS comes from carotenoids in yellow corn. While, many factors else such as the amount of solubles added to grains before drying, drying time and temperature (Stein *et al*., 2006;

Fontaine *et al*., 2007) and total lysine content (Fastinger *et al*., 2006), impact the natural color of DDGS originally caused by feedstock grain used. So, yellowness and lightness of DDGS color appear to be reasonable indicators of digestible lysine content among golden corn DDGS sources for poultry (Ergul *et al*., 2003) and nutritionists should take care to use values of amino acid digestibility from different sources of DDGS before feed formulation.

DDGS Content of metabolizable energy: Lumpkins *et al*. (2004) revealed that the Nitrogen-Corrected True Metabolizable Energy (TMEn) content was 2,905 kcal kg^{-1} in a single DDGS sample. Batal and Dale, 2006) determined the TMEn content of 17 different DDGS samples from six different ethanol plants. Authors found that the contents of TMEn ranged from 2,490-3,190 kcal kg^{-1}. Fastinger *et al*. (2006) found that TMEn content of DDGS averaged 2,871 kcal kg^{-1} and had considerable variation among the samples. Moreover, a large variation in TMEn values of DDGS were also observed by Parsons *et al*. (2006), who found that the mean TMEn value of 20 DDGS was 2,863±224 kcal kg^{-1}.

Hypothesis says that energy in corn DDGS should not be different if samples were taken from ethanol plants using similar technologies of production and corn that is grown in a proximate geographical location (Stein and Shurson, 2009). Metabolizable energy content varied between 3575-3975 kcal kg^{-1} Dry Matter (DM) among the four sources of DDGS drawn from ethanol plants younger than 10 years and located within 250 km from each other, therefore, factors other than corn growing region contribute to the variability of energy in DDGS (Salim *et al*., 2010). Nutritionists can use a TMEn value of 2,851 kcal kg^{-1} for DDGS, according to a survey of published TMEn values in the literature (Waldroup *et al*., 2007).

In a study on laying hens, Roberson *et al*. (2005) determined the Apparent Metabolizable Energy (AMEn) of a single DDGS sample and found it to be 2,770 kcal kg^{-1}. This result was lower than the TMEn value determined for the same DDGS sample using cockerels by about 4%, similar to the relationship between AMEn and TMEn in corn grain. Batal and Dale (2006) and Fastinger *et al*. (2006) reported that the AMEn and TMEn values in DDGS vary due to its content of oil and protein, lightness degree (L* values) and the method of estimation as well.

Noll *et al*. (2007) stated that the solubles contain oil over three times as much as the wet grains and the rate of soluble addition during the manufacturing process of DDGS is directly related to the DDGS TMEn content. The oil content of corn DDGS range from 2.5-16% in DDGS samples, with potential variation in TMEn content (Batal and Dale, 2006; Parsons *et al*., 2006; Dale, 2013). Swiatkiewicz and Koreleski (2008) postulated that a high level of fat in corn DDGS is accompanied with high gross energy content while digestibility of energy is variable and may be influenced by non-starch polysaccharide content.

One of the reasons of why the digestible energy in DDGS is low as compared with other feed ingredients is content of fiber in DDGS. The fiber content, particularly, Acid Detergent Fiber (ADF) and Neutral Detergent Fiber (NDF) in corn, is not converted to ethanol, so DDGS contains about 35% insoluble and 6% soluble dietary fiber as reported by Stein and Shurson (2009). The apparent digestibility of dietary fiber is 43.7% in a monogastric animal (Stein and Shurson, 2009) and results in a low digestibility of dry matter. So, nutritionists should be alert of the content of fiber and sources of data for DDGS ME values and energy variability as well when formulating diets for poultry (Adeola and Ileleji, 2009; Salim *et al*., 2010).

Content of pigments: Isler (1971) theorized that carotenoids are a class of naturally occurring pigments grading from yellow to red in color and play a critical role in many of biological processes.

Pigments are highly susceptible to oxygen, light and temperature (Kerrer and Jucker, 1950). Deposition of carotenoids in skin, egg yolk or adipose tissue causes yellow coloration which makes it more acceptable and attractive by the consumers (Perez-Vendrell *et al*., 2001; Leeson and Caston, 2004). Leeson and Summers (2005) reported that yellow corn grains have about 20 ppm of xanthophylls and corn DDGS it is expected that may by a good source of xanthophylls pigment, because of their concentration during the production process. But the actual content of xanthophylls may be lower in DDGS due to heat destruction during drying process. When analyzing two DDGS samples, Roberson *et al*. (2005) observed that xanthophylls content was 29.75 ppm in one of the samples but only 3.48 ppm in another. The dark colored sample was considered to be heat damaged. Salim *et al*. (2010) analyzed 16 samples of DDGS deriving from the United States. Results revealed that average concentration of xanthophylls and carotene was 36.72 and 8.58 ppm, respectively. The aforementioned values were higher than those reported by Roberson *et al*. (2005), showing variable levels of these pigments in DDGS.

Based on the latter information regarding DDGS content of pigments and since the typical corn and soybean-based commercial poultry diet does not supply the necessary amount and type of xanthophylls for egg yolk and skin, DDGS can be a good source of these pigments (Salim *et al*., 2010).

Composition of minerals: The analysis of the US corn DDGS revealed that DDGS can be a good source of P (0.76%), K (0.91 ppm), Zn (57.26 ppm) and other minerals. In NRC (1994), phosphorus content in DDGS has been reported at 0.72% and varies widely from 0.48-0.91%. Spiehs *et al*. (2002) and Stein *et al*. (2006) reported similar results. They found that the P variation in DDGS ranged from 0.59-0.95%. This difference in P content derives mainly from its variation in corn grain and amount of starch residue in DDGS (Amezcua *et al*., 2004), in addition to the technological process of ethanol production (Shurson, 2003). The rate of addition of solubles to the wet grains prior to drying could also affect the P content, as the solubles have more than three times as much P as do the wet grains (Martinez-Amezcua *et al*., 2007; Noll *et al*., 2001). Noll *et al*. (2002, 2007) reported that the addition rate of solubles to DDGS is highly correlated with the DDGS colour and phosphorus content ($r^2 = 0.96 - 0.98$).

With regard to the bioavailability of DDGS P for poultry, reports showed that phosphorus bioavailability is also highly variable (Singsen *et al*., 1972; Kim *et al*., 2008). Lumpkins and Batal (2005) found that the relative bioavailability of P in a DDGS sample containing 0.74% total P was 68 and 54% in two different determinations. Also, Martinez-Amezcua *et al*. (2006) observed a relative P bioavailability of 62% in a sample of DDGS containing 0.67% total P.

One of another mineral which is also highly variable in DDGS is sodium. Batal and Dale (2003) reported that Na ranged from 0.09-0.44% in 12 samples of DDGS with the mean value of 0.23%. Authors claimed that the source of this large variability in Na content of DDGS is not well defined. So, they stated that nutritionists need to take this under consideration prior to incorporation of DDGS into balanced diets for different poultry species. Klasing and Austic (2003) reported that poultry could tolerate high levels of Na in the diet. So, high levels of Na may result in a higher level of water consumption and consequently increase dirty eggs and the incidence of wet litter (Leeson *et al*., 1995; Klasing and Austic, 2003). Spiehs *et al*. (2002) demonstrated substantial in plant variation of Na in DDGS and concluded that it would be difficult to characterize the Na content of a single plant by a few analyses. Waldroup *et al*. (2007) recommended that Na addition in feed mills should be made in order to meet the requirements for poultry of this nutrient.

Corn grain content of other minerals such as K, Ca and S in are low (Babcock *et al*., 2008). It is expected that the rate of all the nutrients that have not been utilized in the fermentation process will increase 3 fold, because about 2/3 of the weight of corn grain is converted into ethanol and CO_2 during fermentation process (Batal and Dale, 2003). Sulpher content in corn grain is greater from what could be expected (0.3-1%). The high levels of sulpher in DDGS come from using well water, yeast and H_2SO_4 added in the process of production (Babcock *et al*., 2008). Poultry can tolerate higher levels of dietary sulpher (Leeson and Summers, 2005), so increased levels of sulpher in DDGS is not detrimental when applied in poultry diets.

Generally, nutritionists should examine continuously the composition of the corn grain for minerals to avoid any unexpected effects on the quality of poultry products. Essential trace elements are a group of minerals required by poultry in little amounts. They have an important role in the physiological and biochemical processes. The deficient in the diet of any of essential trace elements, the animals may result in loss of feed intake, reduced growth, productive and reproductive performance (Underwood and Suttle, 1999). Batal and Dale (2003) found that the average composition of many of the other minerals in DDGS (except Ca and S) agree with projected values based on a 3-fold increase levels found in yellow corn grain going through the process of fermentation. But there is a noticeable variation in their amounts derived from many factors. In a study to evaluate the nutrient content and variability of DDGS deriving from less than 5 years old ethanol plants in Minnesota and South Dakota, Spiehs *et al*. (2002) found that across years, differences appear for Zn, Mn and Cu contents and these differences in level of nutrients resulted from differences in corn crop and the fermentation processes during production. Salim *et al*. (2010) worked on imported US corn DDGS and found that the average trace mineral contents for Cu, Zn, Fe and Mn were 3.86, 57.26, 81.54 and 10.37 ppm, respectively. These results were lower than those reported by Spiehs *et al*. (2002) and Batal and Dale (2003).

More research should take place on the trace element content in corn DDGS from different ethanol plants to monitor their variability and measure the effect on stability of other nutrients, particularly after long transportation times to many overseas customers, because conditions of transport can affect significantly the concentration of trace minerals and other nutrients stability.

DDGS content of other nutrients: Besides its good content of protein, energy and minerals; DDGS is a rich source of water soluble vitamins (riboflavin, thiamine and others in particular) (Morrison, 1954; Salim *et al*., 2010). D'Ercole *et al*. (1939) found that DDGS is a valuable source of thiamine and riboflavin. The most of the riboflavin in DDGS derive from the solubles fraction (Sloan, 1941). Also, DDGS have some biologically active substances such as mannan oligosaccharides, nucleotides, glutamine and nucleic acids, β-1, 3 or 1, 6 glucan, inositol which have a beneficial effect on animal health and its immune responses (Swiatkiewicz and Koreleski, 2008).

Regarding, fatty acid concentration, DDGS that are produced under conventional conditions contain a small amount of docosahexaenoic acid (22:6n-3), that are completely absent in the corn grain (Martinez-Amezcua *et al*., 2007). More studies need to be conducted to identify levels of micronutrients in DDGS to satisfactorily formulate the diets and avoid potential deficiency or toxicity.

EFFECT OF USING DDGS IN LAYING HEN DIETS

PRODUCTIVE PERFORMANCE

Live body weight and weight gain: Lumpkins *et al.* (2005) examined four different diets that contained either 0 or 15% corn DDGS with two levels of nutrient formulation, either recommended or low nutrient for laying hens. Diets were fed to white leghorn hens from 21-43 weeks of age. The first two diets were formulated to meet commercial standards (2,871 kcal kg^{-1} TMEn and 18.5% protein), in the same time, the other two diets were low-density diets (2,805 kcal kg^{-1} TMEn and 17% protein). Hens fed the commercial diet with 15% DDGS showed no significant effects on live body weight. Roberts *et al*. (2007a, b) reported no negative effects on body weight in Hy-Line W-36 laying hen when feeding on 10% of maize DDGS within 23-58 weeks of age. Furthermore, Masa'deh (2011) revealed that mean hen weight gain was similar among dietary treatments for the entire production period with no significant effect of DDGS inclusion rates. Jiang *et al*. (2013) found that the effects of DDGS supplementation on body weight and any production parameter were not significant. Recently, Abd El-Hack (2015) noticed that replacing soybean meal in the diet by DDGS up to 75% (16.5% DDGS in the diet) did not exert any determintal ($p \leq 0.05$) effect on final body weight and body weight change during the whole experimental period (22-42 weeks of age).

Feed intake: With regard to feed intake, Jensen (1973) claimed that DDGS did not impact feed intake when fed at 2.5, 5.0, 10 or 10% plus 0.025% lysine in a corn-based diet. Lumpkins *et al*. (2005) and Swiatkiwicz and Koreleski (2006) reported no significant difference in feed intake for hens fed DDGS up to 15 or 20%, respectively. Furthermore, Roberson *et al*. (2005) pointed out that feed consumption did not influenced by levels of maize DDGS up to 15% DDGS. Roberts *et al*. (2007a, b) postulated that DDGS had no negative effects on feed intake of Hy-Line W-36 laying hen when feeding on level of 10% during 23-58 weeks of age. Romero *et al*. (2012) postulated that feed intake of laying hens (112 g per day per hen, on average) was not affected by dietary inclusion of DDGS. Also, Masa'deh (2011) observed that increasing levels of DDGS from 0 to 25% for White Leghorn type hens did not have any negative effects on feed intake during either phases of egg production with an average of 109.4 and 100.8 per day per hen for phase I or II, respectively. Deniz *et al*. (2013) reported that the use of 20% DDGS into the laying hen diets significantly depressed feed intake ($p \leq 0.05$) compared to diets that did not contain DDGS. Authors showed that the highest value of feed intake was recorded for diets containing 0% DDGS and the worst was recorded for diets containing 20% DDGS. In a study on Hisex Brown laying hens, Abd El-Hack (2015) concluded that increasing DDGS in the diet up to 16.5% associated with an increase in feed intake while increasing the level up to 22% led to a marked depression in feed intake.

Feed conversion rate: In a trial on laying hens, feed conversion was not affected by DDGS levels up to 15% DDGS (Roberson *et al*., 2005). Shalash *et al*. (2009, 2010) and Ghazalah *et al*. (2011) reported that inclusion of 20% DDGS in the laying hen diets yielded the worst feed conversion compared with the 0% DDGS ($p<0.05$). Deniz *et al*. (2013) observed that feed conversion was negatively affected ($p<0.001$) by the inclusion of 20% of DDGS compared to other levels (0, 5, 10 and 15%). The authors attributed this reduction to the decreased percentage of laying rate and egg weight which caused when feeding layers on 20% DDGS. Similarly, Jiang *et al*. (2013) postulated that feeding 20% DDGS in the diets produced the worst ($p<0.05$) feed conversion compared with the 0% DDGS. Furthermore, Abd El-Hack *et al*. (2015) reported that feed conversion was negatively affected ($p \leq 0.01$) when soybean meal was substituted by DDGS. Authors added that diets with no DDGS produced the best feed conversion, followed by diets containing 25 and 50 % substitution rate while the worst feed conversion was recorded when soybean meal was fully replaced by maize DDGS. Contradictive results were reported by Romero *et al*. (2012), who found insignificant ($p= 0.09$) improvement in feed conversion (1.98 vs. 2.04 g of feed/g of egg mass) in hens fed 20% DDGS diets comparing with those fed the basal diet.

Egg yield: Researchers tried to study the effect of using DDGS as an alternative feedstuff on egg yield. In an old study, Jensen (1973) found that DDGS did not impact egg production when fed at 2.5, 5, or 10% using 0.025% lysine supplementation in a corn-based diet. Lumpkins *et al.* (2005) revealed that laying hens fed the basal diet with 15% DDGS did not show any significant effect on hen-day egg yield. Also, Roberson *et al.* (2005) suggested that egg production was not influenced by DDGS level during most periods of production. Swiatkiwicz and Koreleski (2006) studied the effect of higher inclusion rates of corn DDGS on laying hen performance. Results of phase one (26-43 week of age) showed no significant impact on egg production when Lohmann brown hens fed DDGS up to 20%. But egg production was negatively affected when hens fed 20% DDGS compared to other DDGS treatments during phase two of production (44-68 weekk of age). Pineda *et al.* (2008) examined the effect of increasing DDGS level (0, 23, 46, or 69%) on egg production. Authors recommended that laying hens could be fed on high level of DDGS, such as 69%, without adverse effects on egg production but advised that all nutrients should be considered when formulating diets containing DDGS. Loar *et al.* (2010) assured that feeding up to 32% DDGS in diets of second-cycle layers had no detrimental effects on egg production. Similar results were obtained by Masa'deh (2011), who stated that increasing DDGS level from 0-25% for White Leghorn type hens did not negatively affect egg production. On the other hand, Deniz *et al.* (2013) found that the inclusion of 20% DDGS significantly ($p\leq 0.05$) depressed laying rate of laying hen compared to those fed diets that did not contain DDGS. Recent studies of Abd El-Hack *et al.* (2015) and Abd El-Hack and Mahgoub (2015) showed that increasing DDGS level up to 22% declined the number of egg produced from Hisex Brown laying hens.

Egg weight and egg mass: Jensen (1973) recorded a significant improvement in egg weight when hens fed on 2.5 or 5% DDGS in a corn-based diet or 5% DDGS in a wheat based diet. Also, Lumpkins *et al.* (2005) concluded that hens fed a basal diet with 15% DDGS showed no significant impact on egg weight. Similarly, Roberson *et al.* (2005) claimed that egg weight and mass did not affect by DDGS level. Contrariwise, Swiatkiwicz and Koreleski (2006) realized that daily egg weight was negatively influenced by the inclusion of DDGS in laying hen diets up to 20%. Masa'deh (2011) revealed that egg weight and mass were decreased as DDGS increased in the diet during phase I of production, meanwhile, it was not affected by DDGS levels during phase II. In Super Nick white laying hens, Deniz *et al.* (2013) and Abd El-Hack (2015) declared that the inclusion of 20% DDGS into diets significantly depressed egg weight and egg mass ($p\leq 0.05$) compared to diets that did not contain DDGS.

EGG QUALITY CHARACTERISTICS

Lumpkins *et al.* (2005), Swiatkiwicz and Koreleski (2006) and Jung and Batal (2009) reported no significant differences in Haugh units, eggshell thickness or shell breaking strength between hens fed a basal diet or diets contain different inclusion levels of DDGS. Also, Cheon *et al.* (2008) revealed no differences in weigh, strength and color of eggshell when feeding layer on 0, 10, 15 or 20% DDGS. Pineda *et al.* (2008) suggested that high inclusion levels of DDGS up to 69% had no effect on egg composition or Haugh units. Negative effect on shell thickness was observed by Ghazalah *et al.* (2011) associated with increasing DDGS ratio in the diet. Furthermore, Masa'deh (2011) found no significant differences in Haugh units among the levels of DDGS. Author also found that egg yolk color was linearly increased ($p<0.0001$) as dietary level of DDGS increased throughout the study. Deniz *et al.* (2013) stated that feeding laying hens on DDGS up to 15% with or without synthetic enzyme supplementation had no adverse effects on both exterior (eggshell thickness and shell breaking strength) and interior (Haugh units and egg yolk color) egg quality criteria. Moreover, Abd El-Hack and Mahgoub (2015) pointed out that the best yolk index and shell thickness were obtained from hens fed the basal diet or diets included 5 and 10% DDGS compared with those fed 15% DDGS. Authors added that yolk color density increased ($p \leq 0.01$) as the level of DDGS increased.

APPARENT DIGESTIBILITY OF NUTRIENTS

Feeding cockers on 100% DDGS reduced digestibility coefficient for ether extract to 69.3% compared to 82.37% for those fed 50% DDGS as reported by Shalash *et al*. (2009). No significant effects due to DDGS levels were observed on digestibility coefficient values for crude protein, crude fiber, ether extract and nitrogen free extract (Shalash *et al*., 2010). Also, Ghazalah *et al*. (2011) reported no significant variation among DDGS levels for dry matter, organic matter, ether extract and nitrogen free extract digestibilities, meanwhile there were significant differences ($p \leq 0.05$) for crude fiber and crude protein digestibility. Authors revealed that the highest DDGS inclusion level (75% substitution for soybean meal) had the worst CP and CF digestibilities. Recently, Abd El-Hack (2015) recorded that digestion coefficient values of nutrients were more preferable in hens fed diets contained 25% DDGS instead of soybean meal (5.5% in the diet) than that of the control diet and other treatment groups (11, 16.5 and 22%). The reduction of digestibility of nutrients with increasing the dietary DDGS level may be due to increase in dietary crude fiber with increasing DDGS replaced soybean meal. The decrease of apparent protein digestibility with increasing fiber contents might be which increase the endogenous losses apparent digestibility (Josson and Carre, 1989). It is worthy to note that the higher fiber content causes a strong barrier to the penetration of digestive enzymes. This latest point can explain the negative relationship between dietary fiber and digestibility of fat and crude protein (Omar, 2003).

BLOOD BIOCHEMICAL PARAMETERS

Typically, blood parameters are related to the health status and vital indicators of physiological and nutritional status of birds and animals. Bor-Ling *et al*. (2011) postulated that DDGS levels (0, 6, 12 and 18%) did not influence plasma total protein of laying hens diet while plasma cholesterol was significantly ($p \leq 0.01$) increased when 12 or 18% DDGS diets were used. The same authors added that serum triglycerides were not influenced by DDGS levels. Ghazalah *et al*. (2011) stated that DDGS incorporation level at 75% instead of soybean meal significantly depressed total protein compared to the control group. Jiang *et al*. (2013) concluded that increasing DDGS to 10 or 20% in laying hen diets significantly ($p \leq 0.05$) increased P content in serum compared to 0% DDGS. Moreover, Abd El-Hack (2015) noticed that replacing soybean meal by 25% DDGS insignificantly increased serum total protein, albumin and globulin; with increased DDGS replacement of soybean meal with DDGS at 50 or 75 % depressed total protein and globulin values. The same author indicated that increasing DDGS level significantly ($p \leq 0.01$) increased serum triglycerides, cholesterol and LDL from 194.40, 92.53 and 17.63 for the control group to 380.18, 144.29 and 36.13 for hens fed diet contained 22% DDGS in the diet, respectively. Abd El-Hack (2015) also added that serum calcium was insignificantly increased by 3.51% when hens fed 75% DDGS substituted for soybean meal, consistent with previous results of Jiang *et al*. (2013).

ENVIRONMENTAL EMISSIONS

There is no doubt that harmful emission from chicken manure became one of the environmental challenges that the poultry industry has been faced (Kristensen and Wathes, 2000; Song *et al*., 2012). The manure of poultry and its N compounds are a potential pollutant causing nitrate or nitrite water contamination, eutrophication, ammonia volatilization and acid deposition in the air as explained by Summers (1993), Moore (1997) and Alagawany *et al*. (2014, 2015). So, reducing N excretion in poultry manure is an important first step toward the environment sustaining (Alagawany and Abou-Kassem, 2014). Salim *et al*. (2010) stated that there are indirect environmental ramifications accompanied with feeding hens on a high level of DDGS. One of the most controversial matters is excreted nitrogen. Generally, crude protein levels in laying hen diets based on corn or soybean meals ranges between 15-18% but, a balanced ration including 50% corn DDGS will contain more than 20% crude protein. This extra protein is excreted as uric acid in the manure and then the manure microbes convert it to ammonia (NH_3) (Pineda *et al*., 2008). Roberts *et al*. (2007b) found a high and positive correlation between the amount of the DDGS in the diet and both consumption of N and excretion by the birds. However, the inability to properly digest fiber by poultry may provide environmental benefits when feeding DDGS. Undigested fiber deriving from DDGS included in poultry diets is fermented by microbes in the large intestine producing short chain fatty acids which in turn lower the manure pH. This minimized manure pH results in the production of a less volatile ammonium form of N that does not evaporate and consequently has less harmful effect on air quality (Babcock *et al*., 2008; Bregendahl *et al*., 2008). Therefore, it is noticeable that dietary DDGS has a weakening impact on emission of NH_3 (Roberts *et al.* (2007a) through remaining in the manure and may maximize the economic value of the manure if applied correctly on the field (Babcock *et al*., 2008). Leytem *et al*. (2008) and Applegate *et al*. (2009) reported a linear increase in excreted nitrogen from broilers chicks as levels of DDGS increased in the diets. Masa'deh (2011) found that the phosphorous output per kilogram of dry matter intake decreased linearly as DDGS level increased ($p \leq 0.0001$). Abd El-Hack and Mahgoub (2015) reported that excreted nitrogen declined by 8.62 and 4.31% in laying hens fed 5 or 10 % DDGS, respectively while excreted phosphorous depressed by 3.33, 7.22 and 10.56% in hens fed 5, 10 or 15% DDGS, respectively comparing to those fed the basal diet. The levels of phosphorous in poultry diets supplemented with DDGS could be higher to minimize the costs of supplementation with this expensive microelement and reducing the need for supplementing diets with inorganic P (Lumpkins and Batal, 2005). Also, corn DDGS contains a relatively high level of sulpher, which lead to elevated hydrogen sulphide emissions when excreted from poultry it may. Pineda *et al*. (2008) theorized that both NH_3 and hydrogen sulphide emissions can have a negative effect on egg production. So, feeding laying hens on DDGS has positive environmental implications by reducing land fill absence of any negative effect air quality.

ECONOMICS

After the linear increase in prices of corn, soybean meal and other feed ingredients; the poultry industry has been working to minimize feed costs of production. Nutritionists exert efforts to test the best combinations of alternative feed ingredients and feed additives to optimize production (Alagawany and Attia, 2015; Ashour *et al*., 2015). According to many of previous studies, it is clear that using alternative feed ingredients such as DDGS have proven to be a way for cost saving (Schilling *et al*., 2010). Cheon *et al*. (2008) postulated that the feed cost per kg egg increased somewhat by the use of DDGS, especially at the 20% level of DDGS. However, the feed cost per kg egg of 15% DDGS supplementation group was very much comparable to that of no DDGS supplementation group. Rew *et al*. (2009) investigated the effects of using corn DDGS (0, 10 and 20%) on production performance and economics in laying hens and observed very similar results as obtained by Cheon *et al*. (2008). In the aforementioned studies, high quality DDGS turned out to be an economically viable feed ingredient in the Korean feed market, as an alternative feed stuff substituting corn and soybean meal. Furthermore, Ghazalah *et al*. (2011) found that hens fed diet containing 50% DDGS substitution for soybean meal plus Avizyme supplementation was economically the best treatment which had economic and relative efficiency values of 0.50 and 116.32%, respectively. Also, Masa'deh (2011) found that feeding laying hens on 30% DDGS saved $31.16/ Mt and $28.58/Mt for phase I and II compared to the control group which received diets without DDGS. Recently, results of Abd El-Hack (2015) showed that laying hens fed the diet contained 50% DDGS substitution for soybean meal resulted in the best economic efficiency value compared with other treatments (25 and 75% substitution rate) or the control group which fed diet with no DDGS.

CONCLUSION

In conclusion, based on results of researches and studies discussed in this review DDGS can be a highly acceptable feed ingredient for laying hens and poultry as general. It may provide a rich source of crude protein (23% at least), crude fiber, amino acids, energy, xanthophyll, minerals, etc. in poultry diets. This study highlights the production method of DDGS, nutritive value and contents of nutrient in DDGS and its use as protein and energy sources with SBM in layer diets. Also, this review focused on the effects of using DDGS in laying hens diets, productive performance, egg quality criteria, apparent digestibility of nutrients, blood parameters and environmental emissions and economics. Current recommended maximum dietary levels for DDGS are 10-15% for laying hens but the higher levels of DDGS can be used successfully with appropriate diet formulation with adjustments for amino acids particularly lysine and methionine. The main restrictions on use of DDGS as a traditional feed ingredient in poultry diets are the variation and bioavailability of nutrients in DDGS, particularly some amino acids such as lysine, methionine, energy and minerals.

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