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Effect of exogenous lipase supplementation in low-energy diets on growth performance, nutrient digestibility, blood parameters, antioxidative status and economic indices of broilers

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ABSTRACT

A total of 300 one-day-old chicks were divided into five treatments. Five diets were formulated as follows: PC (positive control), NC1 (negative control 1; ME was reduced by 80 kcal/kg diet), NC2 (negative control 2; ME was reduced by 100 kcal/kg diet), NC1 with lipase (negative control 1+ lipase at 200 g/ton diet) and NC2 (negative control 2+ lipase at 200 g/ton diet). Body weight was higher ($P < 0.05$) in birds fed the PC diet and the NC1 diet supplemented with lipase, and lower for those that received the NC2 diet. Moreover, the highest digestibility of CP and ether extract was observed in the groups fed NC1 supplemented with lipase and PC. The highest glutathione peroxidase level was observed in the group fed the NC1 diet, and the lowest malondialdehyde level was recorded in the groups fed low-energy diets supplemented with lipase, followed by those fed low-energy diets without lipase. Additionally, the group reared on the NC1 diet supplemented with lipase exhibited the highest economic indices and the lowest ($P < 0.05$) feed costs per kg body weight gain, without significant differences from the PC diet-fed group. It could be concluded that supplementation of lipase to reduced-energy diets markedly improved performance, nutrient utilization, economic efficiency and antioxidative status of broilers.

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Exogenous lipase; growth; digestibility; economic indices; broilers

1. Introduction

Energy is one of the major cost components in broiler diets due to the increasing demand and the high costs of ingredients. Therefore, it is necessary to optimize the levels of high-energy ingredients to counteract the rise in feed prices (Sizova and Ryazantseva 2022). In poultry diets, vegetable oils and animal fats are the most common sources used to fulfill the high energy requirement of fast-growing broilers (Ravindran et al. 2016). Energy is the most expensive component of the diet. The use of fat in the diet increases dietary energy and has a direct impact on growth rate, feed efficiency and carcass criteria. The use of fat should be based on an economic analysis to determine the most economical dietary energy level, considering the value of incremental changes in energy on production indicators and market price (Baião and Lara 2005; Fébel 2008). Unfortunately, increasing fat levels in the feed of broilers could adversely affect fat digestion and compromise bird growth due to factors like the limited digestive capacity of young birds, the influence of fat characteristics, and the potential need for emulsifiers or specific enzyme supplementation to improve utilization (Siyal 2017; Siyal 2019). The inefficient fat utilization in broilers is attributed to

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the reduced activity and secretion of lipase and bile salts, particularly in young broilers (Jansen et al. 2015; Pantaya et al. 2020). In order to overcome this limitation, different strategies have been applied, such as the inclusion of emulsifiers in the diet to increase the availability of fat and reduce the costs of production (de Oliveira 2019; Upadhaya et al. 2019). Another strategy that has been adopted to improve fat utilization in broilers is exogenous lipase supplementation (Adeola and Cowieson 2011; Nagargoje et al. 2016). It has been confirmed that the health status of birds and liver function are enhanced by the incorporation of exogenous enzymes such as lipase into the diet (Zaefarian et al. 2019). Lipase is an enzyme involved in the hydrolysis of triglycerides to produce glycerol and fatty acids (Castro and Kim 2021). It can be obtained from various sources and can also be extracted from different organisms including microbial, plant and animal species (Negi 2019). There are three sources of lipases: microbial, plant and animal sources; 1. **Microbial lipases; Advantages:** High yield and abundance: Microorganisms can produce lipases in large quantities, leading to higher yields and greater availability for industrial use. Ease of production and Manipulation: They are easily cultured on inexpensive media, and their genetic makeup can be manipulated to optimize enzyme characteristics, including activity, stability, and specificity. Stability: Microbial lipases often exhibit superior stability at various pH values and temperature ranges, making them suitable for diverse industrial conditions. Absence of seasonal fluctuations: Unlike plant and animal sources, microbial lipase production is not subject to seasonal variations, ensuring a consistent supply. Versatility: These compounds can catalyze a wide range of reactions, including esterification, transesterification, and hydrolysis, making them valuable in various sectors, such as food, pharmaceuticals and biodiesel production (Bharathi and Rajalakshmi 2019). **Plant lipases; Advantages:** Presence in specific tissues: Found in various plant tissues, particularly in lipid-storing seeds during germination for breaking down storage triacylglycerols. Potential for Specific Oil Modification: Research indicates that some plant lipases can specifically attack certain oils to generate free fatty acids or esters (Villeneuve 2003). 2. **Animal lipases; Advantages:** Naturally occurring: Animal lipases are naturally produced in the body for essential physiological processes, such as fat digestion (Filho et al. 2019). A previous study reported that the incorporation of lipase from the yeast *Yarrowia lipolytica* into broiler diets improved growth performance, FCR and fat digestibility (Wang et al. 2018). Moreover, the negative effect of a low-energy diet on the growth performance of broilers are alleviated by supplementation of dietary lipase (Zhou et al. 2009; Hu et al. 2018). On the other hand, Arshad et al. (2020) found that the addition of lipase to low-energy diets had no marked effect on performance and fat digestibility of broilers. Indeed, there is a large contrast between previous studies concerning the effect of exogenous lipase supplementation on broiler performance. Also, the studies conducted for evaluation of supplemental lipase are very limited. Besides, the economic aspects have not been investigated yet. Therefore, the present study aimed to evaluate the impact of the addition of exogenous lipase to low-energy diets on growth performance, nutrient digestibility, blood parameters, antioxidative status and economic indices of broilers.

2. Materials and methods

2.1 Birds and experimental design

The current study was approved by the Ethics Committee of the Local Experimental Animals Care Committee of Kafrelsheikh University, Egypt (Number, KFS-IACUC/260/2025). A total of 300 one-day-old Ross 308 broiler chicks were divided into five treatments, each consisting of six duplicates of ten chicks with an average starting body weight of 45.50 g/chick. According to the experimental design shown in Table 1, birds were randomly assigned to the various experimental treatments. Five diets were formulated, namely PC (positive control basal diet with balanced metabolizable energy (ME)), NC1 (negative control 1; ME content was reduced by 80 kcal/kg compared with PC), NC2 (negative control 2: ME content was reduced by 100 kcal/kg compared with PC), NC1 with lipase (negative control 1+ lipase at 200 g/ton diet) and NC2 (negative control 2+ lipase at 200 g/ton diet). The basal diet (BD) was developed based on the nutritional needs of broiler chickens (Aviagen, 2019). The experimental diets were fed to the birds in three phases: starter (1–14 d), grower (15–28 d) and finisher (29–35 d). Table 2 shows the chemical analysis and composition of the experimental diets at the various growth stages. The exogenous lipase was added to

Table 1. Description of dietary treatments.

No.	Treatment	Code	Description of diet	Lipase (g/ton)
1	Positive Control	PC	Commercial broiler diet formulated with corn and soybean meal to meet the commercially practiced levels of metabolizable energy (ME)	-----
2	Negative Control 1	NC1	PC – 80 kcal ME/kg diet	-----
3	Negative Control 2	NC2	PC –100 kcal ME/kg diet	-----
4	Negative Control 1+ Lipase	NC1+ Lipase	PC – 80 kcal ME/kg diet	20
5	Negative Control 2+ Lipase	NC2+ Lipase	PC – 100 kcal ME/kg diet	20

Table 2. Composition of the experimental starter, grower and finisher diets.

Ingredient, g/kg	Starter (1–14 days)			Grower (15–28 days)			Finisher (29–35 days)		
	PC	NC1	NC2	PC	NC1	NC2	PC	NC1	NC2
Yellow corn	56.526	56.385	55.287	62.457	61.546	60.448	66.478	64.752	63.622
Soybean meal, 46%	36.364	35.851	35.597	31.103	30.499	30.244	27.455	26.786	26.620
Soya oil	1.517	0.500	0.500	1.583	0.750	0.750	1.640	1.000	1.000
Monocalcium phosphate	0.796	0.770	0.749	0.486	0.450	0.429	0.252	0.205	0.184
Wheat bran	2.000	3.684	5.047	2.000	4.367	5.730	2.000	5.063	6.377
DL-Methionine, 99%	0.358	0.356	0.355	0.323	0.321	0.320	0.300	0.298	0.296
L-Lysine, 98%	0.222	0.227	0.229	0.215	0.220	0.221	0.206	0.211	0.209
L-Threonine	0.080	0.081	0.082	0.065	0.066	0.067	0.053	0.054	0.053
Limestone	1.300	1.309	1.315	0.935	0.946	0.953	0.791	0.805	0.811
Salt	0.203	0.199	0.198	0.203	0.200	0.199	0.206	0.203	0.203
Premix ¹	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Sodium bicarbonate	0.227	0.232	0.235	0.223	0.229	0.232	0.217	0.224	0.225
Choline chloride	0.077	0.075	0.075	0.078	0.076	0.076	0.072	0.070	0.069
Smart NSPase	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Smart Phytase	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	100	100	100	100	100	100	100	100	100
Chemical analysis on DM basis									
Crude protein, %	21.67	21.68	21.69	19.69	19.71	19.72	18.30	18.34	18.38
ME, kcal/kg	2975	2895	2875	3050	2970	2950	3100	3020	3000
Calcium, %	0.95	0.95	0.95	0.75	0.75	0.75	0.65	0.65	0.65
Available P, %	0.50	0.50	0.50	0.42	0.42	0.42	0.36	0.36	0.36
Ether Extract, %	4.49	3.53	3.55	4.66	3.89	3.90	4.78	4.21	4.22
Crude Fiber, %	3.08	3.24	3.35	2.98	3.19	3.31	2.91	3.18	3.29
Sodium, %	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Chloride, %	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
L-Lysine, 98%	1.34	1.34	1.34	1.20	1.20	1.20	1.10	1.10	1.10
DL-Methionine, 99%	0.68	0.67	0.67	0.62	0.62	0.62	0.58	0.58	0.58

¹ Provided per kilogram of the complete diet: vitamin A (from vitamin A acetate), 12,500 IU; vitamin D3, 2500 IU; vitamin E (from DL- α tocopheryl acetate), 20 IU; vitamin K3, 2 mg; vitamin B1, 2 mg; vitamin B2, 5 mg; vitamin B6, 3 mg; vitamin B12, 18 μ g; calcium pantothenate, 8 mg; folic acid, 1 mg; biotin, 50 μ g; and niacin, 24 mg. ² Provided per kilogram of complete diet: Fe (as FeSO₄·7H₂O), 40 mg; Cu (as CuSO₄·H₂O), 8 mg; Zn (as ZnSO₄·H₂O), 60 mg; Mn (as MnSO₄·H₂O) 90 mg; Mg (MgO) as 1500 mg.

the premix combination. The enzyme used in this work was Smart Lipase (10,000 U/g; carrier: calcium carbonate), obtained from Devenish, 96 Duncrue St, Belfast BT3 9AR, United Kingdom. Throughout the trial, feed and water were given to all birds in each well *ad libitum*. A temperature-controlled house with an 18-h light and 6-h dark cycle was used for the feeding trial. The temperature was set to start at 32 \pm 1 $^{\circ}$ C and was decreased by 1 $^{\circ}$ C every three days until it reached 24 \pm 1 $^{\circ}$ C, which was maintained for the entire 35-day experiment. Relative humidity was also maintained between 50% and 70%. Daily records of health condition and mortality were performed throughout the trial.

2.2 Growth performance and organ weights

The body weights (BW) of the broilers were recorded separately on a weekly basis, while feed intake (FI) was recorded daily throughout the entire experimental period. Based on these parameters, the feed conversion ratio (FCR) was determined. At the end of the experiment, six birds/treatment were chosen as the same body weight (one bird/replicate), and the weights of the breast, thigh, liver, gizzard, heart, spleen and

abdominal fat were subsequently measured after slaughtering and dissection of the birds. Every organ was weighed and reported as a percentage of the total body weight.

2.3 Nutrient digestibility

During the final three days of the feeding trial, the excreta of six birds per treatment (one bird/replicate) were collected, weighed, and kept in the freezer until analysis. All the samples were subsequently homogenized after being dried for 24 h at 60 °C in a drying oven. The samples were tested in accordance with the Association of Official Analytical Chemists guidelines. The Kjeldahl method was used to quantify the crude protein concentration in the feed and excreta in order to evaluate nitrogen digestibility while, Soxhlet method (AOAC 945.38 F and 920.39 °C, respectively) was used to measure crude fat. Additionally, crude fiber was assessed by CF method (AOAC 932.09). The formula used to determine nutrient digestibility was as follows:

$$\text{Nutrient digestibility (\%)} = (\text{total nutrient intake} - \text{total nutrient excreted}) / \text{total nutrient intake} \times 100.$$

2.4 Serum biochemical parameters and hepatic lipid peroxidation

Just prior to slaughter, blood samples (six birds/group; one bird/replicate) were drawn from the wing vein, placed into heparinized test tubes, and centrifuged immediately (3000 rpm for 20 min at 5 °C) for separation of the plasma. After that, the plasma was stored at -20 °C until analysis. The blood parameters (total cholesterol (TC), albumin, globulin, glutamic oxaloacetic transaminase (GOT), glutamate pyruvate transaminase (GPT), glucose, total protein, high-density lipoprotein (HDL) and low-density lipoprotein (LDL) cholesterol) were measured colorimetrically using reagent kits from Diamond Diagnostics, Egypt, according to the manufacturer's instructions. Malondialdehyde (MDA), Catalase (CAT) and glutathione peroxidase (GPX) activities in the liver were determined according to the methods of Marklund and Marklund (1974).

2.5 Economic parameters

Costs and returns were calculated depending on the market prices when the inputs were purchased and output was sold.

2.5.1 Costs calculations

The total costs (TC) were calculated by the summation of fixed costs and variable costs. The fixed costs (TFC) included depreciation, and the cost of day-old chicks, labour and veterinary services, as they were the same for all experimental groups. The cost of the feed (variable cost) was calculated based on the type of feed by multiplying the cost of one kilogram of feed by the amount of feed consumed (kg) for one bird.

2.5.2 Returns calculations

The total economic return (TR) depends on the sales of the live birds and was obtained according to the following formula:

$$\text{TR} = \text{live body weight of the bird (kg)} \times \text{the price of one kg meat}$$

2.5.3 Net profit (NP)

Calculated by subtracting the economic cost (TC) from the return (TR).

2.5.4 Efficiency measures

Feed costs/kg BWG = FCR × cost of one kg of feed

Benefit–cost ratio (BCR) = TR/TC

Economic efficiency (EE) = NP/feed costs

Rate of return on investment (RRI) = NP/TC × 100

The economic indices were calculated following Hamad and Kareem (2019); Ghanima (2023).

2.6 Statistical analysis

Using SPSS Statistics 17.0 (Statistical Packages for the Social Sciences, SPSS Inc., Chicago, IL, U.S.A., released August 23, 2008), the differences between the experimental treatments and the control were examined using a General Liner model. While all of the chosen broilers from each replicate served as the experimental unit for blood analyses and nutrient digestibility, the pen served as the experimental unit for performance data. The significance between treatments was determined using Tukey's multiple comparison test, with a significance level of $P < 0.05$.

3. Results

3.1 Growth performance and nutrient digestibility

Table 3 shows the effect of exogenous lipase supplementation in low-energy diets on growth performance and nutrient digestibility in broilers. Final body weight and body weight gain were higher ($P < 0.05$) in birds fed the PC diet and the NC1 diet supplemented with exogenous lipase, and lower ($P < 0.05$) for those that received the NC2 diet. The feed intake did not differ significantly ($P > 0.05$) among the dietary treatments. However, FCR was higher ($P < 0.05$) in birds fed the NC2 diet compared with the birds in the other treatments. The crude fiber digestibility was similar ($P > 0.05$) among the different treatments. Moreover, the highest ($P < 0.05$) digestibility of CP and ether extract percentages were observed in the groups fed NC1 supplemented with lipase and PC while the lowest ($P < 0.05$) percentages were recorded in the NC2 group.

3.2 Organs weights

The effect of adding exogenous lipase to low-energy diets on organ weights in broiler chickens is shown in Table 4. It was observed that the dietary treatments did not affect ($P > 0.05$) the percentages of carcass and the weights of breast muscle, thigh muscle, liver, spleen or heart. Meanwhile, the weight of the gizzard and abdominal fat varied significantly ($P < 0.05$) between the different groups. The highest ($P < 0.05$) gizzard weight was observed in birds fed the NC1 diet supplemented with lipase, while the percentage of abdominal fat was higher ($P < 0.05$) in the group fed the PC diet than in the other groups.

Table 3. Effect of exogenous lipase supplementation to low-energy diets on growth performance and nutrient digestibility in broilers.

	PC	NC1	NC2	NC1 + lipase	NC2 + lipase	<i>P</i> -value
Initial body weight, g	45.7 ± 0.59	45.4 ± 0.56	45.6 ± 0.27	45.5 ± 0.42	45.8 ± 0.29	0.966
Final body weight, 35 day, g	2513 ± 35 ^a	2393 ± 19 ^{bc}	2349 ± 16 ^c	2494 ± 47 ^{ab}	2469 ± 28 ^{abc}	0.011
Body weight gain, g	2467 ± 34 ^a	2348 ± 19 ^{bc}	2303 ± 16 ^c	2449 ± 47 ^{ab}	2423 ± 27 ^{abc}	0.012
Feed intake, 35 day, g	3617 ± 32	3646 ± 48	3745 ± 49	3617 ± 39	3706 ± 50	0.187
FCR	1.439 ± 0.01 ^c	1.524 ± 0.02 ^b	1.594 ± 0.02 ^a	1.477 ± 0.02 ^{bc}	1.501 ± 0.01 ^b	0.001
CP, %	79.35 ± 0.53 ^{ab}	76.94 ± 0.99 ^c	77.41 ± 1.16 ^c	80.42 ± 0.42 ^a	78.34 ± 0.41 ^b	0.024
CF, %	26.85 ± 1.14	25.65 ± 1.66	26.11 ± 0.93	25.91 ± 0.77	25.65 ± 0.76	0.336
Ether extract, %	48.23 ± 0.57 ^a	46.01 ± 0.97 ^{ab}	44.35 ± 0.40 ^b	47.87 ± 1.23 ^a	45.95 ± 0.60 ^{ab}	0.048

PC, positive control basal diet with balanced ME; (NC1) negative control 1; ME content was reduced by 80 kcal/kg compared with PC; (NC2) negative control 2: ME content was reduced by 100 kcal/kg compared with that of PC.^{a,b} Mean values with different letters in the same row differ significantly at $P < 0.05$. The values are expressed as the means ± standard error. CP, crude protein digestibility; CF, crude fiber digestibility.

Table 4. Effect of Exogenous lipase supplementation to low-energy diets on organ weights in broiler chickens.

	PC	NC1	NC2	NC1 + lipase	NC2 + lipase	P-Value
Carcass, %	72.92 ± 0.96	73.37 ± 1.5	72.03 ± 1.23	73.24 ± 1.37	73.22 ± 0.56	0.428
Breast muscle weight, %	24.22 ± 0.82	24.83 ± 0.36	23.42 ± 0.33	24.59 ± 0.63	24.4 ± 0.55	0.494
Thigh muscle weight, %	18.07 ± 0.3	17.98 ± 0.51	17.23 ± 0.54	17.85 ± 0.36	17.27 ± 0.51	0.570
Gizzard weight, %	1.01 ± 0.07 ^b	1.02 ± 0.05 ^b	1.12 ± 0.04 ^{ab}	1.22 ± 0.04 ^a	1.09 ± 0.01 ^{ab}	0.029
Liver weight, %	2.07 ± 0.08	1.99 ± 0.06	1.93 ± 0.08	2.04 ± 0.09	2.15 ± 0.09	0.431
Spleen weight, %	0.15 ± 0.02	0.13 ± 0.02	0.12 ± 0.01	0.09 ± 0.01	0.1 ± 0.00	0.274
Abdominal fat, %weight	1.88 ± 0.1 ^a	1.23 ± 0.12 ^{bc}	1.20 ± 0.09 ^c	1.53 ± 0.1 ^b	1.19 ± 0.07 ^c	0.001
Heart weight, %	0.44 ± 0.04	0.48 ± 0.02	0.43 ± 0.01	0.47 ± 0.01	0.46 ± 0.01	0.744

PC, positive control basal diet with balanced ME; (NC1) negative control 1, ME content was reduced by 80 kcal/kg compared with PC; (NC2) negative control 2, ME content was reduced by 100 kcal/kg compared with PC.^{a,b} Mean values with different letters in the same row differ significantly at $P < 0.05$. The values are expressed as the means ± standard error.

Table 5. Effect of exogenous lipase supplementation to low-energy diets on blood parameters in broiler chickens.

	PC	NC1	NC2	NC1 + lipase	NC2 + lipase	P-value
Total protein, (mg/dL)	2.63 ± 0.04	2.63 ± 0.08	2.68 ± 0.22	2.66 ± 0.07	2.71 ± 0.07	0.989
Albumin (mg/dL)	1.16 ± 0.04 ^b	1.33 ± 0.03 ^{ab}	1.53 ± 0.08 ^a	1.45 ± 0.02 ^a	1.37 ± 0.03 ^a	0.048
Globulin (mg/dL)	1.46 ± 0.07	1.29 ± 0.07	1.14 ± 0.17	1.21 ± 0.06	1.33 ± 0.09	0.286
Total cholesterol (mg/dL)	143 ± 3.72 ^a	131.5 ± 5.59 ^b	125.33 ± 2.41 ^b	129.83 ± 1.30 ^b	127.83 ± 1.66 ^b	0.010
Triglycerides (mg/dL)	8.36 ± 0.71 ^a	6.26 ± 0.79 ^b	6.39 ± 0.61 ^b	6.41 ± 0.19 ^b	5.97 ± 0.33 ^b	0.052
HDL-cholesterol (mg/dL)	87.33 ± 3.57	87.33 ± 2.83	89 ± 2.67	86.83 ± 1.74	87.33 ± 1.94	0.982
LDL-cholesterol (mg/dL)	37.33 ± 4.35 ^a	29.83 ± 1.85 ^{ab}	29.83 ± 0.98 ^b	31 ± 2.12 ^{ab}	29 ± 1.94 ^b	0.045
GOT (I/U)	284 ± 23.07	258.6 ± 4.88	253 ± 5.44	254 ± 11.89	255.16 ± 7.37	0.383
GPT (I/U)	4.28 ± 0.45	4.11 ± 0.35	3.35 ± 0.17	3.46 ± 0.18	3.36 ± 0.21	0.124

PC, positive control basal diet with balanced ME; (NC1) negative control 1; ME content was reduced by 80 kcal/kg compared with PC; (NC2) negative control 2: ME content was reduced by 100 kcal/kg compared with PC.^{a,b} Mean values with different letters in the same row differ significantly at $P < 0.05$. The values are expressed as the means ± standard error.

3.3 Blood parameters

Table 5 shows the effect of exogenous lipase supplementation via low-energy diets on blood parameters in broilers. There were no significant ($P > 0.05$) changes in total protein and globulin among the birds in different treatments. The levels of HDL-cholesterol, GOT and GPT also showed the same trend. The other measured blood parameters (albumin, total cholesterol, triglycerides and LDL-cholesterol) were affected ($P > 0.05$) by the dietary treatment. The albumin level increased markedly ($P < 0.05$), while the levels of total cholesterol, triglycerides and LDL-cholesterol decreased markedly ($P < 0.05$) in the birds fed low-energy diets, either supplemented or not with exogenous lipase enzyme as compared to the birds that received the balanced energy-containing diet.

3.4 Indicators of lipid peroxidation in the liver

Figure 1 shows the indicators of lipid peroxidation (A (GPX), B (CAT) and C (MDA)) in the liver of the broilers after they were fed the experimental diets. In general, the birds that received reduced-energy diets presented greater ($P < 0.05$) GPX than those that received the balanced energy-containing diet. Among them, the highest ($P < 0.05$) GPX level was observed in the group fed the NC1 diet. Furthermore, the CAT levels were significantly ($P > 0.05$) similar across all the experimental groups. The lowest ($P < 0.05$) MDA level was recorded in the groups fed low-energy diets supplemented with lipase, followed by those fed the low-energy diets without lipase, while the highest level was observed in the PC group.

3.5 Economic parameters

Table 6 summarizes the effect of adding the lipase enzyme to low-energy diets on the economics of broiler production. The feed costs and total costs per bird did not significantly differ between the experimental groups ($P > 0.05$). However, the treatments of PC and NC1+ lipase presented the highest ($P < 0.05$) total return, net profit, benefit cost ratio, economic efficiency, rate of return on investment and the lowest ($P < 0.05$) feed costs per kg body weight gain compared to other treatments.

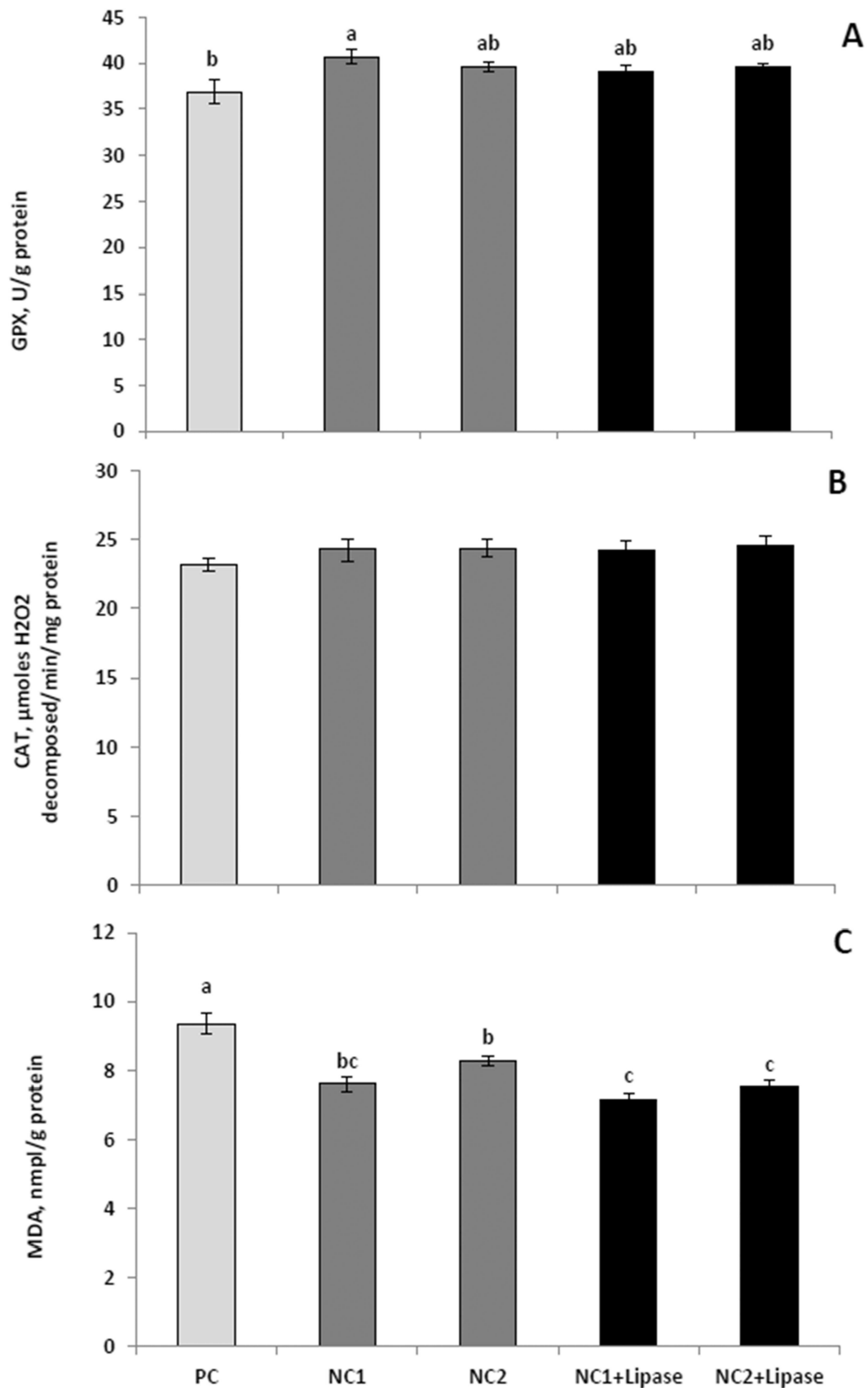


Figure 1. Effect of exogenous lipase supplementation to low-energy diets on liver lipid peroxidation in broilers. PC, positive control basal diet with balanced ME; (NC1) negative control 1; ME content was reduced by 80 kcal/kg compared with PC; (NC2) negative control 2; ME content was reduced by 100 kcal/kg compared with PC. ^{a,b} Mean values with different letters in the same row differ significantly at $P < 0.05$. The values are expressed as the means \pm standard error. GPX (A), CAT (B), MDA (C).

Table 6. Effect of exogenous lipase supplementation to low-energy diets on economic parameters in broiler chickens.

	PC	NC1	NC2	NC1 + lipase	NC2 + lipase	P-value
Feed costs (EGP)/bird	63.36 ± 0.56	62.11 ± 0.81	63.63 ± 0.83	61.81 ± 0.67	63.14 ± 0.85	0.370
TC (EGP)/bird	116.36 ± 0.56	115.11 ± 0.81	116.63 ± 0.83	114.81 ± 0.67	116.14 ± 0.85	0.370
TR (EGP)/bird	180.93 ± 2.49 ^a	172.32 ± 1.36 ^{ab}	169.15 ± 1.16 ^b	177.40 ± 3.37 ^{ab}	175.58 ± 2.01 ^{ab}	0.010
NP (EGP)/bird	64.57 ± 2.03 ^a	57.20 ± 1.60 ^{ab}	52.51 ± 1.57 ^b	62.59 ± 3.11 ^a	59.44 ± 1.98 ^{ab}	0.005
B/C ratio	0.56 ± 0.01 ^a	0.50 ± 0.01 ^{ab}	0.45 ± 0.01 ^b	0.55 ± 0.02 ^a	0.51 ± 0.01 ^{ab}	0.004
EE	1.02 ± 0.02 ^a	0.92 ± 0.03 ^{ab}	0.83 ± 0.03 ^b	1.02 ± 0.04 ^a	0.94 ± 0.03 ^{ab}	0.007
Feed cost (EGP)/kg BWG	25.22 ± 0.20 ^b	25.96 ± 0.39 ^{ab}	27.09 ± 0.44 ^a	25.12 ± 0.44 ^b	25.90 ± 0.39 ^{ab}	0.010
RRI	55.46 ± 1.56 ^a	49.72 ± 1.64 ^a	45.07 ± 1.57 ^b	54.49 ± 2.64 ^a	51.20 ± 1.83 ^{ab}	0.005

PC, positive control basal diet with balanced ME; (NC1) negative control 1; ME content was reduced by 80 kcal/kg compared with that of PC; (NC2) negative control 2: ME content was reduced by 100 kcal/kg compared with PC.^{a,b} Mean values with different letters in the same row differ significantly at $P < 0.05$. The values are expressed as the means ± standard error.

4. Discussion

In broiler production, numerous strategies have been adopted to improve fat utilization and reduce feed costs without compromising growth performance. One of these strategies is the supplementation of exogenous lipase to the diet. In the present study, the addition of exogenous lipase to the low-energy diets improved the growth performance of the birds compared to those fed a low-energy diets without the enzyme. Similar results were reported by Shoab et al. (2021) and Ahmad (2023), who concluded that the addition of lipase improved the growth performance of broilers reared on a low-energy diets. However, it was observed that lipase supplementation to a low-energy diets strongly improved the body weight gain in broilers (Cho et al. 2012; Wang et al. 2018; Wickramasuriya 2019; Arshad et al. 2020). The mechanisms of growth improvement may be by the following ways: 1. Improving fat digestion: lipase enzymes break down triglycerides (fats) into free fatty acids and glycerol, making them more digestible and absorbable by the animal. 2. Addressing physiological limitations: In poultry, endogenous lipase production might not be sufficient to fully digest fats, especially in low-energy diets, so exogenous lipase helps overcome this limitation. 3. Improved nutrient utilization: By improving fat digestion, lipase supplementation leads to better overall nutrient utilization and energy extraction from the diet. 4. Mitigating low-energy diet effects: The addition of lipase can compensate for the negative impacts on growth performance that might otherwise arise from the consumption of a low-energy diet (Ahmad 2023). Furthermore, the present study showed that growth performance was negatively influenced by energy reduction. This finding was consistent with Ge (2019), who reported that the weight gain of broilers fed a low-energy diets was decreased as compared to the lower than that of birds fed a high-energy diets. That is due to the fact that dietary energy is directed first towards maintenance and then towards growth of the bird. Therefore, when a low-energy diets is offered, the birds fulfill only the maintenance requirements, which in turn leads to a decrease in weight gain. Based on our study, the FCR increased by feeding diets with a reduced energy level; however, it improved with lipase supplementation. This result is in agreement with Al-Marzooqi and Leeson (2000) and Shoab et al. (2021), who reported that the addition of lipase to the broiler diet had a positive effect on FCR. Moreover, our results demonstrated that feed intake was not affected by dietary treatment. Similarly, Richards (2003) and Movagharnejad et al. (2020) reported that FI was similar in birds fed diets with different energy concentrations either supplemented or not supplemented with lipase. In contrast, Harrington et al. (2016) and Ahmad (2023) reported that FI was higher in birds fed a low-energy diets as compared to high-energy diets. Additionally, the incorporation of lipase in a low-energy diets did not improve feed efficiency (Arshad et al. 2020).

The current research revealed that the digestibility of CP and EE increased in the birds fed a diet containing balanced energy (PC) and a low-energy diets supplemented with lipase (NC1+ lipase). Similarly, Dierick and Decuypere (2004), Hu et al. (2018) and Shoab et al. (2021) noticed that the addition of lipase to a reduced-energy diet improved CP and EE in broilers. The effective and better utilization of nutrients induced by dietary lipase may explain the improvement in growth performance observed in our study. The nutrients digestibility is improved by lipase supplementation due to enhance the activity of digestive enzymes such as amylase, lipase and chymotrypsin, and improves intestinal morphology. In contrast, Meng et al. (2004) and Ahmad (2023) reported that lipase supplementation did not improve the digestibility of CP and EE in broilers. However, the present study showed that the digestibility of CP and EE was significantly

reduced by the consumption of low-energy diets without lipase. However, Dairo et al. (2010) and Papadopoulous (2018) reported that nutrient digestibility was not affected by the different energy levels in the diets of broilers.

Neither lipase supplementation nor the energy level affected on the carcass yield and organs weights including breast and thigh muscles, liver, spleen, or heart, in this study. Similar results were reported by Hu et al. (2018) and Arshad et al. (2020), who found that the organs weights were similar regardless of dietary lipase inclusion or energy level in broiler feeds. Similarly, Corduk et al. (2007) and Ge (2019) confirmed that the dietary energy level had no effect on the carcass traits of broilers. Nevertheless, in the present study, the percentage of abdominal fat markedly decreased with decreasing dietary energy level, especially in the diet with a 100 kcal reduction. This finding is in agreement with Zhao and Kim (2017) and Mohammadigheisar et al. (2018) but disagree with the result of Arshad et al. (2020). In fact, diets with high levels of energy lead to fat deposition and accumulation inside the birds body which represent the main cause of the elevated abdominal fat percentage in chickens fed a PC diet (Nahashon et al. 2005; Zhao and Kim 2017; Alzawqari 2023).

The dietary treatments in our study did not influence plasma HDL, GOT and GPT. Similarly, Wickramasuriya (2019) and Ahmad (2023) reported no changes in the concentrations of GOT, GPT and HDL in the blood of broilers supplemented with lipase. Additionally, Saleh et al. (2020) reported that the total protein, globulin and high-density lipoprotein (HDL) contents were reduced, while, albumin did not change in birds fed a low-energy diet. These findings are inconsistent with our results, which revealed that energy level had a non-significant impact of on total protein, globulin and HDL but had a significant negative effect on albumin concentration. Moreover, dietary lipase further increases the albumin content. Unfortunately, data concerning the effect of dietary lipase on albumin are lacking. Furthermore, the total cholesterol, triglyceride and LDL levels in the present study were significantly reduced by the consumption of low-energy diets supplemented with or without lipase. Studies have shown that caloric restriction, a component of low-energy diets, can lead to positive changes in lipid profiles, including significant decreases in total cholesterol, LDL cholesterol, and triglycerides, particularly in overweight or obese individuals. This reduction is often linked to weight loss and improved fat deposition. While lipase enzymes are involved in breaking down triglycerides into fatty acids and glycerol for absorption. While the effects of lipase supplementation on lipid metabolism in animals have been studied, some research indicates that low-energy diets may be sufficient to achieve significant lipid reductions, even without lipase supplementation. In fact, some studies on lipase in broilers found a decrease in total serum cholesterol with lipase supplementation (Kirrella 2021; Hussein et al. 2021; Luna-Castillo 2022).

Accordingly, Hu et al. (2018) reported that supplemental lipase significantly decreased TC, TG and LDL, while HDL remained unchanged. Furthermore, Brenes et al. (2008) confirmed that lipase supplementation has a hypocholesterolemic effect on broilers. Arshad (2021) suggested that the inclusion of lipase in the diets of broilers could increase the metabolism and absorption rate of dietary fat, hence reducing plasma TG. In contrast, neither the energy level nor lipase inclusion affected the concentrations of TC, TG, and LDL in the studies of Arshad et al. (2020) and Ahmad (2023).

Broilers are characterized by accelerated growth rates, which require providing them with a diet containing high levels of energy. On the other hand, energy is a very expensive component that contributes to rising feed prices (Sizova and Ryazantseva 2022; Saleh 2025). This has increased interest in the search for less expensive energy sources or substances that enhance the digestion and utilization of dietary lipids with/without a reduction in dietary energy levels. Thus, feed costs, the total costs of production and, accordingly, the price of the product could be reduced. In accordance with Acamovic (2001) and Adeola and Cowieson (2011), the incorporation of exogenous enzymes into poultry diets could increase productive efficiency. In addition, it has several economic benefits, such as increasing the digestion of low-quality ingredients and making it possible to reduce nutritional levels, thus improving economic efficiency. In this context, the present study revealed that supplementation of lipase to a low-energy diets (NC1) resulted in the highest economic indicators (total return, net profit, benefit cost ratio, and economic efficiency as well as the rate of return on investment) and the lowest feed costs per kg body weight gain without significant differences from those associated with the PC diet. Similarly, Nagargoje et al. (2016) reported that the addition of lipase to the diet increased the profitability of broiler chickens. Indeed, high energy density can increase the productivity and income of broilers and consequently reduce fixed costs. On the other hand, the costs of raw materials and the production of high-energy diets compared to low-energy diets may negate the benefits of higher productivity (Waldroup 1981).

Oxidation is a natural process that occurs in the bodies of living organisms and results in the production of free radicals. Nonetheless, the excessive formation of such radicals can cause oxidative stress, which can damage vital biomolecules, including proteins, lipids and DNA (Kismiati et al. 2021). As a result, the productivity and meat quality of poultry can be negatively affected (Smet et al. 2008). Recently, the increasing costs of feed ingredients, especially energy, have driven the need to identify cheaper alternatives. Therefore, for economical poultry production, some producers may use low-quality fat sources to fulfill the energy requirements of birds (Delles et al. 2014; Saleh 2020). This practice can increase the oxidation process. However, the use of some feed additives constitutes a potent strategy for elucidating the effect of oxidative stress on broiler production. The level of MDA, an indicator of lipid oxidation, in the present study was significantly decreased by lipase supplementation. These findings suggest the positive role of dietary lipase in reducing lipid peroxidation. Interestingly, the activity of GSH-PX (antioxidant enzyme) was greater in birds fed low-energy diets with/without lipase than in those fed the PC diet. Meanwhile, CAT activity was not influenced by the dietary treatments. The findings of Ahmad et al. (2024) regarding CAT are consistent with our findings. However, the authors reported a non-significant effect of lipase and energy level on MDA and GSH-PX. Further investigations should be conducted regarding the effect of dietary lipase on the antioxidant status of broilers. Lipase can decrease malondialdehyde (MDA) and increase glutathione peroxidase (GPx) in broilers by enhancing their antioxidant defense systems, which helps protect against oxidative stress. MDA is a marker of lipid peroxidation, indicating cellular damage, while GPx is a key antioxidant enzyme that scavenges harmful free radicals and reduces oxidative stress. Lipase works by upregulating the expression of genes involved in antioxidant defense, including GPx, superoxide dismutase (SOD), and catalase (CAT). The reduction in MDA levels may be due to the effectively scavenging of free radicals and protecting cell membranes from lipid peroxidation; enzymes indirectly lead to a decrease in the levels of MDA, a product of this damage (Hidayat et al. 2023).

Conclusion

Overall, the findings of the present research showed that the supplementation of lipase to a low-energy diets (PC-80 kcal ME/kg diet) for 35 d improved the growth performance, nutrient digestibility, antioxidant status and economics of broilers. Besides, it ameliorated the negative impacts of the low-energy diets, and led to results comparable to the PC diet.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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