

Impacts of dietary inclusion of dried brewers' grains on growth, carcass traits, meat quality, nutrient digestibility and blood biochemical indices of broilers

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(Received 16 March 2019; Accepted 8 April 2019; First published online 22 June 2019)

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Abstract

The current investigation aimed to evaluate the effect of dietary inclusion of dried brewers' grains (DBG) on growth performance, carcass traits, meat quality, nutrient digestibility, blood biochemical constituents and antioxidant indices of broiler chickens. A total of 300 unsexed one-week-old Hubbard chicks were randomly allotted to five treatment groups. The dietary treatments consisted of a basal diet as the control and DBG groups (3%, 6%, 9% and 12%, respectively). The best feed conversion ratio (FCR) was found in the group of birds fed a diet containing 9% DBG, compared the other groups. Dressing and abdominal fat percentages decreased significantly but gradually with the elevated DBG level in the diets from 6% to 12%. The inclusion of DBG in broiler diets resulted in significant positive effects on all of the sensory evaluation indicators except appearance and tenderness. Broilers fed a diet containing 3% DBG had significant higher of digestion coefficients for crude protein than those fed on the other experimental diets. Based on growth performance and health status, 3% or 9% DBG may be the optimum percentages for inclusion in the diets of poultry until six weeks old. In addition, DBG exerted several health benefits in meat, which would be reflected positively on human health.

Keywords: unconventional feedstuff, inclusion, performance, chicken, meat quality

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Introduction

Among the challenges to the poultry industry in developing countries are the high prices of soybean meal and yellow corn, which are used mainly for the formulation of poultry diets. The cost of feed is between 65% and 70% (Al-Sagheer *et al.*, 2019) and 70% and 75% (Abd El-Hack *et al.*, 2015) of the total cost of production, as opposed to about 50% to 60% in developed countries (Saeed *et al.*, 2017). The best strategy to reduce the cost of poultry feeds is to use alternative cheaper local ingredients (Abd El-Hack *et al.*, 2015; Ashour *et al.*, 2016). Reducing the cost of feed is therefore an important target in the poultry industry. Increased feed costs and limited amounts of animal protein sources in poultry feed have led to the use of alternative plant proteins that make up some or all animal protein in feed (El Boushy *et al.*, 2000; Vasso & Russ, 2007). Therefore, considerable attention has been given to the use of unconventional feedstuffs, such as agro-industrial by-products, in the formulation of poultry diets, with the intention of achieving suitable utilization and economic efficiency of poultry production (Alagawany *et al.*, 2015; Abd El-Hack *et al.*, 2017a; 2017b).

Dried brewers' grain (DBG) is a brewery by-product. The residue is obtained from barley, wheat, maize, rice and oats. DBG consists of the insoluble materials that remain after the process of soaking,

mashing and boiling in water, and contains crude fibre (CF) fractions, ether extract (EE), crude protein (CP) and starch (Amire, 2001; Areghore & Abdulrazak, 2005). DBG or spent grains can be fed to livestock in wet form or after drying. Because wet grains deteriorate easily, the product is usually dried to the DBG. Spent grain or DBG contains 93% dry matter (DM), 48.6% nitrogen free extract (NFE), 22.4% CP, 19.1% CF, 6.2% EE, 4% ash and 2360 kcal/kg of metabolizable energy (ME) (Longe *et al.*, 1983). DBG material is available in large quantities in Egypt. The Egyptian vision for 2030 is to decrease the importation of feedstuffs and make the best use of local materials. So, it is the responsibility of nutritionists to re-examine local feedstuffs (such as DBG) and try to use them as a replacement for maize and soybean meal.

Dried brewers' grain is high in CP and ME, and could be used to reduce the quantity of maize grain and soybean meal in broiler chicken diets. However, the use of DBG is limited in poultry diets because of its high fibre content. Therefore, the current trial was performed to evaluate on broilers the effect of various dietary inclusion levels of DBG on growth performance, carcass traits, serum metabolites, nutrient digestibility and quality of broiler meat.

Materials and Methods

The present investigation was carried out at Poultry Research Farm, Department of Poultry, Faculty of Agriculture, Zagazig University, Zagazig, Egypt. All authors gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the guidelines of the Local Experimental Animal Care Committee, and the protocol was approved by the Ethics Committee of the Department.

A total of 300 one-week old unsexed Hubbard chicks, with an initial weight of 114.5 ± 1.35 g, were allotted to a complete randomized experimental design with five treatments and 60 chicks in six replicates ($5 \times 6 \times 10$). Galvanized wire cages (40 cm height x 50 cm width x 100 cm length) were used for housing (10 chicks per cage). Fresh water was available automatically and continuously. Feed treatments consisted of a basal diet (control) and DBG supplemented groups (3%, 6%, 9% and 12% DBG). The choice of levels was based on a review of previous reports on the usage of DBG in poultry feed. Each group of broiler chicks was fed the experimental diet (in mash form) from one to six weeks old. The experimental diets were fed in two phases: starter (1 - 3 weeks) and finisher (3 - 6 weeks). Throughout the experiment, feed and water were available *ad libitum*. All chicks were kept under similar hygienic management (such as vaccinations) and environmental conditions. The chicks were fed according to their nutritional requirements (NRC, 1994). The formulation and composition of commercial broiler diets are provided in Tables 1 and 2. The chemical analysis of DBG used in the experiment was 20.9% CP, 15.3% crude fibre (CF), 6.2% crude fat and 2840 kcal/kg ME, according to AOAC (2003).

The weight of each bird was recorded weekly. Average daily feed intake (FI), bodyweight gain (BWG) and feed conversion ratio (FCR) were calculated. Feed wastage was recorded daily to calculate FI. Ten birds per treatment were randomly selected for carcass evaluation. The weights of the carcasses were recorded in kg, while the weights of the liver, gizzard, heart, thigh, breast and abdominal fat were recorded as g/kg of slaughter weight. Dressed weights were calculated with this formula: {dressed weight = (carcass weight + giblets weight) / live body weight}. At the end of the experiment, blood samples were collected in sterilized tubes from 10 broiler chicks in each group. Samples were centrifuged at 2328.24 (*g* force) for 15 min to obtain serums, which were stored in Eppendorf tubes at -20 °C until analysis. The serum biochemical constituents including total protein (TP), albumin (ALB), aspartate aminotransferase (AST, EC 2.6.1.1), alanine aminotransferase (ALT, EC 2.6.1.2), creatinine, urea, total cholesterol (TC), high density lipoprotein (HDL), triglyceride (TG), malondialdehyde (MDA), glutathione peroxidase (GPx, EC 1.11.19) and glutathione-S-transferase (GSTs, EC 2.5.1.18) were evaluated spectrophotometrically using commercial diagnostic kits (Biodiagnostic Co., Giza, Egypt).

To calculate the economic efficiency of meat production, the amount of feed consumed during the entire experimental period and the final live bodyweight were considered. An economic evaluation of experimental diets was performed as the feed cost needed to obtain one kilogram of live bodyweight. The dominant market prices of various elements in the study were considered. The economic efficiency of the product (growth rate) was calculated from an input and output analysis based on the differences in growth rate and feeding costs (Sarbaz *et al.*, 2018).

Digestion trials were conducted at the end of the experimental period (42 days old) to estimate the digestion coefficients of the diets. Five birds per treatment group were housed individually in metabolism cages. To ensure that all birds maintained their weight, they were weighed before and after the collection period. The metabolism cages were made of metallic wire with wooden frames and a drawer for excreta collection, with the dimensions of 50 x 50 x 50 cm. A sheet of aluminium foil that covered the drawer facilitated excreta collection. Experimental diets and water were available *ad libitum* through fixed containers. A small drawer covered with a plastic sheet placed under the food trough was used to facilitate the collection

of feed remnants. The objective of the preliminary period (three days) was to adjust feed intake and minimize residual feed during the collection period (four days), to obtain material that was suitable for chemical analysis.

Table 1 Formulation and chemical analysis of the starter diets through 1 - 3 weeks of age for broiler chicken

Ingredients (%)	Inclusion levels of brewers' dried grains (%)				
	0	3	6	9	12
Maize	57.1	55.2	53.6	51.3	49.0
Soybean meal	31.7	30.6	28.8	28.2	27.7
Gluten meal	6.50	6.50	7.00	6.70	6.40
Brewers' dried grains	0.00	3.00	6.00	9.00	12.00
Di Calcium	1.70	1.70	1.70	1.70	1.70
Limestone	1.24	1.22	1.22	1.22	1.20
Vitamin-mineral premix*	0.30	0.30	0.30	0.30	0.30
NaCl	0.30	0.30	0.30	0.30	0.30
DL Methionine	0.05	0.04	0.03	0.02	0.02
L-Lysine	0.13	0.14	0.16	0.16	0.15
Soybean oil	1.00	1.04	0.90	1.10	1.30
Total	100	100	100	100	100
Calculated analysis**					
Crude protein %	23.0	23.0	23.0	23.0	23.0
ME Kcal/kg diet	2951	2950	2951	2951	2951
Calcium %	1.00	1.00	1.00	1.00	1.00
Phosphorus (available) %	0.45	0.45	0.45	0.45	0.45
Lysine %	1.20	1.20	1.20	1.20	1.20
M+C %	0.83	0.83	0.83	0.83	0.83
Crude fibre %	3.56	3.90	4.20	4.57	4.93
Determined analysis***					
Crude protein %	22.8	23.1	23.1	22.9	23.2
Crude fibre %	3.78	3.98	4.72	4.79	5.00
Price/ ton (\$)*****	344.38	336.71	327.43	320.88	314.86

* Vitamin and mineral premix - 2.5 kg contained: vitamin A, 12 000 000 IU; vitamin D₃, 2 000 000 IU; vitamin E, 10 g; vitamin K₃, 2 g; vitamin B₁, 1000 mg; vitamin B₂, 49 g; vitamin B₆, 105 g; vitamin B₁₂, 10 mg; pantothenic acid, 10 g; niacin, 20 g; folic acid, 1000 mg; biotin, 50 g; choline chloride, 500 mg, Fe 30 g; Mn, 40 g; Cu, 3 g; Co, 200 mg; Si, 100 mg; Zn, 45 g

**According to NRC (1994)

***According to AOAC (2003)

**** Prices were calculated according the market price in 2019

NaCl: sodium chloride; ME: metabolizable energy

The experimental diets were weighed on the first day of the collection period and given once daily. At the end of the experiment, feed residue was weighed and subtracted from the total feed provided. Excreta collection began 24 hours after the start of the collection period. Feathers and scattered feed were separated from the excreta. To prevent any loss in ammonia during drying, the excreta were sprayed with 2% boric acid solution. The excreta of each bird during the collection period was pooled and dried at 65 °C for 24 hours. The dried excreta from three successive days were equilibrated with the atmosphere for a few hours, then ground, mixed thoroughly, and stored in glass jars for chemical analysis. The proximate analysis of tested

material, feeds and dried excreta was carried out according to the protocols of the Association of Official Analytical Chemists (AOAC, 2003) using triplicate samples for each nutrient.

Table 2 Formulation and chemical analysis of the finisher diets for broiler chickens through 3 - 6 weeks old

Ingredients (%)	Inclusion levels of brewers' dried grains (%)				
	0	3	6	9	12
Maize	60.5	58.4	57.1	55.1	53.3
Soybean meal	27.2	26.3	24.1	23.1	21.8
Gluten meal	6.10	6.00	6.65	6.65	6.80
Brewers' dried grains	0.0	3.0	6.0	9.0	12.0
Di Calcium	1.50	1.50	1.50	1.50	1.50
Limestone	1.15	1.12	1.12	1.12	1.11
Vitamin-mineral premix*	0.30	0.30	0.30	0.30	0.30
NaCl	0.30	0.30	0.30	0.30	0.30
DL Methionine	0.02	0.01	0.00	0.00	0.00
L-Lysine	0.10	0.10	0.13	0.14	0.15
Soybean oil	2.85	3.00	2.75	2.80	2.81
Total	100	100	100	100	100
Calculated analysis**					
Crude protein %	21.0	21.0	21.0	21.0	21.0
ME Kcal/kg diet	3099	3102	3101	3100	3101
Calcium %	0.90	0.90	0.90	0.90	0.90
Phosphorus (available) %	0.40	0.40	0.40	0.40	0.40
Lysine %	1.05	1.05	1.05	1.05	1.05
M+C %	0.74	0.74	0.74	0.75	0.76
Crude fibre %	3.31	3.66	3.95	4.29	4.62
Determined analysis***					
Crude protein %	21.2	21.0	21.1	20.6	21.7
ME Kcal/kg diet	3111	3098	3135	3095	3109
Crude fibre %	3.45	3.86	4.10	4.35	4.98
Price/ ton (\$)****	338.25	331.36	320.93	313.61	305.81

* Vitamin and mineral premix - 2.5 kg contained: vitamin A, 12 000 000 IU; vitamin D₃, 2 000 000 IU; vitamin E, 10 g; vitamin K₃, 2 g; vitamin B₁, 1000 mg; vitamin B₂, 49 g; vitamin B₆, 105 g; vitamin B₁₂, 10 mg; pantothenic acid, 10 g; niacin, 20 g; folic acid, 1000 mg; biotin, 50 g; choline chloride, 500 mg; Fe, 30 g; Mn, 40 g; Cu, 3 g; Co, 200 mg;

Si, 100 mg; Zn, 45 g

**According to NRC (1994)

***According to AOAC (2003)

**** Prices were calculated according the market price in 2019

NaCl: sodium chloride; ME: metabolizable energy

At the end of the experiment, chickens were slaughtered, plucked, dressed, washed in water, and cut into separate parts. Ten samples per treatment group were taken from the thigh (biceps femoris muscle) and breast (pectoralis major muscle). Three hundred grams from the thigh plus 300 g from the breast were cut into 3 - 4 cm-thick steaks and minced in the laboratory using a Moulinex meat grinder (1400 W/600W locked motor output, HV8, France). The basic formulation of chicken meat was (g/g) 952 meat, 2.5% spice mixture (50 g black pepper, 30 g cloves), 2% salt, with 3 g onion juice. Chicken patties (50 g) were grilled in an air oven, before being brushing with a small amount of corn oil and grilled under a moderate heat for 20 - 30 min at 190 - 200 °C (375 °F (Nath *et al.*, 1996) in an oven.

Patty cooking yields (expressed as a percentage) were calculated as the ratio of the cooked weight to the raw weight of patties from each group. The cooking loss percentage was calculated as the difference in weight between individual raw and cooked patties. The moisture retention value was the amount of moisture retained in the cooked product per 100 g raw sample (Kumar & Sharma, 2004).

Colour attributes of poultry meat (L^* , a^* , and b^*) were evaluated using the Hunter Lab colour analyser (ColorFlex EZ, USA), according to Rao *et al.* (2011). The L^* value (lightness index scale) ranges from 0 (black) to 100 (white), a^* value indicates the redness ($+a^*$) or greenness ($-a^*$), and the b^* value refers to the yellowness ($+b^*$) or blueness ($-b^*$). Samples (minced mix of thigh and breast muscles) filled petri dishes to the top, then the petri dish was placed directly on the colorimeter sensor.

$$\Delta E = [(l - l^*)^2 + (a - a^*)^2 + (b - b^*)^2]^{0.5}$$

where: L^* , a^* and b^* were the values of the reference sample, which refers to the control sample, and (ΔE) the total colour differences in comparison with an untreated control.

All samples at a temperature of 30 - 35 °C were assessed for their appearance and colour, flavour and juiciness, by a panel of eight experienced judges using an 8-point descriptive scale, in which 8 denoted extremely desirable and 1 denoted extremely poor. Tap water was provided between samples to cleanse the palate. The results were expressed as the mean \pm standard error of mean (SEM) for eight patties/treatment.

The data (cage means) were assessed with a one-way ANOVA using the GLM procedures of SPSS (2008). The applied model was as follows:

$$Y_{ijk} = \mu + T_i + e_{ij}$$

where: Y_{ijk} = an observation,
 μ = the overall mean,
 T_i = effect of DBG inclusion levels (0, 3, 6, 9, 12), and
 e_{ij} = random error.

The significant differences were assessed using Duncan's multiple range test. The results were expressed as mean values and standard error means (SEM). Statistical significance statements were based on $P < 0.05$.

Results and Discussion

The results indicated that live body weight (LBW) at 6 weeks old and 8 through 3 - 6 and 1 - 6 weeks old decreased ($P < 0.05$) in chicks fed diets containing DBG. The reduction in LBW and BWG increased with DBG levels from 3% to 12% (Table 3). Studies have shown that as the inclusion of DBG increases, birds do not compensate for the reduced dietary metabolizable energy levels and do not increase their feed intake (Denstadli *et al.*, 2010). The present results agree with those obtained by Wondifraw & Tamir (2014), who showed that growth rate generally decreased progressively with increasing levels of DBG in White Leghorn chicks, and concluded that DBG could be incorporated in chick rations up to 18% without an adverse effect on growth performance to increase economic efficiency. Adama *et al.* (2007) incorporated four levels of sorghum DBG up to 40% to replace maize and groundnut cake in broiler chicken diets, and reported that the growth rate remained similar up to 20%, and then decreased. A study by Esonu *et al.* (1999) suggested that diets with 30% maize-sorghum-based DBG to replace maize showed similar performance to the control group with only maize, thus reducing the total cost of broiler production. Feeding DBG at the level of 20% (replacing maize and soybean meal) did not affect the BWG of Vanaraja chicks at 9 weeks old (Swain *et al.*, 2012). Aghabeigi *et al.* (2013) concluded that the addition of DBG up 20%, in broiler chick diets through 11 to 42 days and 5% DBG through 25 to 42 days approached the growth of the control birds. Alabi *et al.* (2014) found that increasing the level of DBG up to 25% without commercial enzyme supplementation resulted in a decrease in weight gain. It could be concluded that merging DBG with the broiler diet did not have positive effects on growth performance traits. These conflicting results may be because of varying sources of DBG and experiment conditions.

Average FI values decreased with increasing dietary DBG throughout the experimental period (1 - 6 weeks old) (Table 3). The present results agree those of Wondifraw & Tamir (2014), who reported a small difference in the mean dry matter intake between starter chicks that were fed with 25% DBG and their counterparts that were fed the control diet. This represents an advantage for breeders, as DBG is regarded as a waste material that can be purchased cheaply, and can thus reduce the production cost without

Table 3 Growth performance of broiler chickens from 1 to 6 weeks old as affected by various levels of dried brewers' grains

Dried brewers' grains (%)	Number of pens	Live bodyweight (g)			Bodyweight gain (g)			Feed intake (g DM/day)			Feed conversion (g feed/g gain)			Economic efficiency
		1 wk	3 wk	6 wk	1 - 3 wk	3 - 6 wk	1 - 6 wk	1 - 3 wk	3 - 6 wk	1 - 6 wk	1 - 3 wk	3 - 6 wk	1 - 6 wk	
0	6	112.7	581.0	1876 ^a	33.5	61.7 ^a	50.4 ^a	65.0	156.5	111.0	2.00	2.53	2.20	0.88 ^{ab}
3	6	114.2	525.7	1749 ^{ab}	29.4	58.3 ^{ab}	46.7 ^{ab}	59.7	147.8	103.7	2.00	2.53	2.21	0.76 ^{bc}
6	6	115.3	572.5	1651 ^b	32.7	51.4 ^b	43.9 ^b	63.7	142.5	103.3	2.00	2.83	2.35	0.76 ^{bc}
9	6	115.5	562.2	1747 ^{ab}	31.9	56.4 ^{ab}	46.6 ^{ab}	61.0	134.5	98.0	1.90	2.40	2.10	0.98 ^a
12	6	114.8	561.7	1409 ^c	31.9	40.3 ^c	37.0 ^c	61.0	134.4	98.0	1.93	3.33	2.65	0.64 ^c
SEM		0.38	11.83	46.11	0.84	2.19	1.13	0.97	3.97	2.27	0.05	0.12	0.06	0.02
<i>P</i> -value		0.085	0.700	0.001	0.691	0.001	0.002	0.443	0.371	0.383	0.962	0.068	0.093	0.001

* Each pen involved 10 birds

Means in the same column with no superscript or a common superscript are not significantly different ($P < 0.05$)

affecting FI (Wondifraw & Tamir, 2014). With regard to FCR, it was not strongly affected by the addition of DBG to the diet of broiler chicks throughout the experiment (Table 3). This may be because of the reduction in BWG as a result of DBG inclusion. DBG contains a high concentration of non-starch polysaccharides and tannins, which have been shown to interfere with the efficiency of feed utilization in monogastric organisms, thus inhibiting the absorption of essential nutrients and digestive enzymes, and hence decreasing feed utilization (Lacassagne, 1998). Furthermore, Alabi *et al.* (2014) demonstrated that when the dietary level of BDG increased, FCR decreased. Data in Table 3 showed that broiler chicks exposed to 9% BDG recorded the best ($P < 0.01$) economic efficiency value compared with the other treatments. This group showed the best feed conversion ($P > 0.01$) (Table 3).

The various DBG levels did not have an effect on carcass and giblet percentages, apart from dressing percentage and abdominal fat relative weights ($P > 0.05$) (Table 4). Dressing and abdominal fat percentages decreased ($P < 0.05$) gradually with the increasing DBG level in the diets from 6% to 12% which may be because of lower bodyweight. Lopez & Carmona (1981) evaluated DBG at levels of 0%, 10%, 20%, 30% and 40% in broiler chick diets, and reported minor differences in average dressing percentage up to the 20% inclusion level ($P > 0.05$). These authors observed that when a DBG inclusion level of 20% or more was used, there was a reduction in abdominal fat pads and meat tissue ($P < 0.05$), though no effect was observed in bone tissue. Additionally, Chumpawadee *et al.* (2008) reported that the inclusion of DBG in broiler diets did not induce an effect on carcass cuts ($P > 0.05$). Kokol *et al.* (2012) found that most carcass traits that were evaluated were not affected by DBG inclusion level ($P < 0.05$), apart from gizzard percentages, which varied among groups ($P < 0.05$).

Table 4 Carcass characteristics of broiler chickens from 1 to 6 weeks old as affected by various levels of dried brewers' grain

Dried brewers' grains (%)	Number of birds	Weights relative to live weight (%)							Caecum length (cm)
		Dressing	Carcass	Giblets	Liver	Heart	Gizzard	Abdominal fat	
0	10	75.8 ^a	70.4	5.40	2.49	0.57	2.34	2.01 ^a	19.6
3	10	75.4 ^a	69.6	5.82	2.79	0.59	2.45	1.87 ^b	21.5
6	10	74.6 ^{ab}	69.2	5.37	2.51	0.64	2.22	1.38 ^c	18.5
9	10	73.5 ^b	67.9	5.52	2.60	0.61	2.31	1.04 ^d	21.0
12	10	73.2 ^b	67.8	5.41	2.59	0.56	2.27	0.66 ^e	19.0
SEM		0.34	0.36	0.09	0.04	0.02	0.05	0.07	0.43
<i>P</i> -value		0.020	0.090	0.530	0.204	0.639	0.705	0.031	0.101

Means in the same column with no superscript or with common superscripts are not significantly different ($P < 0.05$)

The effects of DBG levels on colour values of broiler chicken meat, compared with the control, are presented in Tables 5 and 6. Increased DBG levels was associated with elevated L^* and b^* values, and decreased a^* values. The increase in protein concentration in meat is responsible for increasing lightness (L^*) and decreasing redness (a^*) values (Su *et al.*, 2000; Rhee & Ziprin, 2001). Munekata *et al.* (2015) suggested that variations in L^* values may depend on phenolic concentrations. O'Keefe & Wang (2006) reported a reduction in L^* values with elevations in phenolic content, at concentrations in excess of 400 parts per million in ground cooked beef ($P < 0.05$). Sensory evaluations of broiler chicken meat, which involved tests of appearance, flavour, tenderness, texture, juiciness and cooking loss, were all affected by DBG inclusion ($P < 0.05$) (Table 6). All meat samples from DBG groups showed lower appearance and tenderness values, compared with the control group ($P < 0.05$). All samples decreased in cooking loss percentage, compared with the control (11.40% \pm 0.43). The opposite trend was observed in other sensory traits (flavour, texture and juiciness), which increased as a response to DBG inclusion ($P < 0.001$). Therefore, the inclusion of DBG in broiler diets exerts significant positive effects on the sensory properties of broiler chicken meat.

The results revealed that the digestibility coefficient values for DM and CF were not affected by DBG ($P > 0.05$) (Table 7). On the other hand, the digestibility coefficients of OM, CP, EE and NFE were affected ($P < 0.01$ or $P < 0.05$) by feeding treatments. The results showed a decrease in digestion coefficients for the

Table 5 Meat colour of samples as affected by various levels of dried brewers' grains from 1 to 6 weeks old

Dried brewers' grains (%)	Number of birds	Colour		
		<i>L</i> *	<i>a</i> *	<i>b</i> *
0	10	46.7 ^d	7.83 ^a	12.57 ^d
3	10	47.0 ^d	6.73 ^b	13.43 ^c
6	10	56.0 ^c	5.90 ^c	13.80 ^c
9	10	66.3 ^b	4.70 ^d	15.17 ^b
12	10	74.0 ^a	3.70 ^e	15.90 ^a
SEM		2.89	0.39	0.33
<i>P</i> -value		0.001	<0.00	<0.00

*L**: whiteness; *a**: redness; *b**: yellowness

Means in the same column with no superscript or with common superscripts are not significantly different ($P < 0.05$)

Table 6 Sensory evaluation and cooking loss of broiler chicken meat using one to one mix of biceps femoris muscle of thigh and pectoralis major muscle of breast as affected by various levels of dried brewers' grains from 1 to 6 weeks old

Dried brewers' grains (%)	Number of birds	Appearance	Flavour	Tenderness	Juiciness	Texture	Cooking loss
0	10	7.97 ^a	5.27 ^c	7.70 ^a	6.53 ^d	7.03 ^b	11.40 ^a
3	10	7.60 ^b	5.97 ^a	7.50 ^{ab}	7.63 ^a	7.53 ^a	7.20 ^d
6	10	7.47 ^b	5.60 ^b	7.03 ^b	7.40 ^{bc}	7.57 ^a	9.00 ^c
9	10	7.10 ^c	5.55 ^b	6.83 ^b	7.33 ^c	7.43 ^a	9.80 ^b
12	10	6.87 ^c	5.80 ^{ab}	7.03 ^b	7.60 ^{ab}	7.53 ^a	7.27 ^d
SEM		0.11	0.09	0.09	0.11	0.06	0.43
<i>P</i> -value		<0.000	0.001	<0.000	<0.000	<0.000	<0.000

Means in the same column with no superscript or with common superscripts are not significantly different ($P < 0.05$)

9% DBG level, compared with other groups and the control ($P < 0.01$ or $P < 0.05$). However, the digestion coefficients of EE decreased for chicks fed 3% DBG levels ($P < 0.01$). The highest CP digestion coefficient was obtained from groups with a diet that contained 3% DBG ($P < 0.01$). Likewise, Aghabeigi *et al.* (2013) evaluated the impact of a gradual replacement of soybean meal with 0%, 5%, 10%, 15%, 20% and 25% DBG on protein digestibility in broiler chickens. The ileal protein digestibility was recorded from chicken samples slaughtered at 42 days old and was increased with the inclusion of 10% DBG in diets, compared with the 0%, 5%, 15%, and 20% DBG groups ($P < 0.05$). Conversely, Denstadli *et al.* (2010) observed a reduction in protein digestibility as DBG replaced a wheat and soy-based control diet, probably because of the insoluble properties of the DBG protein. These authors added that apparent ash availability decreased gradually due to the inclusion of DBG in the diets, which was attributed to the complexation between fibrous structures of DBG and minerals. Adama *et al.* (2007) incorporated four levels of sorghum DBG, up to 40%, in broiler chickens, which replaced maize and groundnut cake in the diet, and reported that the digestibility of all nutrients (CP, EE, NFE, and ash) decreased with increasing levels of DBG, but was not generally affected dramatically up to 20% levels of DBG.

No substantial impact of DBG inclusion was detected on any of the constituents, except from globulin, A/G ratio and HDL-cholesterol (Table 8). The highest ($P = 0.038$) globulin concentration value was recorded for broiler chicks fed diets containing 3% DBG (3.67 g/dL). The broilers fed the diet supplemented with 9% DBG had the best albumin/globulin ratio (A/G) (0.48), compared with other levels. The HDL concentration differed statistically according to DBG levels. Serum HDL concentration recorded the highest value for chicks fed 12% DBG. These results may be because of the existence of bioactive components in DBG. Decreasing

the concentration of serum LDL might be because of minimizing microbial intracellular pH (Abdo & Zeinb, 2004). The inhibition of microbial enzymes forced the bacterial cell membrane to use energy to release acidic protons, which leads to a decline in intracellular pH (Aruna & Srilatha, 2012).

Table 7 Digestibility coefficients of broiler chickens as affected by various levels of dried brewers' grains in the diet from 1 to 6 weeks old

Dried brewers' grains (%)	No. of birds	DM	OM	CP	EE	NFE	CF
0%	5	77.2	79.5 ^a	82.8 ^c	76.6 ^{ab}	82.1 ^a	23.4
3%	5	78.5	80.5 ^a	88.1 ^a	69.0 ^c	82.2 ^a	24.1
6%	5	78.0	78.9 ^a	86.7 ^{ab}	75.3 ^b	78.4 ^b	24.0
9%	5	77.9	74.7 ^b	85.7 ^b	76.8 ^{ab}	73.9 ^b	23.8
12%	5	78.4	81.7 ^a	85.8 ^b	79.2 ^a	83.5 ^a	23.4
SEM		0.75	0.84	0.54	1.25	0.95	0.65
<i>P</i> -value		0.546	0.002	0.003	0.002	0.001	0.632

DM: dry matter; OM: organic matter; CP: crude protein; EE: ether extract; NFE: nitrogen free extract; CF: crude fibre
Means in the same column with no superscript or with common superscripts are not significantly different ($P < 0.05$)

Table 8 Serum protein and lipid profiles of broiler chickens as affected by various levels of dried brewers' grains in the diet from 1 to 6 weeks old

Dried brewers' grains (%)	No of birds	Tot prot (g/dL)	Album (g/dL)	Glob (g/dL)	A/G ratio	Triglyc (mg/dL)	Total chol (mg/dL)	LDL -chol (mg/dL)	HDL chol (mg/dL)
0	10	3.80	1.16	2.64 ^b	0.44 ^a	35.4	131.0	64.3	58.3 ^b
3	10	4.67	1.00	3.67 ^a	0.27 ^c	70.3	132.0	59.6	59.7 ^b
6	10	4.43	1.32	3.11 ^{ab}	0.43 ^a	42.3	146.6	66.5	71.7 ^{ab}
9	10	3.79	1.23	2.56 ^b	0.48 ^a	25.1	137.7	73.0	59.7 ^b
12	10	4.00	1.08	2.93 ^{ab}	0.37 ^b	55.1	154.7	65.4	78.3 ^a
SEM		0.15	0.05	0.14	0.02	6.57	4.01	2.65	2.64
<i>P</i> -value		0.239	0.184	0.038	<0.000	0.219	0.294	0.682	0.020

Tot prot: total protein; Album: albumin; Glob: globulin; A/G: albumin/ globulin ratio; Triglyc: triglycerides; chol: cholesterol; LDL: low-density lipoprotein; HDL: high-density lipoprotein
Means in the same column with no superscript or with common superscripts are not significantly different ($P < 0.05$)

The effects of dietary DBG on liver and kidney function and blood oxidative status were unique. Apart from serum ALT activity, all other constituents were affected statistically because of DBG inclusion levels (Table 9). Increasing the dietary DBG level was associated with a gradual elevation ($P = 0.019$) in the activity of glutathione peroxidase enzymes and a depression ($P < 0.01$) in the serum AST activity, and urea, creatinine and MDA levels. This result indicates an improvement in the kidney and liver function, along with oxidative status. Enhancement of immune functions in treatment groups may be because herbal supplements and plant-derived materials such as DBG have a rich content of flavonoids, which act as strong antioxidants (Acamovic & Brooker, 2005). The main role of glutathione peroxidase enzymes is to prevent cells from oxidative damage. This process requires dietary resources of specific nutrients (Ashour *et al.*, 2014). The present conclusions are in line with those of Lin *et al.* (2003), who found that the intake of plant-derived components caused an increase in serum antioxidant enzyme activities and a reduction in MDA levels. Abd El-Hack (2015) and Alagawany *et al.* (2015) detected that dietary supplements of herbs into

rabbit diets led to positive effects on antioxidant agents activities. From these findings, it can be inferred that DBG is a source of natural antioxidants and can be utilized in future to enhance the health status of broilers (Abd El-Hack *et al.*, 2019).

Table 9 Liver and kidney functions and the antioxidative status of broilers as affected by various levels of dried brewers' grains in the diet from 1 to 6 weeks old

Dried brewers' grains (%)	Number of birds	AST (IU/L)	ALT (IU/L)	Urea (mg/dL)	Creatinine (mg/dL)	MDA (mol/mg)	GPx (IU/L)	GSTs (IUL)
0	10	18.33 ^a	269	46.0 ^a	0.85 ^a	3.75 ^a	2.71 ^c	3.55
3	10	11.67 ^b	287	44.7 ^{ab}	0.82 ^{ab}	3.66 ^b	2.73 ^{bc}	3.55
6	10	15.80 ^a	279	44.3 ^{ab}	0.80 ^{ab}	3.61 ^b	2.77 ^{ab}	3.56
9	10	9.27 ^b	283	43.0 ^b	0.76 ^b	3.52 ^c	2.79 ^a	3.54
12	10	6.50 ^c	248	41.0 ^c	0.65 ^c	3.38 ^d	2.76 ^{ab}	2.39
SEM		1.19	10.9	0.51	0.02	0.03	0.01	0.24
P-value		<0.000	0.847	0.002	<0.000	<0.000	0.019	0.479

AST: aspartate aminotransferase; ALT: alanine aminotransferase; MDA: malondialdehyde; GPx: glutathione peroxidase; GSTs: glutathione-S-transferase

Means in the same column with no superscript or with common superscripts are not significantly different ($P < 0.05$)

Conclusions

From the data, the conclusion could be drawn that including DBG in broiler diets did not have positive effects on growth performance traits. If blood biochemical constituents and nutrient digestibility are considered, 3% or 9% DBG may be the optimal percentage for inclusion in diets of poultry up to 6 weeks old.

Acknowledgements

This work was supported financially by the Deanship of Scientific Research at King Saud University through a research group project (#RG-1438-018).

Authors' Contributions

EA, MEH and AA designed the study plan. MAEH collected literature and drafted the manuscript. AO helped in conducting research work. AS, ANA and IS provided technical help in the write-up of this manuscript. MAEH reviewed and performed the final check. All authors read and approved the final manuscript.

Conflicts of Interest Declaration

The authors declare there is no conflict of interest.

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