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Use of Distiller´s Dried Grains with Solubles (DDGS) from corn or wheat in broiler diets

Pavlina Hristakieva *, Nadya Mincheva, Ivelina Ivanova, Magdalena Oblakova, Nikolay Ivanov and Ivan Slavov

Agricultural Academy, Agricultural Institute - Stara Zagora, 6000, Bulgaria

**Corresponding author*: poly_31@abv.bg

Abstract

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The production of grain-based bioethanol is increasing due to the rising demand for biofuels and the global decline in fossil fuel sources.

Distiller's dried grains with solubles (DDGS) from corn or wheat are the main by-product of bioethanol fermentation, primarily through dry milling technology, and have been used as low-cost animal feed. With the increase in ethanol production from grains, the production of DDGS from corn or wheat also increases.

Several studies have found that DDGS has high nutritional value but variable composition, and researchers have found ways to enhance its quality and safety. Various approaches have been proposed to improve the digestibility and nutritional value of DDGS. However, despite its high nutritional value, DDGS has not yet been fully studied and is less utilized in broiler feeding.

The benefits and risks associated with the use of DDGS have been studied for a long time, but more research is needed to establish quality and safety standards for DDGS. This review aims to highlight the challenges of using DDGS in broiler chicken nutrition.

Keywords*:* broiler chickens; distiller´s dried grains with solubles (DDGS); productivity; blood and immune indicators

Introduction

The costs of feed account for between 60 and 70% of the total production costs, which necessitates the evaluation of alternative feed sources for broiler feeding (Thirumalaisamy et al. 2016; Henchion et al.,2017). Currently, 80% of the protein raw materials for animal feeding in the EU are imported from countries outside the EU(Watson et al. 2017). This makes the EU, and Bulgaria in particular, dependent on the changing prices of raw materials caused by increased international demand and climate change, which affects the amount of produced proteins. The use of waste products from biofuel production as animal feed, such as meal, expellers and DDGS, provides a good protein source and makes them a valuable component of feed.

There are two main methods of ethanol production from grain crops: dry milling and wet milling. The primary products of the dry milling process are ethanol and DDGS, while wet milling produces gluten flour and gluten feed along with ethanol**.**

Distiller's dried grains with solubles (DDGS) is a dried product obtained after the starch fraction of corn (DDGSc), wheat (DDGSw), or another type of grain is fermented with specific yeast and enzymes to produce ethanol and carbon dioxide. After the fermentation is complete, the alcohol is separated by distillation, and the remaining fermented product is dried. One ton of corn yields 378 liters of ethanol and 309 kg of DDGSc, while one ton of wheat yields 372 liters of ethanol and 295 kg of DDGSw (Nyachoti et al., 2005; Adebiyi, 2014).

Nutrient composition of distiller´s dried grains with solubles (DDGS) from corn or wheat

The nutritional composition of DDGS varies under the influence of various factors, depending on the quality of the raw material and the processing techniques and conditions (Belyea et al., 2010). The factors determining the quality of the raw material include the type, variety, and quality of the grain, the type of soil and fertilization, the climatic conditions during cultivation, and the conditions during harvesting and grain storage. The factors related to the processing techniques and conditions include the grain milling method and particle size, the purity of the grain, the duration and temperature of heating, the amount of added water, the time and temperature of cooling, the quantity and quality of amylase, the quantity and quality of yeast, the duration of fermentation, and the conditions during drying. Consequently, the nutrient content of DDGS can vary significantly, making it essential to analyze the specific nutrient composition of each batch for accurate feeding and nutritional planning .

The corn DDGS has an energy content equal to or greater than that of corn grain. This is due to the high fat content in corn. Corn DDGS has higher levels of crude fat (165 vs. 49 g/kg DM-dry matter) and sulfur (7.2 vs. 3.9 g/kg DM) but lower crude protein (320 vs. 393 g/kg DM) compared to wheat DDGS (Nuez Ortín and Yu, 2009).

Corn DDGS contains high levels of unsaturated fatty acids. Linoleic acid (C18:2), oleic acid (C18:1), and palmitic acid (C16:0) are the most prevalent fatty acids, constituting around 89% of the total fatty acids (Díaz-Royón et al., 2012). The high content of unsaturated fatty acids (linoleic and oleic acid) contributes to the high energy value of corn DDGS, but it also makes the fats in corn DDGS susceptible to easier oxidation (Winkler-Moser and Breyer, 2011).

The values reported in the literature for the metabolizable energy (ME) content of corn DDGS vary significantly (Salim et al., 2010). For example, the metabolizable energy can range from 2 490 kcal/kg DM to 3190 kcal/kg DM (Shurson et al., 2005; Batal and Dale, 2006).

Similarly to the metabolizable energy content, differences were also observed in terms of crude protein (CP) and amino acids (AA) in different samples of corn DDGS. The crude protein content ranges from 23% to 41.2% and is significantly higher than in the row matherial. According to NRC (1994) data, the CP value in corn DDGS is around 28%, while corn grain contains 8.5% CP.

Methionine is the first limiting amino acid for birds and is known to vary from 0.41% to 0.65% in corn DDGS (Spiehs et al., 2002; Martinez-Amezcua, 2005; Fastinger et al., 2006). Lower values for methionine are reported by Kanev and Stanchev (2009), with a methionine level in corn DDGS of 0.31±0.05g/100g. The higher protein content in corn DDGS compared to corn grains is due to the synthesis of yeast protein accumulated during the fermentation process. The fermentation and heating process also contribute to reducing the anti-nutritional value of corn DDGS compared to corn and other feed ingredients such as soybean and rapeseed, which contain trypsin inhibitors and glucosinolates, respectively (Becker & Wittmann, 2012; Zschetzsche, 2019). Similar to corn, lysine is the first limiting amino acid in corn DDGS, followed by threonine and tryptophan. It should be noted that the amino acid composition of feeds is an important factor determining its suitability as a protein source.

The content of neutral detergent fiber (NDF) in corn DDGS ranges from 26% to 49.1%, and acid detergent fiber (ADF) ranges from 6.85% to 33.5%. Calcium content is between 0.04% and 0.07%, while phosphorus content ranges from 0.27% to 0.89% (Shurson et al., 2005; Batal and

Dale, 2006). Roberson et al. (2005) analyzed two DDGS samples and observed 30 ppm of xanthophylls in one of the samples, but only 3 ppm in another dark-colored sample considered heat damaged.

Ethanol production may concentrate mycotoxins present in corn into DDGS (Joint FAO/WHO Expert Committee on Food Additives, 2001). Previous experiments have reported contamination of corn DDGS with various mycotoxins such as aflatoxins, zearalenone, ochratoxin, and deoxynivalenol (DON) (Wu and Munkvold, 2008; Rodrigues and Chin, 2012). Rodrigues and Naehrer (2012) analyzed mycotoxin contamination in various feed ingredients and noted that DON contamination is the highest among the four mycotoxins in corn DDGS. Kim et al. (2021) found that feeding broiler chickens with diets containing more than 10% DON-contaminated corn DDGS has negative effects on growth, gut permeability, and energy and nutrient utilization. Therefore, it is recommended to limit the inclusion level of corn DDGS to 5.0% in broiler diets.

Wheat DDGS (DDGSw) is the dried residue left after the fermentation of the carbohydrate portion present in the endosperm of wheat grains during ethanol production, resulting in ethanol and carbon dioxide. The concentration of nutrients in wheat DDGS is up to three times higher than that in wheat grains (Widyaratne and Zijlstra, 2007; Min et al., 2009). After fermentation, alcohol is removed through distillation, and the remaining fermentation residues are dried. Wheat DDGS is an excellent source of digestible protein and energy for ruminants, especially cattle, as well as poultry (Kluth and Rodehutscord, 2010).

Despite this, specialists using wheat DDGS in monogastric animal feed should be aware of the variability in nutrient content and different digestibility. The main limitation associated with using wheat DDGS in poultry feed is the varying content and availability of nutrients, as well as the poor digestibility of some amino acids such as lysine, tryptophan, and arginine (Choct, 2006). Additionally, there is a high content of crude fiber, the possibility of mycotoxin presence, and some anti-nutritional factors like phytates. Nevertheless, using enzymes to improve nutrient digestibility in wheat DDGS, especially protein quality and the release of metabolizable energy (ME), lead to an increase in the nutritional value of wheat DDGS as a feed component (Noblet et al., 2012).

As a by-product of ethanol production, wheat DDGS is characterized by a dark brown color. In the past, there was no corelation between the color and the nutritional value of wheat DDGS, but previous studies with pigs and poultry (Cromwell et al., 1993; Fastinger et al., 2006) have shown a lower nutritional value for darker-colored wheat DDGS. Usually, prolonged processing, especially overheating during drying, leads to a dark brown color, which is cause binding or destruction of nutrients, especially the amino acid lysine. Several researchers (Nyachoti et al., 2005; Pedersen et al., 2007; Widyaratne and Zijlstra, 2007) reported that wheat DDGS is characterized by a high content of crude fiber, approximately 8%, and the crude protein content is around 37%, as reported by Heuze et al., 2015 (Table 1).

Furthermore, Dong et al. (1987) found that the carbohydrate concentration in wheat DDGS is very low due to the conversion of a large portion of carbohydrates into ethanol during production. Consequently, the energy content in wheat DDGS is equal to or lower than that of wheat grains. The metabolizable energy for different poultry categories ranges from 2412 kcal/kg to 2701 kcal/kg (Waldroup et al., 2007; Vilariño et al., 2007; Cozannet et al., 2010a).

Table 1*. Approximate composition of wheat DDGS (% of DM)

composition	%
Dry matter DM	91
Crude protein CP	37
Crude fat CF (Ether extract)	5
Crude fiber	8
NDF	34
Ash	6

** According to: Heuze et al., (2015).*

The levels of neutral detergent fiber (NDF) in wheat DDGS also vary depending on the production method. For example, DDGS produced using whole grains has about 32% NDF on a dry matter basis, while DDGS produced from ground grains has approximately 27% NDF on a dry matter basis.

Additionally, wheat DDGS has a low fat content of around 5% on a dry matter basis, which is significantly lower than that of other feed components.

According to data from one of the largest producers of corn and wheat DDGS in Bulgaria, the values for the main components, trace elements, and amino acids are shown in Table 2.

It should be noted that DDGS from corn or wheat contain high concentrations of non-starch polysaccharides (NSP) (Ward et al., 2008). This can negatively impact broiler productivity due to their inability to digest fibers (Albuquerque et al., 2011). The level of NSP in DDGS can be two to three times higher than that in corn grain (Cromwell et al., 1993; Bennett and Richard, 1996). According to Swiatkiewicz and Koreleski (2007), corn DDGS contains high levels of total NSP. The use of enzymes can overcome nutritional challenges associated with feeding high levels of DDGS to broilers (Malkki, 2001; Swiatkiewicz et al., 2014; Abudabos et al., 2017).

Distillers dried grains with solubles (DDGS) from corn or wheat are considered valuable sources of phosphorus (P) because the fermentation and drying processes increase the concentration of inorganic phosphorus by releasing some of the phytate-bound phosphorus in the grain (Martinez-Amezcua et al., 2004; Martinez-Amezcua and Parsons, 2007; Widyaratne and Zijlstra, 2007; Liu and Han, 2011).

Initially, the inclusion of corn or wheat DDGS in poultry diets was limited (up to 5%) due to several reasons, such as product availability, its cost (Waldroup et al., 1981), and especially the variable nutritional composition and digestibility (Noll et al., 2001). However, numerous studies have shown that it can be successfully fed to poultry and used in broiler diets as a substitute for easily digestible and expensive feeds without affecting growth (Parsons and Baker, 1983; Olentine, 1986; Noll et al., 2001; Lumpkins et al., 2004, Thacker and Widyaratne, 2007; Lalev et al., 2010; Todorova, 2018; Sharyari et al., 2020). Moreover, DDGS is a good partial substitute for expensive protein sources (such as soybean meal) and helps save costs on certain raw materials needed to balance poultry diets, like inorganic phosphorus (Belyea et al., 2010; Salim et al., 2010; Liu 2011).

The higher nutrient content of DDGS compared to the original grain crops, combined with

Table 2*. Analytical values of DDGS from corn and wheat

List	M.U.	Wheat DDGS	Corn DDGS
Dry matter	%	90	90
Crude protein	%	31,4±1,6	26,6±1,1
Crude fiber	%	7,7±1,6	7,5±1,2
Crude fat	%	7,7±1,7	14,1±0,6
Ash	%	8,3±0,9	4,7±0,9
Calcium	%	0,17	0,1
Phosphorus	%	0,75	0,8
Manganese	mg/kg	121	26
Zinc	mg/kg	232	66
Iron	mg/kg	95	80
Aspartic acid	%	1.7	1,50
Threonine	%	0,95	0,74
Serine	%	0,99	0,70
Glutamic acid	%	10,1	4,90
Proline	%	3,3	1,75
Cysteine	%	0,93	0,30
Glycine	%	1,37	0,82
Alanine	%	1,39	1,60
Valine	%	1,6	1,20
Methionine	%	0,56	0,18
Isoleucine	%	1,3	0,80
Leucine	%	2,36	2,75
Tyrosine	%	0,8	0,65
Phenylalanine	%	1,6	1,05
Histidine	%	0,9	0,75
Lysine	%	0,8	0,60
Arginine	%	1,4	0,80

** According to data: https://zaharnizavodi.com/biznes-divizii/etanol-i-ddgs/ddgs/.*

increased accessibility of this product, encourages higher inclusion levels in poultry diets than in the past. As a result, DDGS has become more widely used as a feed ingredient in poultry nutrition.

Effect of DDGS inclusion in broiler diets on performance

Lumpkins et al. (2004) conducted an experiment with isocaloric and isonitrogenous diets containing varying levels of DDGS (ranging from 0 to 18%). The key finding of the study was that there were no significant differences in productive traits, except for reduced growth during the starter period when chicks were fed with 18% DDGS in their feed.

Wang et al. (2007a) investigated the effects of different levels of DDGS in broiler diets (0, 5, 10, 15, 20, or 25%), throughout a 49 d growing period. The diets were formulated based on digestible amino acid content, following the standards for broilers. The feed fed during the starter period (0-14 days) were in mash form, while during the grower (14-35 days) and finisher (35-49 days) periods, they were in pellet form. Incorporating DDGS at levels up to 25% in broiler diet did not show any effect on body weight, however chicks fed diets with 25% DDGS consumed significantly more feed and had poorer feed conversion compared to chicks fed the control diet with no DDGS. Birds fed 15 and 25% DDGS had significantly lower dressing percentage than did birds fed the control diet with no DDGS. Additionally, birds fed diets with 25% DDGS had significantly lower breast weight when expressed as percentage of live weight.The results suggest that high-quality DDGS can be used in broiler diets at levels of 15-25%, with little adverse effect on live prformance, but it may influence dressing percentage or breast meat yield.

The additional information provided from the studies by Wang et al. (2007b) and Shim et al. (2011) adds valuable insights into the effects of incorporating DDGS in broiler diets. Wang et al. (2007b) concluded that diets containing 15% DDGS can be provided throughout the entire rearing period from 1 to 42 days of age without any adverse effects on productivity or body composition when formulated based on digestible amino acids. This finding further supports the idea that moderate levels of DDGS can be successfully used in broiler diets without compromising performance. Similarly, the study by Shim et al. (2011) found that chicks showed good productive performance when DDGS was included up to 24% in a well-balanced diet in terms of amino acid composition during the starter, grower, and finisher stages. This suggests that carefully formulating the diet to meet the amino acid requirements can allow for higher levels of DDGS inclusion without detrimental effects.

Studies by Thacker and Widyaratne (2007) and Wang et al. (2008) adds further depth to the understanding of the effects of wheat DDGS inclusion in broiler diets. Wang et al. (2008) examined the inclusion of higher levels of wheat DDGS (up to 50%) in broiler diets and found that breast meat yield decreased with increasing DDGS inclusion levels. Based on their findings, the authors recommended adding no more than 30% wheat DDGS in broiler diets to maintain optimal breast meat yield. This information highlights the potential limitations of higher DDGS inclusion levels on certain productive indicators. On the other hand, the study by Thacker and Widyaratne (2007) investigated the effects of lower levels of wheat DDGS (up to 20%) on broiler diets. They found that although nutrient digestibility decreased with increasing DDGS inclusion, there were no significant differences in live weight (P=0.721), feed consumption (P=0.748), or feed conversion ratio (P=0.766). This suggests that despite lower nutrient digestibility, the overall productivity of broilers was not significantly affected by moderate DDGS inclusion levels. Wheat DDGS can be successfully included in broiler diets, and drawbacks such as lower energy and lysine content can be compensated for during diet formulation. When cost is a determining factor, wheat DDGS can be included in broiler diets at levels above 15% without negatively affecting productivity.

Other authors have concluded that the growth rate of broilers was reduced when including 12% wheat and corn DDGS in their diets (Abdel-Raheem et al., 2011). The prececal digestibility of amino acids (AA) was not affected by 6 or 12% DDGS until the end of the third week, but adding 12% DDGS significantly decreased the overall digestibility of amino acids by the fifth week of rearing. From their results, it can be concluded that wheat and corn DDGS are suitable protein sources when included in broiler diets up to 6% without adverse effects on prececal digestibility of amino acids and growth. However, higher levels (12%) of wheat and corn DDGS led to reduced prececal digestibility of specific amino acids, including threonine, arginine, valine, and total amino acids. Further Loar et al. (2012) observed increased feed conversion with the inclusion of 8% DDGS during the starter and grower phases.

Bolu et al. (2012) investigated the effects of different DDGS inclusion levels (0, 10, 20, 30, and 40%) in feeds on broiler chicken reared up to 8 weeks of age. The results indicated that the group fed with 40% DDGS had the highest feed conversion ratio, while the best live weight results were achieved by chickens fed with 10% DDGS. This implies that higher DDGS inclusion levels can negatively impact feed conversion, but moderate levels can be beneficial for live weight.

The study conducted by Lukasiewicz et al. (2012) provided a comprehensive evaluation of the effects of different levels of DDGS inclusion in broiler diets during various growth phases and reported their impact on productive performance and meat composition. During the starter period, the inclusion of 5% and 7% DDGS in broiler diets did not result in statistically significant differences in productive performance compared to the control group. Interestingly, broilers fed with higher levels of DDGS in their feeds (9.5% during the grower and finisher phases) had similar body weight and better feed conversion compared to those in the control group, indicating that DDGS can positively impact growth performance and feed efficiency when included at certain levels. Regarding the chemical composition of the meat, no significant differences were observed between the control and experimental groups in breast meat. However, in the thigh muscles, broilers from the experimental groups showed a significantly lower moister content (approximately 0.3-1.3% less) and higher fat content (approximately 1.2% more) compared to the control group. Additionally, the protein content in the thigh muscles of broilers receiving feeds with 5% DDGS was significantly higher compared to the other two groups (approximately 0.5-1% more), indicating potential beneficial effects on thigh muscle protein content. These findings suggest that DDGS inclusion at certain levels may influence the composition of thigh muscles, leading to changes in water and fat content and protein levels. Furthermore, the study found that the percentage of DDGS inclusion did not significantly affect the pH values, water-holding capacity, and cooking loss in both breast and thigh muscles. However, it was noted that regardless of the DDGS inclusion level, the breast muscles of broilers were characterized by lower pH values (approximately 0.3-0.4 units lower), poorer water-holding capacity, and twice the cooking loss compared to the thigh muscles. These differences in meat characteristics between breast and thigh muscles are normal and commonly observed in poultry.

Foltyn et al. (2013) provides important findings on the effects of corn DDGS inclusion in broiler diets, particularly in relation to body weight, feed conversion, and meat quality. In the first experiment, broilers fed diets containing 60 and 120 g/kg of corn DDGS showed significantly higher body weights at 35 days of age (2498.5 g and 2496.3 g) compared to the control group (2425.9 g). However, until the age of 30 days, there were no statistically significant differences in body weight between the groups. This suggests that the effects of DDGS on body weight may become more pronounced as the birds age. In the second experiment, where broilers were fed diets with 200 g/kg of corn DDGS from day 23 to day 35, a significantly lower body weight was observed compared to the group fed diets without DDGS ($P<0.05$). This indicates that higher levels of corn DDGS inclusion during a specific growth phase can negatively impact body weight. Interestingly, feed conversion was similar for all groups in both experiments, implying that DDGS inclusion did not significantly affect feed efficiency. Furthermore, the study did not find a significant effect of corn DDGS on abdominal fat weight, suggesting that DDGS inclusion did not have a notable influence on fat deposition in the abdominal region of the broilers. Regarding meat quality, in the first experiment, feeding diets with corn DDGS resulted in a statistically significant decrease in the L* values of breast meat (P<0.05). The L* value represents the lightness of meat, and a decrease in L* value indicates darker meat color. This change in meat color was not observed in the second experiment, indicating that the impact of DDGS on meat color may vary depending on the specific dietary conditions.

Todorova et al. (2014) conducted an experiment using corn DDGS as a partial replacement for soybean meal and corn. In the starter phase, two experimental groups received diets containing 15% corn DDGS, and in the finisher phase, one group received 15% and another group received 30% corn DDGS. At the end of the experiment at 44 days of age, it was found that the inclusion of 15% or 30% corn DDGS in broiler diets did not have a negative effect on growth and feed consumption. However, the higher level of corn DDGS led to a significant increase in the amount of internal fat in the carcass by 21.4% (P<0.05).

Ivanova (2015) investigated the impact of various levels of corn DDGS in broiler diets on both slaughter performance and meat chemical composition. The experiments included constant levels (0%, 10%, 15%, and 20% in starter, grower, and finisher, respectively) and increasing levels (0/10/10%; 0/10/15%; 0/10/20%; 0/10/25%; 0/15/15%; 0/15/20%; and 0/15/25%, respectively, in starter, grower, and finisher) of DDGS. The results showed that including 10% DDGS in grower/finisher (G/F) diets until 49 days of age did not significantly influence slaughter performance. However, feeding diets with higher levels of DDGS (10/20% and 10/25% in G/F, as well as 15/15%, 15/20%, and 15/25% in G/F periods) led to a significant reduction in the weight of the gizzard, breast, and thigh compared to the control group (P<0.05). Regarding meat composition, broilers fed diets with 10% DDGS in G/F had the highest protein content in breast meat, while the lowest protein content was observed in broilers fed diets containing 15/25% DDGS (P<0.05). The fat content in breast meat increased when 15/15% and 15/25% DDGS were included in G/F (P<0.05). Lower protein content in thigh meat was observed when diets containing 10/15%, 10/20%, 10/25%, and 15/15%, 15/20%, and 15/25% DDGS in grower and finisher phases were fed. Additionally, the inclusion of 10/25%, 15/15%, 15/20%, and 15/25% DDGS in G/F increased the fat content in thigh meat (P<0.05). Based on the experiments, it is recommended to include 10% DDGS in diets for broilers during the grower and finisher phases. However, another study by Shilling et al. (2010) reported that broilers can be fed up to 24% DDGS without affecting the protein and fat content in the muscle tissue when the diets are properly formulated. Furthermore, in an experiment with 15%, 30%, and 45% DDGS in broiler diets, it was found that broilers achieved the highest body weight with 15% and 30% DDGS inclusion in the diet, while broilers fed 45% DDGS had the highest protein content (23.93%) in breast meat (Abdulmajid Rashid et al., 2015).

However, it's worth noting that not all studies have shown positive results with high DDGS inclusion in broiler diets. For example, the study by Campasino et al. (2015) observed a negative effect on productive parameters, feed conversion, and growth rate when 15% DDGS was included in the diets of 14-day-old broilers.

On the other hand, a recent study by Fries-Craft and Bobeck (2019) concluded that DDGS with 34% CP (crude protein) can be included in broiler diets up to 10% without any negative impact on productivity or the need for supplementation with amino acids Lysine and Arginine. This finding is further supported by Valentim et al. (2023), who recommended including DDGS in the broiler diets at a rate of up to 12% during the 42-day rearing period to achieve higher body weight and good feed conversion.

Effect of DDGS inclusion in broiler diets on serum biochemical, some hematological and immune indicators

Several studies have indicated that including DDGS in the diets of various types and categories of livestock and poultry affects plasma cholesterol levels (Shalash et al., 2009; Yoon et al., 2010). This impact can be attributed to the fatty acid composition, particularly the presence of saturated and unsaturated fatty acids in DDGS (Elbaz et al., 2022).

In chickens fed with corn DDGS, the concentrations of total protein, globulin, and high-density lipoproteins (HDL) in the blood serum significantly increased (P<0.05) compared to the control group (Mustafa et al., 2017; Elbaz et al., 2022). However, the authors also noted that the concentrations of albumin, total cholesterol, and low-density lipoproteins (LDL) were significantly reduced (P<0.05) in the experimental groups. Todorova (2018) confirmed these findings and reported significantly lower levels of serum cholesterol in broiler chickens fed with diets containing 15% and 30% corn DDGS.

On the other hand, Ghaly et al. (2017) found that including DDGS in broiler diets at levels of 5%, 10%, and 15% significantly affected (P<0.01) total protein, albumin, globulin, and glucose in the blood serum. However, Damasceno et al. (2020) observed that the concentrations of total protein, uric acid, and gamma-glutamyl transferase (GGT) in the serum were not influenced (P>0.05) by the inclusion of DDGS. Ghaly et al. (2017) also reported that the highest (P<0.01) glucose value was recorded in chickens fed with 15% DDGS compared to other levels of DDGS. Elevated serum glucose levels may be attributed to the good source of energy in DDGS for broilers, which is consistent with the findings of Olentine (1986) and Noll et al. (2003). In Japanese quails, other authors reported the highest plasma concentrations of total protein and globulin when diets contained DDGS at a rate of 50% and 100% (El-Abd, 2013).

Regarding the serum levels of total lipids, triglycerides, and cholesterol in broiler chickens fed diets with different levels of DDGS, the data showed significant influence, while the value of creatinine did not change (Ghaly et al., 2017). However, these findings do not correspond to those of other authors (Shalash et al., 2009), who reported that the plasma content of cholesterol, lipids, and creatinine in broilers fed with 12% DDGS with or without enzymes were not affected.

Youssef et al. (2013) found that hemoglobin (Hb) levels significantly increased when DDGS was included in the diets of broilers compared to the control group. In contrast, Ghaly et al. (2017) reported the lowest (P<0.05) red blood cell count and Hb values for broilers in both the control group and those with 10% DDGS compared to other DDGS levels (5% and 15%). Generally, broilers fed with 15% DDGS showed the highest (P<0.01) values of RBC (total red blood cells), PCV% (Packed Cell Volume), Hb, MCH (mean corpuscular hemoglobin), and MCHC (mean corpuscular hemoglobin concentration) compared to the other groups.

Gacche et al. (2015) summarized that replacing soybean meal with DDGS up to 30% in broiler diets did not lead to adverse effects on hematological (hemoglobin, cell volume, total erythrocyte count, total leukocyte count, and differential leukocyte count) and biochemical (total protein, albumin, aspartate aminotransferase, alanine aminotransferase, and creatinine) profiles.

Furthermore, the inclusion of DDGS in broiler diets has minimal effect on serum hepatic enzymes (AST - Aspartate Aminotransferase and ALT - Alanine Aminotransferase) (El-Afifi et al., 2015). Overall, this study suggests that DDGS can be safely included in broiler diets up to 5% in the starter period, 7.5% in the grower, and 10% in the finisher stage without any adverse effects on the growth of birds, carcass characteristics, and blood parameters.

Elbaz et al. (2022) analyzed the concentrations of ALT and AST in broilers fed with different levels of DDGS inclusion in their diets and reported that the various levels of DDGS inclusion did not significantly affect the concentrations of these hepatic indicators. Moreover, with increasing levels of DDGS inclusion in broiler diets (10, 40, 70, 100, 130, and 160 g kg-1), increased serum albumin (ALB) and AST concentrations were observed when using 160 g kg-1 of DDGS (Damasceno et al., 2020). It's worth noting that the enzyme GGT (Gamma-glutamyltransferase), which is indicative of damage to various tissues, including the liver (Schmidt et al., 2007), was not affected by the inclusion of DDGS up to 160 g kg-1 (Damasceno et al., 2020).

In summary, the inclusion of DDGS in broiler diets can have varying effects on blood parameters, with some studies showing positive impacts on hemoglobin levels and others reporting minimal changes in hepatic indicators. Properly formulated diets with appropriate levels of DDGS can be safely used without adverse effects on broiler health and performance. However, further research is needed to better understand the interactions and optimal levels of DDGS inclusion in broiler diets.

Conclusion

This review demonstrates the potential of by-products from ethanol production using cereal crops, such as wheat and corn, as valuable sources of energy and protein for broiler diets. These by-products, known as DDGS, have a long history of use in poultry feeds, although typically at relatively low levels, usually around five percent or less in starter feeds. This limitation is mainly due to the variability in their nutritional composition. One notable challenge posed by DDGS is the significant presence of non-starch polysaccharides (NSP), which can negatively impact digestibility and broiler productivity. The high NSP content may require special attention in feed formulation to ensure optimal nutrient utilization and performance. Over the years, researchers have extensively studied the effects of including ethanol by-products in broiler diets, identifying both advantages and disadvantages in obtaining a high-quality product. Various experiments have been conducted with inclusion levels of up to 45-50% of DDGS in broiler feeds.

From these studies, it can be concluded that inclusion levels above 10% are generally considered safe. However, it is crucial to formulate the feed carefully, considering the amino acid and energy balance, to avoid any potential negative effects on broiler productivity. Further research will contribute to more efficient and sustainable broiler production.

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