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Effect of using distillers dried grains with solubles of corn as an unconventional feedstuff on broiler performance

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ABSTRACT

This study evaluated the effects of incorporating different levels of corn distiller dried grains with solubles (DDGS) with or without NSPase enzyme supplementation in broiler diets on growth performance, carcass traits, digestibility, and economic efficiency. A total of 240 one-day-old (Avian 48) broiler chicks were randomly divided into eight groups, each containing 30 chicks (3 replicates of 10 chicks). Experimental diets were iso-caloric and iso-nitrogenous and included 0%, 5%, 10%, and 20% DDGS, with or without NSPase enzyme. The inclusion of Smart NSPase® enzyme significantly enhanced body weight (BW) and feed conversion ratio (FCR) ($p \leq 0.05$), particularly at moderate DDGS levels. Group G2 (0% DDGS + enzymes) achieved the highest BW, followed by G4 (5% DDGS + enzymes) and G6 (10% DDGS + enzymes). High DDGS levels (20%) without enzymes negatively impacted growth. Up to 5 and 10% DDGS inclusion without enzymes showed comparable performance to the control, but enzyme supplementation further optimized growth and nutrient utilization. Carcass traits, including yield and dressing percentages, showed no significant differences ($p > 0.05$) among most groups, although high DDGS levels without enzymes reduced breast meat weight. Economic feed efficiency (EFE) was highest in diets with 5% DDGS + enzymes among DDGS-fed groups. The study concluded that among DDGS-fed groups, the 5% DDGS with enzyme supplementation showed the best economic returns, achieving (137.72%) relative to the control. Incorporating up to 5 and 10% DDGS with enzyme supplementation is a sustainable alternative to traditional broiler diets, enhancing growth, nutrient absorption, and economic returns.

1. INTRODUCTION

Feed costs account for 60–70% of total production expenses in poultry farming, making them a critical factor in determining profitability [1, 2]. Proper nutrition is essential for optimal growth, reproduction, and the overall health of poultry, directly influencing the quality of meat or eggs produced. Corn and soybean meal are the predominant feed ingredients due to their high energy and protein content. However, their rising costs and limited availability have posed significant challenges for poultry producers.

In response to these challenges, researchers have explored alternative feed ingredients to reduce reliance on traditional components. Distillers Dried Grains with Solubles (DDGS), a by-product of the ethanol industry, has gained significant attention as a promising alternative. The increasing global production of biofuels is expected to enhance the availability of DDGS. According to [3], biofuel production is projected to grow by over 20% between 2022 and 2027, which will result in a substantial rise in DDGS supply. This trend highlights its potential as a sustainable and economical feed ingredient.

DDGS is derived from the fermentation of cereal grains, primarily corn, and contains valuable nutrients such as crude protein (27.4%), ether extract (17.7%), and metabolizable energy (2,480 kcal/kg) [4]. Its high nutrient content makes it a cost-effective option for broiler diets. Despite its advantages, DDGS contains non-starch polysaccharides (NSPs), Soluble NSPs can impair nutrient digestion by increasing the viscosity of digesta [5, 6], while insoluble fractions may encapsulate nutrients, further limiting their availability [5]. These effects are particularly concerning in young broilers, whose digestive systems are not fully developed until approximately two weeks of age [7].

Previous studies have evaluated the optimal inclusion levels of DDGS in broiler diets. For example, [8] suggested that 6% DDGS during the starter period and 12–15% during the grower and finisher phases can be incorporated without negative effects. Similarly, diets containing up to 15% DDGS throughout the entire feeding period (1–42 days) have been shown to maintain performance and carcass quality when formulated on a digestible amino acid basis [9–11]. However, higher levels, such as 18%, may negatively impact body weight and feed conversion ratios [12]. To combat these limitations, enzyme supplementation has emerged as an effective strategy. Enzymes such as NSPase break down NSPs, improving nutrient digestibility and absorption [13–17]. This approach not only enhances the nutritional value of DDGS but also enables higher inclusion rates without compromising broiler performance.

The present study was conducted to evaluate the effect of incorporating different levels of DDGS (0, 5, 10, and 20%) into broiler diets over a 35-day period. Additionally, it evaluated the impact of NSPase enzyme supplementation on growth performance, carcass traits, digestibility and economic feed efficiency (EFE) to optimize DDGS utilization in broiler nutrition while maintaining performance and reducing feed costs.

2. MATERIALS AND METHODS

2.1 Animal ethics statement:

All applicable national and institutional guidelines for the care and use of animals were followed. All samples were from birds used in experiments approved by the Animal Ethics Committee of Menoufia University, Faculty of Veterinary Medicine (Approval No. MN/VET/NUT/25/02/03/01)

2.2. Experimental study:

The study was conducted at the Department of Nutrition and Clinical Nutrition, Faculty of Veterinary Medicine, Menoufia University. A total of 240 one-day-old (Avian 48) broiler chicks were randomly divided into eight groups, with each group containing 30 chicks (3 replicates of 10 chicks each). Experimental groups were fed diets containing different levels of DDGS (0%, 5%, 10%, and 20%) with or without NSPase enzyme supplementation (0.5 g/kg diet).

Representative feed samples, including yellow corn, soybean meal, and DDGS, were analyzed for their chemical composition. Feed composition was determined following [18] methods: Dry matter (DM) via a hot air oven, crude protein (CP) by the Kjeldahl method, ether extract (EE) via Soxhlet extraction, crude fiber (CF) by acid-alkali digestion, and ash using a muffle furnace. Nitrogen-free extract (NFE) was calculated by difference, while metabolizable energy (ME) was estimated from gross energy (GE) [4]. The analyzed Chemical composition and calculated metabolizable energy values of the feed ingredients used in the experimental diets are presented in Table (1).

Table 1: Proximate chemical composition and calculated metabolizable energy values of the feed ingredients used in the experimental diets.

Ingredients	DM	CP	EE	CF	Ash	NFE	ME* (kcal/kg diet)
Chemical composition, %(as dry basis)							
Yellow corn, ground	87.99	9.45	3.8	2.2	1.2	71.34	3325
Soybean meal	87.39	45	1.9	3.6	4	31.34	2450
Corn gluten	91.96	60	6.3	2	3.6	20	3680
DDGS	88.47	25	8	7.9	4.79	42.73	2525

ME* Metabolizable Energy is derived from Gross Energy (GE) of proteins, carbohydrates, and fats using specific conversion factors [4].

2. Housing and Feeding Management:

All experimental groups were reared under standard management practices. The experimental room was disinfected using Virkon S (LANXESS®, United Kingdom) prior to the study and divided into 24 compartments each with a floor area of 1.5 m² and bedded with a layer of wood shaving. Each compartment equipped with feeders, waterers, heaters, and ventilation systems. Temperature was gradually reduced from 34°C on day 1 to 25°C by the end of week 3 and maintained at 24°C thereafter, and artificial light was provided 23 h daily. Chicks of all treatment groups were routing vaccinated against common viral disease such as Newcastle disease, infectious bronchitis, low, and highly pathogenic avian influenza and infectious bursal disease.

The feeding program consisted of three phases: starter (0-14 days), grower (15–28 days), and finisher (29–35 days). Eight experimental groups were established: G1 (control), G2 (basal diet + 0.05% NSP enzyme), G3 (5% DDGS without enzyme), G4 (5% DDGS + 0.05% NSP enzyme), G5 (10% DDGS without enzyme), G6 (10% DDGS + 0.05% NSP enzyme), G7 (20% DDGS without enzyme), and G8 (20% DDGS + 0.05% NSP enzyme). Basal diets were formulated to meet (Avian 48) nutritional requirements and provided *ad libitum*, with fresh available water always. Diets were balanced for crude protein and metabolizable energy. Ingredients and calculated chemical composition of basal control and experimental starter, grower and finisher diets are shown in Tables (2), (3), and (4), respectively.

Smart NSPase® enzyme, produced by Devenish™, contains a combination of five active enzymes: 7,503 U/g Xylanase, 2,500 U/g Glucoamylase, 1,443 U/g β - Glucanase, 375 U/g Pectinase, and 144 U/g Cellulase). This enzyme provides an energy matrix of ME (Kcal/kg) 1,050,000.

3. Growth Performance and Feed Efficiency:

The live body weight (LBW) of broilers was recorded individually at the start and weekly thereafter. Body weight gain (BWG) was calculated weekly as the difference between the initial and final weights, while feed intake (FI) was measured by subtracting leftover feed from the amount offered. The cumulative feed conversion ratio was also calculated as the total feed intake (g) divided by the total body weight gain (g) up to that specific period throughout the 35-day feeding trial.

4. Carcass Traits:

At the end of the trial, three birds per group were randomly selected for carcass evaluation. Dressed carcass weights, internal organ weights (liver, gizzard, and heart), and immune organ weights (bursa, spleen, thymus) were recorded as a percentage of live weight.

5. Digestibility:

Digestibility was assessed using three healthy broilers of similar weight at the end of experiment, isolated from each group, and plastic sheeting was placed under them to collect feces accurately. Apparent digestibility coefficients (ADC) for dry matter, crude protein, ash, fiber, and nitrogen-free extract were determined using the direct method. Feed intake was recorded for three days, and fecal samples were collected twice daily, dried at 60°C, and ground for analysis. Crude protein (CP) was determined using the Kjeldahl method, ether extract (EE) by Soxhlet extraction, crude fiber (CF) by acid-alkali digestion, ash by incineration in a muffle furnace at 550–600°C, and nitrogen-free extract (NFE) was calculated by difference. All analyses followed [18].

ADC was calculated as:

$$\frac{(\%\ \text{Nutrient in feed X Feed Intake}) - (\%\ \text{Nutrient in feces X Fecal Output})}{(\%\ \text{Nutrient in feed X Feed Intake})} \times 100$$ [19]

Table 2: Ingredients Composition and proximate analysis of the starter experimental diets.

Item / Group	Starter diets							
	G1	**G2**	**G3**	**G4**	**G5**	**G6**	**G7**	**G8**
Yellow corn, ground	55.2	57.5	52.5	54.30	49.8	51.2	43.3	44.6
Soybean meal	36.5	35.4	33.1	33.40	30.0	31.0	25.4	26.7
Corn. gluten	1.60	2.00	2.40	1.90	3.00	2.00	3.30	2.05
DDGS	0.00	0.00	5.00	5.0	10.0	10.0	20.0	20.0
Vegetable oil	2.43	0.65	2.60	1.04	2.80	1.40	3.6	2.20
L-Lysine-HCL (99%)	0.22	0.24	0.28	0.27	0.33	0.31	0.41	0.38
DL-Methionine (99%)	0.24	0.25	0.24	0.24	0.22	0.23	0.20	0.21
Dicalcium phosphate	1.50	1.48	1.46	1.45	1.42	1.45	1.43	1.42
limestone	1.305	1.37	1.35	1.37	1.38	1.40	1.44	1.43
Smart NSPase® enzyme [1]	----	0.01	---	0.01	----	0.01	---	0.01
Smart Phytase® enzyme [2]	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Chemical composition (%)								
CP	22.87	22.84	22.84	22.84	22.82	22.80	22.85	22.80
Calcium	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
available Phosphorus	0.51	0.50	0.51	0.51	0.51	0.51	0.51	0.51
Lysine	1.45	1.44	1.44	1.44	1.44	1.44	1.44	1.44
Methionine	0.63	0.63	0.63	0.62	0.62	0.62	0.61	0.61
Meth+cyst	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01
Energy value								
ME (kcal/kg)	3002.37	3003.3	3002.2	3002.1	3001.81	3001.2	3002.6	3001.1

G1 Control basal diet Without NSP enzymes, G2 basal diet + 0.01% NSP enzymes, G3 basal diet + DDGS 5% Without NSP enzymes, G4 basal diet + DDGS 5% + 0.01% NSP enzymes, G5 basal diet + DDGS 10% Without NSP enzymes, G6 basal diet + DDGS 10% + 0.01% NSP enzymes, G7 basal diet + DDGS 20% Without NSP enzymes, G8 basal diet + DDGS 20% + 0.01% NSP enzymes.

[1] Smart NSPs enzymes® (DEVENISH) containing a combination of 5 active enzymes (7,503 u/g Xylanase, 2,500 u/g Glucoamylase, 1,443 u/g β-Glucanase, 375 u/g Pectinase, 144 u/g Cellulase). This enzyme provides an energy matrix of ME (Kcal/kg) 1,050,000.

[2] Smart phytase enzyme® (DEVENISH) containing a (10,000 FTU/g phytase enzyme).

Table 3: Ingredients Composition and proximate analysis of the grower experimental diets.

Item / Group	G1	G2	G3	G4	G5	G6	G7	G8
	Grower diets							
Yellow corn, ground	61.8	63.35	59.27	60.25	55.60	56.59	50.89	50.20
Soybean meal	29.50	29.80	25.80	27.50	24.40	26.00	16.57	21.30
Corn. gluten	2.14	1.70	3.20	1.80	2.70	1.50	5.00	1.84
DDGS	0.00	0.00	5.00	5.00	10.00	10.00	20.00	20.00
Vegetable oil	2.80	1.30	2.90	1.63	3.46	2.11	3.58	2.80
L-Lysine-HCL (99%)	0.21	0.20	0.28	0.24	0.30	0.25	0.44	0.32
DL-Methionine (99%)	0.20	0.20	0.19	0.19	0.18	0.17	0.15	0.16
Dicalcium phosphate	1.20	1.25	1.18	1.205	1.17	1.17	1.15	1.17
limestone	1.15	1.19	1.18	1.17	1.19	1.20	1.22	1.20
Smart NSPase® enzyme [1]	----	0.01	----	0.01	-----	0.01	----	0.01
Smart Phytase® enzyme [2]	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Chemical composition (%)								
CP	20.6	20.6	20.64	20.6	20.6	20.6	20.6	20.6
Calcium	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
available Phosphorus	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Lysine	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Methionine	0.55	0.54	0.55	0.54	0.54	0.53	0.53	0.53
Meth+cyst	0.89	0.89	0.89	0.89	0.89	0.88	0.90	0.89
Energy value								
ME (kcal/kg)	3102.75	3103.45	3102.0	3102.9	3102.84	3102.00	3102.1	3102.1

G1 Control basal diet Without NSP enzymes, G2 basal diet + 0.01% NSP enzymes, G3 basal diet + DDGS 5% Without NSP enzymes, G4 basal diet + DDGS 5% + 0.01% NSP enzymes, G5 basal diet + DDGS 10% Without NSP enzymes, G6 basal diet + DDGS 10% + 0.01% NSP enzymes, G7 basal diet + DDGS 20% Without NSP enzymes, G8 basal diet + DDGS 20% + 0.01% NSP enzymes.

[1] Smart NSPs enzymes® (DEVENISH) containing a combination of 5 active enzymes (7,503 u/g Xylanase, 2,500 u/g Glucoamylase, 1,443 u/g β-Glucanase, 375 u/g Pectinase, 144 u/g Cellulase). This enzyme provides an energy matrix of ME (Kcal/kg) 1,050,000.

[2] Smart phytase enzyme® (DEVENISH) containing a (10,000 FTU/g phytase enzyme).

Table 4: Ingredients Composition and proximate analysis of the finisher experimental diets.

Item / Group	Finisher diets							
	G1	**G2**	**G3**	**G4**	**G5**	**G6**	**G7**	**G8**
Yellow corn, ground	66.58	67.85	64.1	65.20	60.45	61.65	53.38	55.16
Soybean meal	25.10	26.00	21.30	22.70	19.90	21.00	16.45	16.52
Corn. gluten	1.80	1.00	2.90	1.71	2.40	1.50	1.90	1.60
DDGS	0.00	0.00	5.00	5.00	10.00	10.00	20.00	20.00
Vegetable oil	2.90	1.50	3.00	1.70	3.55	2.15	4.52	2.95
L-Lysine-HCL (99%)	0.19	0.16	0.26	0.22	0.28	0.24	0.32	0.305
DL-Methionine (99%)	0.16	0.16	0.14	0.15	0.14	0.14	0.12	0.12
Dicalcium phosphate	1.23	1.25	1.20	1.24	1.20	1.22	1.19	1.19
limestone	1.04	1.07	1.1	1.07	1.08	1.09	1.12	1.14
Smart NSPase® enzyme [1]	----	0.01	----	0.01	-----	0.01	----	0.01
Smart Phytase® enzyme [2]	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Chemical composition (%)								
CP	18.86	18.89	18.86	18.85	18.85	18.88	18.84	18.84
Calcium	0.85	0.86	0.85	0.85	0.86	0.85	0.86	0.85
available Phosphorus	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Lysine	1.11	1.10	1.11	1.11	1.11	1.11	1.10	1.10
Methionine	0.48	0.48	0.47	0.47	0.47	0.47	0.46	0.46
Meth+cyst	0.79	0.79	0.79	0.79	0.80	0.80	0.80	0.80
Energy value								
ME (kcal/kg)	3150.18	3151.81	3150.1	3152.8	3150.73	3151.26	3150.5	3152.2

G1 Control basal diet Without NSP enzymes, G2 basal diet + 0.01% NSP enzymes, G3 basal diet + DDGS 5% Without NSP enzymes, G4 basal diet + DDGS 5% + 0.01% NSP enzymes, G5 basal diet + DDGS 10% Without NSP enzymes, G6 basal diet + DDGS 10% + 0.01% NSP enzymes, G7 basal diet + DDGS 20% Without NSP enzymes, G8 basal diet + DDGS 20% + 0.01% NSP enzymes.

[1] Smart NSPs enzymes® (DEVENISH) containing a combination of 5 active enzymes (7,503 u/g Xylanase, 2,500 u/g Glucoamylase, 1,443 u/g β-Glucanase, 375 u/g Pectinase, 144 u/g Cellulase). This enzyme provides an energy matrix of ME (Kcal/kg) 1,050,000.

[2] Smart phytase enzyme® (DEVENISH) containing a (10,000 FTU/g phytase enzyme).

6- Economic Efficiency

Total production costs included the price of chicks, feed, and management. Net revenue was calculated as the difference between the selling price of live birds and total production costs. Economic feed efficiency (EFE) and relative economic feed efficiency (REFE) were determined as follows:

EFE = Net revenue / Total production costs
REFE = EFE of group / EFE of control × 100

7- Statistical analysis

The results were expressed as the mean ± SE. All data were analyzed using two-way analysis of variance (ANOVA), and differences among means were evaluated using the least significant difference (LSD) post hoc test, with SPSS16.0 statistical software [20]. Significance was indicated as ($p \leq 0.05$).

3. RESULTS

3.1- Growth performance:

Table (5) shows that the inclusion of DDGS and enzyme supplementation significantly influenced broiler body weight (BW). G2 (control + enzyme) consistently achieved the highest BW across the final period, reaching 114.5% of the control. In contrast, G7 (20% DDGS without enzyme) recorded the lowest BW at 90.17% of the control value. No significant differences ($p > 0.05$) were observed between G1 (control), G3 (5% DDGS), G4 (5% DDGS + enzyme), G5 (10% DDGS), G6 (10% DDGS + enzyme), and G8 (20% DDGS + enzyme). Groups with moderate DDGS levels and enzyme supplementation (G4 and G6) achieved 101.48% of the control BW. Body weight gain followed a similar trend, with G2 showing the highest cumulative gain (115.77% of control), while G7 showed the lowest.

Feed intake varied across groups but differences were not statistically significant ($p > 0.05$). G4 and G6 consumed slightly more than G3 and G5. G8 showed the highest feed intake, while G3 showed the lowest among DDGS-fed groups. G1 (control) had the lowest overall intake.

Feed Conversion Ratio (FCR) was significantly affected by both DDGS level and enzyme supplementation. G2 (control + enzyme) showed the best FCR, while G7 (20% DDGS without enzyme) had the poorest. Enzyme inclusion improved FCR in G4 and G6. Diets with up to 10% DDGS, with or without enzymes, did not differ significantly in FCR ($p > 0.05$) compared to control.

Table 5: Growth performance parameters of broilers during the whole experimental period.

Item / Group	G1	G2	G3	G4	G5	G6	G7	G8
Initial body weight (g/chick)	50.40 ± 0.86 ^{a}	50.46 ± 0.74 ^{a}	52.6 ± 0.78 ^{a}	51.93 ± 0.81 ^{a}	51.33 ± 0.78 ^{a}	51.86 ± 0.62 ^{a}	51.26 ± 1.0 ^{a}	52.82 ±0.83 ^{a}
Final body weight (0-35 day)	1558.4 ± 32.81 ^{d}	1784.3 ± 28.20 ^{a}	1602.4 ±33 ^{bcd}	1679.6 ±39.8 ^{b}	1581.5± 25.51 ^{cd}	1665.8± 37.68 ^{bc}	1425.2 ± 31.6 ^{e}	1558.9 ± 29 ^{d}
Weight gain (0-35 day)	1510.18 ± 15.54 ^{d}	1748.34 ± 9.87 ^{a}	1549.7 ± 9.9 ^{c}	1628.7 ± 8.66 ^{b}	1530.2 ± 6.1 ^{cd}	1613.8 ± 8.93 ^{b}	1371.8 ± 25.4 ^{e}	1505.6 ± 8.9 ^{d}
Feed consumption (0-35 day)	3070.94 ± 42.60 ^{c}	3245.8 ± 32.8 ^{ab}	3106.8 ± 40 ^{c}	3146.2 ± 24 ^{bc}	3157.9± 24.10 ^{bc}	3238.5 ±56.34 ^{ab}	3247.2 ± 9.7 ^{ab}	3317.6 ± 38.7 ^{a}
Feed conversion (0-35 day)	2.02 ± 0.029 ^{cd}	1.86 ± 0.017 ^{e}	2.00 ± 0.042 ^{cd}	1.92 ± 0.022 ^{de}	2.07 ± 0.015 ^{c}	2.00 ± 0.051 ^{cd}	2.36 ± 0.068 ^{a}	2.2 ± 0.021 ^{b}

*Means in the same row having the same superscripts are not significantly different ($p \leq 0.05$).
G1 Control basal diet Without NSP enzymes, G2 basal diet + 0.01% NSP enzymes, G3 basal diet + DDGS 5% Without NSP enzymes, G4 basal diet + DDGS 5% + 0.01% NSP enzymes, G5 basal diet + DDGS 10% Without NSP enzymes, G6 basal diet + DDGS 10% + 0.01% NSP enzymes, G7 basal diet + DDGS 20% Without NSP enzymes, G8 basal diet + DDGS 20% + 0.01% NSP enzymes.

3.2- Carcass traits

Table (6) shows no significant differences ($p > 0.05$) in hot carcass percentage, eviscerated carcass percentage, and the relative percentages of the liver, heart, and gizzard among treatment groups. G7 also revealed the lowest breast weight, while G2 had the highest thigh weight. Additionally, the inclusion of DDGS, with or without enzyme supplementation, did not significantly affect the relative percentages of immune organs (thymus, spleen, and bursa of Fabricius). Enzyme-supplemented diets with DDGS showed a trend of improved immune organ percentages

Table 6: Carcass traits and relative weight of immune organs of broilers fed different experimental diets

Item / Group	G1	G2	G3	G4	G5	G6	G7	G8
live weight (Wt. g)	2061.7 ± 75.73 ^{a}	2185 ± 105.3 ^{a}	2020.7 ± 68.4 ^{a}	2091.7 ± 38.6 ^{a}	2007.3 ± 35.4 ^{a}	2029 ± 48.65 ^{a}	1816.7 ± 60.1 ^{b}	2014 ± 49 ^{a}
Hot **carcass %**	86.72 ± 0.21 ^{a}	86.96 ± 0.42 ^{a}	86.955 ± 0.39 ^{a}	87.048 ± 0.24 ^{a}	87 ± 0.29 ^{a}	87.08 ± 0.21 ^{a}	86.64 ± 0.16 ^{a}	86.88 ± 0.16 ^{a}
eviscerated carcass %	70.93 ± 0.24 ^{ab}	71.18 ± 0.26 ^{a}	71.017 ± 0.3 ^{ab}	71.2 ± 0.20 ^{a}	71.2 ± 0.26 ^{a}	71.6 ± 0.25 ^{a}	70.23 ± 0.32 ^{b}	70.76 ± 0.30 ^{ab}
liver %	2.05 ± 0.07 ^{a}	2.08 ± 0.05 ^{a}	2.06 ± 0.07 ^{a}	2.08 ± 0.05 ^{a}	2.075 ± 0.04 ^{a}	2.06 ± 0.02 ^{a}	2.04 ± 0.02 ^{a}	2.07 ± 0.05 ^{a}
heart %	0.42 ± 0.01 ^{ab}	0.41 ± 0.01 ^{ab}	0.43 ± 0.02 ^{ab}	0.43 ± 0.01 ^{ab}	0.40 ± 0.01 ^{b}	0.40 ± 0.01 ^{b}	0.40 ± 0.01 ^{b}	0.46 ± 0.01 ^{a}
gizzard %	1.47 ± 0.02 ^{a}	1.43 ± 0.05 ^{a}	1.4917 ± 0.05 ^{a}	1.4767 ± 0.04 ^{a}	1.44 ± 0.04 ^{a}	1.4533 ± 0.06 ^{a}	1.43 ± 0.01^{a}	1.4133 ± 0.06 ^{a}
breast %	22.632 ± 0.27 ^{a}	22.894 ± 0.09 ^{a}	22.53 ± 0.05 ^{a}	22.715 ± 0.12 ^{a}	22.69 ± 0.18 ^{a}	22.82 ± 0.15 ^{a}	22.018± 0.05 ^{b}	22.62 ± 0.13 ^{a}
thigh %	20.99 ± 0.17 ^{b}	21.43 ± 0.03 ^{a}	20.99 ± 0.097 ^{b}	20.86 ± 0.32 ^{b}	20.94 ± 0.09 ^{b}	21.05 ± 0.07 ^{b}	20.78 ± 0.05 ^{b}	20.99 ± 0.06 ^{b}
spleen %	0.1 ± 0.01 ^{a}	0.1 ± 0.007 ^{a}	0.11 ± 0.01 ^{a}	0.12 ± 0.01 ^{a}	0.11 ± 0.01 ^{a}	0.11 ± 0.01 ^{a}	0.11 ± 0.01 ^{a}	0.11 ± 0.01 ^{a}
thymus %	0.31 ± 0.01 ^{a}	0.315 ± 0.01 ^{a}	0.31 ± 0.01 ^{a}	0.31 ± 0.014 ^{a}	0.32 ± 0.01 ^{a}	0.3217 ± 0.01 ^{a}	0.315 ± 0.02 ^{a}	0.33 ± 0.01 ^{a}
bursa %	0.11 ± 0.01 ^{b}	0.142 ± 0.01 ^{a}	0.12 ± 0.01 ^{ab}	0.14 ± 0.02 ^{ab}	0.12 ± 0.01 ^{ab}	0.13 ± 0.01 ^{ab}	0.11 ± 0.003 ^{ab}	0.14 ± 0.01 ^{ab}

*Means in the same row having the same superscripts are not significantly different ($p \leq 0.05$).
G1 Control basal diet Without NSP enzymes, G2 basal diet + 0.01% NSP enzymes, G3 basal diet + DDGS 5% Without NSP enzymes, G4 basal diet + DDGS 5% + 0.01% NSP enzymes, G5 basal diet + DDGS 10% Without NSP enzymes, G6 basal diet + DDGS 10% + 0.01% NSP enzymes, G7 basal diet + DDGS 20% Without NSP enzymes, G8 basal diet + DDGS 20% + 0.01% NSP enzymes.

3.3- Digestibility parameters

The findings in Table (7) show that including up to 10% DDGS, with or without enzyme supplementation, had no significant impact ($p \leq 0.05$) on the digestibility of crude protein (CP), dry matter (DM), nitrogen-free extract (NFE), crude fiber (CF), or ether extract (EE), which aligns with [11]. However, at 20% DDGS inclusion, digestibility of DM, CP, and NFE significantly declined ($p \leq 0.05$), with G7 showing the lowest values. While CF digestibility remained unchanged across all groups, EE digestibility was significantly lower ($p \leq 0.05$) in G7 compared to other groups. Numerically, the highest digestibility values for CP, CF, and EE were observed in enzyme-treated groups (G2, G4, and G6), with G2 showing the best results, followed by G4 and G6.

Table 7: digestibility parameters of broilers fed different experimental diets.

Item / Group	G1	G2	G3	G4	G5	G6	G7	G8
DM digestibility	77.22 ±0.84 [a]	78.75 ± 0.76 [a]	78.13 ± 0.81 [a]	78.82 ± 0.49 [a]	78.32 ± 0.63 [a]	78.48 ± 0.46 [a]	70.86 ± 1.2 [b]	73.08 ± 0.99 [b]
Crude protein digestibility	69.35 ± 1.13 [c]	75.47 ± 0.88 [a]	70.57 ± 1.09 [bc]	73.47 ± 0.61 [ab]	70.42 ± 0.86 [bc]	73.07 ± 0.58 [ab]	55.34 ± 1.84 [e]	63.74 ± 1.34 [d]
Crude fiber digestibility	18.05 ± 3 [bcd]	27.82 ± 2.6 [a]	21.58 ± 2.9 [abc]	27.43 ± 1.66 [a]	13.8 ± 2.5 [cd]	28.54 ± 1.53 [a]	10.33 ± 2.86 [d]	23.18 ± 2.8 [ab]
EE digestibility	68.78 ± 1.2 [ab]	71.91 ± 1.01 [a]	67.79 ± 1.19 [b]	70.88 ± 0.67 [ab]	69.41 ± 0.89 [ab]	70.71 ± 0.63 [ab]	62.88 ± 1.19 [c]	68.77 ± 1.2 [ab]
NFE digestibility	80.64 ± 0.7 [bc]	79.69 ± 0.73 [c]	82.44 ± 0.65 [ab]	81.28 ± 0.43 [bc]	83.48 ± 0.48 [a]	81.19 ± 0.4 [bc]	77.48 ± 0.72 [d]	77.06 ± 0.85 [d]

*Means in the same row having the same superscripts are not significantly different ($p \leq 0.05$).
G1 Control basal diet Without NSP enzymes, G2 basal diet + 0.01% NSP enzymes, G3 basal diet + DDGS 5% Without NSP enzymes, G4 basal diet + DDGS 5% + 0.01% NSP enzymes, G5 basal diet + DDGS 10% Without NSP enzymes, G6 basal diet + DDGS 10% + 0.01% NSP enzymes, G7 basal diet + DDGS 20% Without NSP enzymes, G8 basal diet + DDGS 20% + 0.01% NSP enzymes.

3.4- Economic Efficiency

The economic impact of DDGS inclusion with or without enzyme supplementation was assessed based on total feed cost, total production cost, net revenue, economic feed efficiency (EFE), and relative economic feed efficiency (REE) as summarized in Table (8). G7 had the highest feed and production costs, while G4 recorded the lowest, highlighting the cost-effectiveness of moderate DDGS inclusion with enzymes. Net revenue was highest in G2 (control with enzymes) and lowest in G7, demonstrating the negative economic impact of high DDGS levels without enzymes. G4 showed the best economic returns among DDGS-fed groups; it was (137.72%) relative to the control.

Table 8: Economical evaluation of the experimental diet fed to broiler chickens.

Item / Group	G1	G2	G3	G4	G5	G6	G7	G8
Total feed cost (L.E)	67.08	68.15	68.11	65.96	69.39	67.98	72.16	71.23
Total production cost (L.E)	112.08	113.15	113.11	110.96	114.39	112.98	117.16	116.23
Net revenue (L.E)	34.40	54.56	37.51	46.91	34.26	43.60	14.92	30.30
Economic feed Efficiency %	30.70	48.22	33.16	42.28	29.95	38.59	12.73	26.07
Relative economic feed Efficiency %	100	157.06	108.01	137.72	97.56	125.71	41.47	84.92

G1 Control basal diet Without NSP enzymes, G2 basal diet + 0.01% NSP enzymes, G3 basal diet + DDGS 5% Without NSP enzymes, G4 basal diet + DDGS 5% + 0.01% NSP enzymes, G5 basal diet + DDGS 10% Without NSP enzymes, G6 basal diet + DDGS 10% + 0.01% NSP enzymes, G7 basal diet + DDGS 20% Without NSP enzymes, G8 basal diet + DDGS 20% + 0.01% NSP enzymes.

4. DISCUSSION

Growth performance metrics revealed a significant impact of DDGS inclusion and enzyme supplementation on broiler productivity. Such findings are in agreement with those of [21], who emphasized the role of enzymes in mitigating the anti-nutritional effects of high DDGS levels. Likewise, [22] highlighted the negative impacts of high DDGS inclusion without enzymatic support. The outcomes observed for G4 and G6 correspond well with the conclusions of [23, 24], which suggest that including up to 10% DDGS in broiler diets can support optimal growth. Increased feed intake observed in some groups may be explained by nutrient dilution and elevated fiber content, as noted by [25, 26]. Additionally, the decline in feed efficiency at higher DDGS levels, particularly without enzymes, was consistent with the findings of [22], who reported compromised FCR during both early and late growth phases (1–21 days and 22–42 days).

In the present study, the inclusion of DDGS, with or without enzyme supplementation, showed no significant effect on hot carcass yield, eviscerated carcass percentage, or the relative weights of internal organs such as the liver, heart, and gizzard. These findings align with [8, 10], who reported no significant effects with similar dietary treatments, confirming the stability of these parameters under various diet compositions. The observation of lower breast weight in G7 and higher thigh weight in G2 agrees with [9] on the impact of high DDGS levels. Furthermore, the lack of significant impact on immune organs corroborates the results of [27, 28], who found no adverse effects of up to 15% DDGS on immune organ development. These data suggest that DDGS does not impair immune function, indicating its suitability as a feed ingredient for broilers. Notably, enzyme-supplemented diets with DDGS showed a trend of improved immune organ percentages, reflecting potential benefits in promoting immune tissue development without compromising their functionality.

The observed decline in nutrient digestibility at 20% DDGS inclusion is consistent with the findings of [29], who reported that higher levels of DDGS (specifically 20%) led to decreased CP digestibility. Enzyme supplementation in G8 improved digestibility, highlighting its role in mitigating the negative effects of high DDGS levels. These findings underscore the beneficial effects of enzyme supplementation in improving nutrient utilization, particularly in high-DDGS diets, by enhancing the breakdown and absorption of key nutrients.

Economic evaluation revealed that enzyme supplementation improved EFE and REE, with Group G2 showing the best performance, while G7 had the lowest values. These results align with previous studies that reported improved cost efficiency with moderate DDGS inclusion. Furthermore, these findings agree with [30], where birds fed a diet of multi-enzymes recorded significantly higher total revenue, net revenue, and economic efficiency than the control group.

CONCLUSIONS

Including 5 and 10% DDGS with enzyme supplementation improved nutrient digestibility, growth performance, and economic efficiency without adverse effects. However, high DDGS levels (20%) without enzymes negatively impacted broiler performance. Enzyme supplementation enhanced feed utilization, making moderate DDGS inclusion a cost-effective alternative in broiler diets. Among DDGS-fed groups, the 5% DDGS with enzyme supplementation group showed the best economic returns, achieving (137.72%) relative to the control.

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Authors' declarations

Publication consent

All authors have given their consent for the publication of this manuscript.

Data and material availability

All relevant data of this study are available upon request.

Conflict of interests

The authors declare no conflict of interest.

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