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Effect of feeding broken rice and distillers dried grains with solubles in a flaxseed-based diet on the growth performance, production efficiency, carcass characteristics, sensory evaluation of meat, and serum biochemistry of broiler chickens

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Abstract: This study investigated the effect of broken rice and distillers dried grains with solubles (DDGS) in a flaxseed-based diet on the growth performance, production efficiency, carcass characteristics, sensory evaluation of meat, and serum biochemistry of broiler chickens. Six dietary treatments were formulated with no flaxseed in the first group (C), 10% in another five (T1, T2, T3, T4, and T5), and 20% broken rice, 40% broken rice, 5% DDGS, and 10% DDGS in the T2, T3, T4, and T5 treatment groups, respectively. Each treatment was allocated 6 replicates with 8 chicks in each at random. Treatment with 10% flaxseed and 10% DDGS was found to have a negative effect on broiler growth and efficiency to some extent, whereas broken rice had no such effect. Feed that included 10% flaxseed and 40% broken rice significantly reduced serum triglyceride and cholesterol. Serum antioxidant enzyme activities and malondialdehyde concentration were increased by 10% flaxseed feeding and were further increased by 5% as well as 10% DDGS addition, whereas broken rice had no effect on them. The present study concluded that 10% flaxseed and 10% DDGS feeding negatively affects broiler performance and serum antioxidant capacity but reduces serum triglyceride and cholesterol levels, whereas broken rice can be safely used as a 40% replacement alternative for corn in broiler diets.

Key words: Flaxseed, broken rice, distillers dried grains with solubles, broiler performance, carcass traits, serum

1. Introduction

In broiler production, feed accounts for about 70% of production, highlighting the importance of evaluating feedstuffs for the birds. Rice byproducts, such as broken rice, may serve as an alternative to costly corn due to their low cost and high availability from the rice industry. They are also a good alternative because they contain similar protein and metabolizable energy contents (1). As a potential energy source, broken rice has been used for feeding trials in laying hen diets and has achieved similar efficiency with respect to energy utilization as corn (2). Furthermore, in recent years, rice byproducts have received increased attention as functional foods due to their phenolic base compounds and for their high amounts of vitamins, minerals, and fiber, which can help lower cholesterol and support antiatherogenic activity (3).

Distillers dried grains with solubles (DDGS) are excellent low-cost alternative feed ingredients that continue to be produced in large quantities by the dry-grind fuel ethanol industry. An increase in ethanol production over the last 5–10 years, due to the increasing prices of conventional oil and limited underground reserves, has led to an increased supply of DDGS available as livestock feed (4). Another interesting feature of DDGS is the abundance of omega-3 fatty acids in its fat fraction that can be used for the fortification of poultry products via poultry nutrition. However, the lower amount of available lysine in DDGS, which occurs due to a drying process during DDGS production, can hamper the growth and efficiency of broilers. It has been reported that DDGS can be safely added at levels of 5%–8% in starter diets for broilers and turkeys and 12%–15% in grower-finisher diets for broilers, turkeys, and laying hens (5).

As a result of the increasing health consciousness among people, there is a rising trend in the consumption of functional foods. Feeding flaxseed to broiler chickens is a way to the produce omega-3 fatty acid-enriched meat. Flaxseed contains approximately 20% α-inolenic acid (ALA; DM basis), an essential omega-3 fatty acid that is a precursor for eicosapentaenoic acid (EPA), which, in turn, is a precursor for eicosanoids, hormone-like compounds that are essential for immunity in the human body.

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However, a number of antinutritional factors including cyanogenic glycosides, mucilage, and pyridoxine antagonist in flaxseed can be detrimental for broiler performance and carcass traits. Many researchers have reported negative effects of flaxseed feeding on broiler performance (6,7), along with an increase of omega-3 fatty acid content of meat and reduction of the abdominal fat pad. Thus, the present study was carried out to observe the effects of broken rice and DDGS in a flaxseed-based diet on the growth performance, production efficiency, carcass characteristics, sensory evaluation of meat, and serum biochemical parameters of broiler chickens.

2. Materials and methods

2.1. Birds, diets, and experimental design

All procedures used in the experiment on the birds were reviewed and approved by the Animal Ethics Committee of the Indian Veterinary Research Institute in Izatnagar, India. Following a completely randomized design, 288 one-day-old straight-run (sex ratio ≈ 1) broiler chicks of uniform body weight were distributed at random into 36 replicates (8 chicks in each) and housed in specially designed broiler battery brooder cages for 6 weeks. Each battery in the cage housed 8 birds, providing a space of 1160 cm^2. Six dietary treatments were formulated as per the recommendations of the Bureau of Indian Standards (8) by using 10% flaxseed meal to replace soybean in the basal diet, two levels of broken rice, and two levels of DDGS as C (no flaxseed, broken rice, or DDGS), T1 (10% flaxseed), T2 (10% flaxseed and 20% broken rice), T3 (10% flaxseed and 40% broken rice), T4 (10% flaxseed and 5% DDGS), and T5 (10% flaxseed and 10% DDGS). The ingredients and nutrient composition of broiler starters and finishers is shown in Table 1. Each dietary treatment was allocated six replicates (48 chicks/treatment).

2.2. Measurement and analysis

Weekly body weight and feed intake was recorded and overall (at 0–3 weeks, 4–6 weeks, and 0–6 weeks) body

Table 1. Ingredients and nutrient composition of broiler starter and finisher diets.

Ingredients (%)	Broiler starter						Broiler finisher					
	C	T1	T2	T3	T4	T5	C	T1	T2	T3	T4	T5
Flaxseed meal	0	10	10	10	10	10	0	10	10	10	10	10
DDGS	0	0	0	0	5	10	0	0	0	0	5	10
Broken rice	0	0	20	40	0	0	0	0	20	40	0	0
Maize	52.715	51.345	29.38	7.085	51.9	52.87	62.335	60.945	37.435	15.135	61.705	62.735
Soybean	39.5	30.5	31.1	31.4	25.35	20	30	21	22.3	23	15.5	9.8
Fish meal	3.1	3.1	3.1	3.5	3	3	3	3	3.5	3.5	3	3
Oil	1.5	1.8	3.16	4.7	1.35	0.9	1.4	1.7	3.4	4.9	1.33	0.9
Limestone	0.9	0.9	0.9	0.9	0.9	0.9	1	1	1	1	1	1
DCP	1.5	1.5	1.5	1.55	1.5	1.5	1.5	1.55	1.5	1.6	1.55	1.55
Salt	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
DL-meth	0.12	0.12	0.12	0.12	0.12	0.12	0.1	0.1	0.1	0.1	0.1	0.1
Lysine	0	0.07	0.07	0.07	0.2	0.3	0	0.04	0.1	0.1	0.15	0.25
TM premix[1]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Vit premix[2]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vit B complex[3]	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Choline chloride	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Toxin binder	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Nutrient composition of diets												
Crude protein (%)	23.02	23.02	23.02	23.02	23.02	23.02	20.08	20.08	20.08	20.08	20.08	20.08
M energy (kcal/kg)	2921	2921	2917	2918	2916	2922	3001	3000	3001	3000	3002	3003
Calcium (%)	1.05	1.06	1.04	1.06	1.05	1.05	1.06	1.07	1.07	1.08	1.06	1.05
Available P (%)	0.47	0.47	0.45	0.46	0.47	0.47	0.45	0.45	0.44	0.45	0.45	0.45
Lysine (%)	1.28	1.21	1.23	1.24	1.24	1.25	1.05	1.05	1.05	1.06	1.06	1.05

[1] Trace mineral mixture: each 100 g contains $FeSO_4.7H_2O$: 8 g, $ZnSO_4.7H_2O$: 10 g, $MnSO_4.H_2O$: 10 g, $CUSO_4.5H_2O$:1 g, KI: 30 g.
[2] Vitamin premix: each 1 g contains vitamin A: 82.5 IU, vitamin B2: 50 mg, vitamin D3: 12,000 U, vitamin K: 10 mg.
[3] Vitamin B complex: each 1 g contains vitamin B1: 8 mg, vitamin B6: 16 mg, vitamin B12: 80 µg, niacin: 120 mg, calcium panthotheonate: 80 mg, vitamin E 50%: 160 mg, L-lysine: 10 mg, DL: methionine: 10 mg.

weight gain, feed intake, and feed conversion ratio (FCR) were calculated. The mortality of the birds was recorded as and when it occurred. The following efficiency parameters were also calculated to assess the impact of the dietary treatments used in the experiment:

Production efficiency factor (PEF) = final body weight (kg) × livability (%) × 100/age in days × FCR

Protein efficiency ratio (PER) = weight gain/protein intake

Energy efficiency ratio (EER) = weight gain (g) × 100/ total energy intake (ME kcal)

Lysine efficiency (LE) = lysine intake (mg)/weight gain (g)

At the end of the 6-week feeding trial, 12 birds from each dietary treatment group (2 birds/replicate) were selected randomly and slaughtered after 12 h of fasting with ad libitum drinking water for the evaluation of carcass characteristics and sensory evaluation of meat. Subjective color and odor measurements were recorded for fresh as well as stored meat samples (refrigerated storage at 1.6 °C for 1 month). For better visual and odor scores, a 5-point descriptive scale was used. In both cases, a score of 5 was extremely desirable and 1 was extremely undesirable. Uniformly sized steam-cooked meat samples were served to semitrained judges in a test panel for sensory evaluation. These individuals were asked for their opinions based on an 8-point descriptive scale, in which a score of 8 was extremely desirable and 1 was extremely undesirable (9). Furthermore, at the time of slaughter, blood samples were collected, serum was harvested, and values of serum cholesterol (10), triglyceride (11), glucose (12), and thiobarbituric acid reactive substances (TBARS) (13) were determined. The assay of serum antioxidant enzymes like superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GSH-Px), and glutathione reductase (GR) was also done (14). Cayman diagnostic kits were utilized for the estimation of serum TBARS and enzymes. All samples and standards were measured in duplicate.

The data obtained from the experiment were subjected to analysis of variance for a completely randomized design using the GLM procedure (SPSS 17), and all replicates were used as experimental units. The significant mean differences were tested as per the Duncan multiple range test (15) with a significance level defined as $P < 0.05$.

3. Results

Results pertaining to growth performance are presented in Table 2. Efficiency parameters are provided in Table 3. Carcass traits are given in Table 4, and sensory evaluation of broiler meat is given in Table 5. The results of serum biochemical parameters are given in Table 6.

4. Discussion

Results pertaining to the growth performance indicate that 10% flaxseed feeding had a negative effect on broiler performance (except for body weight gain at 4–6 weeks and 0–6 weeks), which was increased with the addition of 10% DDGS in broiler diets, whereas the addition of broken rice and 5% DDGS was found to have no effect on broiler performance. These negative effects can be attributed to

Table 2. Effect of feeding broken rice and DDGS in flaxseed-based diet on the growth performance of broiler chickens.

Treatment		C	T1	T2	T3	T4	T5	Pooled SEM	P-value
Overall body weight gain (g)	0–3 weeks	584[b]	514[a]	512[a]	515[a]	528[a]	488[a]	7.23	0.001
	4–6 weeks	1201	1177	1177	1192	1150	1175	12.14	0.903
	0–6 weeks	1785	1691	1689	1707	1678	1663	15.92	0.303
Overall feed intake (g)	0–3 weeks	652	641	645	613	648	663	8.37	0.662
	4–6 weeks	2534[a]	2772[ab]	2890[b]	2942[b]	2842[b]	2972[b]	40.53	0.013
	0–6 weeks	3186[a]	3412[ab]	3535[b]	3554[b]	3489[b]	3635[b]	44.11	0.047
Overall FCR	0–3 weeks	1.12[a]	1.25[b]	1.26[b]	1.19[ab]	1.23[b]	1.36[c]	0.018	0.000
	4–6 weeks	2.11[a]	2.36[b]	2.46[b]	2.47[b]	2.48[b]	2.53[b]	0.034	0.002
	0–6 weeks	1.79[a]	2.02[b]	2.10[bc]	2.08[bc]	2.08[bc]	2.19[c]	0.027	0.000
Mortality (%)		6.25	0.00	0.00	2.08	4.17	2.08	--	--

Values bearing different superscripts within a row differ significantly.

C: Flaxseed 0%, broken rice 0%, DDGS 0%; T1: flaxseed 10%, broken rice 0%, DDGS 0%; T2: flaxseed 10%, broken rice 20%, DDGS 0%; T3: flaxseed 10%, broken rice 40%, DDGS 0%; T4: flaxseed 10%, broken rice 0%, DDGS 5%; T5: flaxseed 10%, broken rice 0%, DDGS 10%.

Table 3. Effect of feeding broken rice and DDGS in flaxseed-based diet on the efficiency parameters of broiler chickens.

Treatment		C	T1	T2	T3	T4	T5	Pooled SEM	P- value
Production efficiency factor (PEF)	At the 3rd week	264.4^{c}	212.8^{b}	209.9^{b}	223.1^{b}	220.9^{b}	185.2^{a}	5.026	0.000
	At the 6th week	242.3^{b}	205.0^{a}	196.9^{a}	198.7^{a}	195.6^{a}	185.2^{a}	4.026	0.000
Protein efficiency ratio (PER)	0–3 weeks	4.21^{c}	3.77^{b}	3.74^{b}	3.96^{bc}	3.85^{b}	3.46^{a}	0.052	0.000
	4–6 weeks	2.59^{b}	2.31^{a}	2.21^{a}	2.20^{a}	2.20^{a}	2.15^{a}	0.037	0.002
	0–6 weeks	2.96^{c}	2.62^{b}	2.52^{ab}	2.54^{ab}	2.54^{ab}	2.42^{a}	0.037	0.000
Energy efficiency ratio (EER)	0-3 weeks	30.68^{c}	27.46^{b}	27.23^{b}	28.90^{bc}	28.05^{b}	25.20^{a}	0.383	0.000
	4–6 weeks	15.96^{b}	14.23^{a}	13.59^{a}	13.56^{a}	13.53^{a}	13.23^{a}	0.229	0.002
	0-6 weeks	18.90^{c}	16.66^{b}	16.01^{ab}	16.13^{ab}	16.16^{ab}	15.37^{a}	0.243	0.000
Lysine efficiency (LE)	0–3 weeks	14.07^{a}	15.72^{b}	15.89^{b}	15.00^{ab}	15.49^{b}	17.15^{c}	0.220	0.000
	4–6 weeks	26.63^{a}	29.72^{b}	30.97^{b}	31.17^{b}	31.22^{b}	31.86^{b}	0.435	0.002
	0–6 weeks	22.50^{a}	25.42^{b}	26.40^{bc}	26.28^{bc}	26.24^{bc}	27.53^{c}	0.340	0.000

Values bearing different superscripts within a row differ significantly.
C: Flaxseed 0%, broken rice 0%, DDGS 0%; T1: flaxseed 10%, broken rice 0%, DDGS 0%; T2: flaxseed 10%, broken rice 20%, DDGS 0%; T3: flaxseed 10%, broken rice 40%, DDGS 0%; T4: flaxseed 10%, broken rice 0%, DDGS 5%; T5: flaxseed 10%, broken rice 0%, DDGS 10%.

Table 4. Effect of feeding broken rice and DDGS in flaxseed-based diet on carcass characteristics of broiler chickens.

Treatment	C	T1	T2	T3	T4	T5	Pooled SEM	P-value
Live weight (g)	1827	1733	1731	1739	1715	1704	16.47	0.319
Defeathered weight (%)	91.5	91.5	91.6	91.5	91.6	91.6	0.09	1.000
Eviscerated weight (%)	68.6	67.0	67.3	67.6	67.1	67.5	0.19	0.149
Liver (%)	2.46	2.49	2.71	2.70	2.69	2.67	0.04	0.359
Heart (%)	0.50	0.50	0.52	0.49	0.48	0.52	0.01	0.546
Gizzards (%)	2.19	2.24	2.14	1.96	2.03	2.15	0.04	0.375
Dressed yield (%)	73.8	72.2	72.7	72.7	72.3	72.8	0.17	0.143
Abdominal fat (%)	1.05	0.99	1.04	1.45	1.07	1.07	0.05	0.135
Drumstick (%)	10.06	10.03	10.14	9.89	9.78	9.88	0.08	0.770
Breast (%)	17.37	17.55	16.61	16.87	16.61	16.61	0.15	0.235
Thigh (%)	9.46	9.66	9.53	9.73	9.69	9.42	0.05	0.470
Back (%)	17.64	17.49	17.93	17.92	17.43	17.37	0.11	0.499
Wings (%)	8.78	8.57	8.43	8.42	8.66	8.59	0.05	0.240
Neck (%)	4.01	3.98	3.96	3.78	3.73	3.66	0.05	0.146
Meat:bone ratio (breast)	5.23	5.05	5.23	5.23	5.22	5.06	0.08	0.972
Meat:bone ratio (thigh)	4.87^{ab}	4.95^{ab}	4.75^{ab}	5.13^{b}	4.43^{a}	4.58^{ab}	0.06	0.008

Values bearing different superscripts within a row differ significantly.
C: Flaxseed 0%, broken rice 0%, DDGS 0%; T1: flaxseed 10%, broken rice 0%, DDGS 0%; T2: flaxseed 10%, broken rice 20%, DDGS 0%; T3: flaxseed 10%, broken rice 40%, DDGS 0%; T4: flaxseed 10%, broken rice 0%, DDGS 5%; T5: flaxseed 10%, broken rice 0%, DDGS 10%.

Table 5. Effect of feeding broken rice and DDGS in flaxseed-based diet on the sensory quality of broiler chicken meat.

Treatment			C	T1	T2	T3	T4	T5	Pooled SEM	P-value
Cooked meat	Color and appearance		6.2^{ab}	6.2^{ab}	6.0^{a}	6.5^{b}	6.1^{ab}	6.5^{b}	0.056	0.038
	Flavor		6.0	6.4	6.1	6.5	6.2	6.5	0.076	0.247
	Texture		6.2	6.2	6.0	6.1	6.5	6.1	0.073	0.478
	Juiciness		6.3	6.1	5.9	6.2	6.0	6.2	0.079	0.734
	Overall acceptability		6.1	6.2	5.8	6.4	6.0	6.4	0.066	0.057
Raw meat	Color Score	Fresh basis	4.0	4.1	4.0	4.0	4.1	4.0	0.098	0.999
		After 1 month	3.1	3.1	3.0	3.0	3.1	3.0	0.096	0.998
	Odor Score	Fresh basis	4.1	4.0	4.1	4.0	4.1	4.0	0.096	0.998
		After 1 month	3.0	3.0	3.1	3.1	3.0	3.1	0.096	0.998

Values bearing different superscripts within a row differ significantly.
C: Flaxseed 0%, broken rice 0%, DDGS 0%; T1: flaxseed 10%, broken rice 0%, DDGS 0%; T2: flaxseed 10%, broken rice 20%, DDGS 0%; T3: flaxseed 10%, broken rice 40%, DDGS 0%; T4: flaxseed 10%, broken rice 0%, DDGS 5%; T5: flaxseed 10%, broken rice 0%, DDGS 10%.

Table 6. Effect of feeding broken rice and DDGS in flaxseed-based diet on the serum biochemical parameters of broiler chickens.

Treatment	C_1	T_1	T_2	T_3	T_4	T_5	Pooled SEM	P-value
Glucose (mg/dL)	213.7	197.0	205.8	193.5	215.7	211.8	3.332	0.278
Triglyceride (mg/dL)	126.8^{c}	111.7^{b}	113.7^{b}	91.8^{a}	111.2^{b}	114.2^{b}	2.087	0.000
Cholesterol (mg/dL)	140.7^{c}	121.7^{b}	123.0^{b}	108.7^{a}	122.8^{b}	130.3^{b}	2.038	0.000
SOD (U/mL)	105.9^{a}	114.5^{b}	118.3^{cd}	117.3^{bc}	121.0^{d}	141.7^{e}	1.881	0.000
Catalase (nmol/min/mL)	45.6^{a}	55.9^{bc}	54.4^{b}	54.5^{b}	58.9^{c}	70.1^{d}	1.293	0.000
GPx (nmol/min/mL)	10.2^{a}	12.6^{b}	12.4^{b}	12.3^{b}	13.0^{c}	15.6^{d}	0.269	0.000
GR (nmol/mim/mL)	12.6^{a}	14.7^{bc}	14.6^{bc}	14.4^{b}	14.8^{c}	17.0^{d}	0.220	0.000
TBARS value (MDA µM)	4.3^{a}	5.8^{c}	5.6^{b}	5.6^{b}	5.9^{c}	7.2^{d}	0.145	0.000

Values bearing different superscripts within a row differ significantly.
SOD: Superoxide dismutase; GPx: glutathione peroxidase; GR: glutathione reductase; TBARS: thiobarbituric acid reactive substances; MDA: malondialdehyde.
C: Flaxseed 0%, broken rice 0%, DDGS 0%; T1: flaxseed 10%, broken rice 0%, DDGS 0%; T2: flaxseed 10%, broken rice 20%, DDGS 0%; T3: flaxseed 10%, broken rice 40%, DDGS 0%; T4: flaxseed 10%, broken rice 0%, DDGS 5%; T5: flaxseed 10%, broken rice 0%, DDGS 10%.

poor energy availability, the presence of antinutritional factors, and the low digestibility of flaxseed, along with the high viscosity of jejunal digesta and lower availability of lysine in DDGS. These observations are corroborated by a number of research reports (16,17). Various studies have shown that feeding ground flaxseed at dietary levels in excess of 7.5% in the dry matter reduced the growth rate and body weight (6), resulting in poor feed conversion efficiency (7), which could explain the drastic reduction in the PER and net protein ratio (6), mainly due to a reduction in the retention of nitrogen and amino acids caused by the presence of mucilage (7). However, contrasting reports exist that show no significant effect on body weight gain but also show lower feed efficiency at 10% flaxseed level (18). Similar to our results, no significant effect of flaxseed feeding was found on broiler mortality (16). Regarding the effect of broken rice, our results are supported by Brum et al. (19), and even total replacement of corn with broken rice was found to have no negative impact on broiler performance (20). In the case of DDGS, a progressive decline in body weight and feed efficiency with increasing DDGS levels occurred, but no effect on feed intake was found (21). Feed conversion and mortality rates were found to have remained unaffected by the dietary inclusion of DDGS, but the growth rate can be negatively affected by feeding diets containing 15% or more DDGS (22). However, in contrast, a few reports have shown that broilers fed diets containing 8% DDGS or more showed an increase in growth rate compared to those fed 0% DDGS during the 0–18 day starter period. In addition, weight gain and the feed:gain ratio were similar among dietary DDGS levels at 42 days (23).

The observations related to carcass characteristics are supported by a number of findings of no effect of flaxseed/flaxseed oil on various carcass traits of birds (18,24). Similar to the present study regarding broken rice feeding, carcass, liver, breast, thigh, and drumstick yields did not differ significantly due to an increasing level of broken rice as a replacement for corn (19,25). In the case of DDGS feeding, our results are supported by findings in many studies (21,23). However, no literature citing the effects of broken rice, DDGS, and flaxseed feeding on the meat:bone ratio is available.

The nonsignificant effect of flaxseed on sensory characteristics has also been reported and is similar to our study's findings (26). However, in contrast, there is a study that reported a significant reduction in the aroma, flavor, taste, and overall acceptability of nugget meat from chickens fed with increasing levels of dietary flaxseed (17). No literature on the sensory attributes of broiler meat being affected by feeding broken rice and DDGS is available.

The results pertaining to serum biochemical parameters indicate that 10% flaxseed feeding caused a significant reduction in both serum triglyceride and cholesterol, which were further reduced by the addition of 40% broken rice. However, no effect of the feeding of 20% broken rice and DDGS was found, and none of these affected serum glucose concentrations. Flaxseed interferes with bile acid metabolism by increasing the intraluminal viscosity of the gut, hindering micelle formation, diminishing lipid uptake, and inhibiting the reuptake of bile acids. This results in an increased hepatic synthesis of bile acids, which diverts cholesterol away from lipoprotein synthesis in the liver, thereby reducing serum cholesterol. The decline of triglyceride levels is attributed to the increase of omega-3 fatty acids due to flaxseed feeding. Similarly, the hypocholesterolemic effect of rice protein can be attributed to the higher arginine/lysine ratio in rice protein relative to animal protein. Further rice feeding causes an increase in fecal cholesterol, bile acid excretion, and reduction in in vitro cholesterol absorption. Rice proteins are also believed to depress the VLDL assembly and secretion, which results in the decreased hepatic secretion of triglycerides and cholesterol into circulation, resulting in hypocholesterolemia and hypotriglyceridemia. Our results are corroborated by a number of studies (24,27). However, in contrast, a report exists about the nonsignificant effect of linseed oil supplementation on serum triglycerides and cholesterol (24). No literature citing the effects of feeding broken rice and DDGS on serum glucose, triglyceride, and cholesterol concentrations of broiler chicken is available.

The observations pertaining to serum antioxidant enzyme and serum TBARS values or malondialdehyde (MDA) concentrations indicated that 10% flaxseed feeding significantly increased the activities of these antioxidant enzymes and MDA levels in serum, which were further increased by the addition of 5% as well as 10% DDGS in the broiler diet. The broken rice feeding tended to decrease MDA levels; however, no effect was found on serum enzymes. These effects of flaxseed and DDGS can be attributed to their ability to increase lipid unsaturation in broiler chicken meat. Even though the literature is limited, it was observed that a significant and progressive increase of both SOD and CAT activity occurs with increasing levels of flaxseed in the diet (17). The SOD converts superoxide radicals to hydrogen peroxide, which is acted upon by CAT. Hence, an increase in SOD activity results in an increase in CAT activity. A similar trend was observed in GSH-Px and GR activity. No literature is available citing the effect of flaxseed on serum MDA levels of broiler chickens. Similar to our study regarding the effects of DDGS, it was observed that a significant increase in serum MDA content occurs with increasing DDGS levels (28). However, in contrast, no effect on serum SOD content was observed. Similarly, the SOD levels were reported to be significantly lower in DDGS breast fillets than in the control (29).

This study concludes that in pursuit of omega-3 enrichment of broiler meat and the reduction of serum triglyceride and cholesterol, 10% flaxseed and 10% DDGS feeding exerts a negative effect on broiler performance to some extent and increases serum antioxidant enzyme and MDA concentrations, which indicates an increase of serum lipid oxidation. Broken rice (lower in cost than corn) feeding has no negative effect on broiler performance and tends to decrease serum triglyceride, cholesterol, and MDA concentrations. Thus, it can be safely used as a 40% replacement of corn in broiler diets.

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