Use of lemongrass essential oil as a feed additive in quail's nutrition: its effect on growth, carcass, blood biochemistry, antioxidant and immunological indices, digestive enzymes and intestinal microbiota

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ABSTRACT The present study was designed to assess the impact of dietary supplementation of lemongrass essential oil (**LGEO**) on growth performance, carcass traits, liver and kidney function, immunity, antioxidant indices and caecal microbiota of growing quail. A total of 200 Japanese quails at 1-week-old were haphazardly allotted to 5 groups of 40 chicks in five replicates (8 per replicate). The first group was the control group, while LGEO was added at levels of 150, 300, 450, and 600 mg/kg diet in the 2nd, 3rd, 4th and 5th groups, respectively. Dietary supplementation of LGEO (150, 300 and 450 mg/ kg diet) increased body weight at 3 and 5 wk of age, and increased body weight gain during all periods compared with the control group ($P < 0.05$). All levels of LGEO improved feed conversion ratio during the periods from 1 to 3 and 1 to 5 wk of age. During 3 to 5 wk, feed conversion ratio was improved in quails fed LGEO (300 and 450 mg/kg diet) compared with the control and other treatments. Carcass traits, plasma globulin, alanine aminotransferase, and urea values did not differ among the treatments ($P > 0.05$), but the activity of aspartate aminotransferase in the plasma was significantly decreased ($P < 0.05$) in LGEO-treated groups. The total protein and albumin values were significantly increased ($P < 0.05$) in quails fed levels of LGEO (except 600 mg/kg diet) compared with the control. The inclusion of LGEO in quail diets improved ($P < 0.05$) plasma lipid profile. The dietary supplementation of LGEO increased (linear and quadratic, $P < 0.05$) plasma immunoglobulins (IgM, IgG, and IgA) levels, lysozyme values and activities of superoxide dismutase, total antioxidant capacity, reduced glutathione and catalase compared with the control group. The caecal *Coliform, E. coli* and *Salmonella* were lowered ($P < 0.0001$) in the quails treated with all LGEO levels, but the total bacterial count and *Lactobacillus* count were increased with dietary supplementation of LGEO levels (300 and 450 mg/kg) compared with those in the control group. The activities of digestive enzymes were significantly higher in birds fed the diet supplemented with LGEO levels than those fed the control diet. In conclusion, dietary supplementation of LGEO can improve the performance, lipid profile, immunity and antioxidant indices and decline intestinal pathogens and thus boost the health status of growing quail.

Key words: lemongrass, growth, digestive enzymes, intestinal microbiota, quail

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INTRODUCTION

The successful use of herbal growth promoter provides more profit to poultry sector by improvement of feed efficiency and health status (Alagawany and Abd El-Hack, 2021). Plant-derived additives used in animal nutrition to boost the performance have been called phytogenic feed additives (Windisch et al., 2008; Alagawany et al., 2019; Ebrahim et al., 2020). Nowadays, these additives were used to augment the poultry growth. Phytogenic feed additives comprise a wide range of spices, herbs and essential oils (Khafaga et al., 2019; Abd El-Hack et al., 2020a; Abo Ghanima et al., 2020; Alagawany et al., 2021).

Lemongrass (*Cymbopogon citratus*) is included in the list of phytogenic substances. *C. citratus* is a widely distributed perennial herb belonging to *Poaceae* family. It

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has been extensively consumed due to its nutritional and cosmetic medicinal effects, and pleasant taste and aroma that it gives to food. Some of its important pharmacological properties were already reported in the literature (Avoseh et al., 2015; Ekpenyong et al., 2015). The medicinal properties of lemongrass and its oil give health benefits that increase the productive performance of birds (Khattak et al. 2014).

Lemongrass essential oil (**LGEO**), as a volatile oil, can be extracted directly from fresh lemongrass. The major components present in LGEO are α-citral, β-citral, isoneral, α-myrcene, and linalool (Al-Sagheer et al., 2018). Citral is the key constituent of LGEO and has been known for its anti-inflammatory, immunomodulatory, fungistatic antimicrobial, antioxidant and antiseptic properties (Lertsatitthanakorn et al., 2006; Bachiega and Sforcin, 2011). LGEO can be used as a substitute for antibiotics in the poultry industry, because of its antimicrobial ability (Tiwari et al., 2018). Lemongrass contains a very high amount of vitamin C and its oil shows antioxidant activities (Guimarães et al., 2011). Some investigations have been stated the use of lemongrass or its secondary metabolites for performance-enhancing purposes in broiler chicks (Mmereole, 2010; Thayalini et al., 2011; Mukhtar et al., 2012). Mukhtar et al. (2012) illustrated that broilers fed diets containing LGEO levels significantly improved body weight gain. Silva et al. (2011) indicated that LGEO improved digestion and nutrient absorption due to its antimicrobial and antioxidant effects.

However, no information is available about the impact of graded levels of LGEO on productive performance and physiological status of growing quail. The aim of the current study was to investigate the impacts of varied inclusion levels of LGEO in the quail diet on growth performance, carcass criteria, liver and kidney function, immunity, antioxidant indices, digestive enzymes, and caecal microbiota of growing quail.

MATERIALS AND METHODS

Birds, Design and Treatments

A total of 200 Japanese quails at 1-week-old with average body weight of 30.02 ± 0.10 g were haphazardly allotted to 5 groups of 40 chicks in 5 replicates (8 per replicate). The first group was the control (basal diet) group (Table 1), while LGEO was added at levels of 150, 300, 450, and 600 mg/kg diet in the 2nd, 3rd, 4th and 5th groups, respectively. All birds were reared under the same managerial conditions in conventional cages (90 × 40 × 40 cm), with free access to the water and feed during the experimental period. The LGEO was purchased from Elhawag Company for Natural oils, Cairo, Egypt. This study was performed at quail unit, Waterfowl Farm, Department of Poultry, Faculty of Agriculture, Zagazig University, Egypt.The experimental procedures were performed according to the Local Experimental Animal Care Committee, Zagazig University.

Table 1. Ingredients and nutrient contents of basal diet of growing Japanese quail.

Items	(g/kg)
Ingredient	
Maize 8.5%	518.00
Soybean meal 44%	367.00
Maize gluten meal 62 %	52.10
Soybean oil	29.00
Limestone	7.00
Di-calcium phosphate	16.50
Salt	3.00
Premix[1]	3.00
L-Lysine	1.30
Dl-Methionine	1.10
Choline chloride	2.00
Total	1000
Calculated composition[2]	
Metabolizable energy (MJ/kg)	12.53
Crude protein (g/kg)	240
Calcium (g/kg)	8.00
Nonphytate phosphorus (g/kg)	4.50
Lysine (g/kg)	13.00
Total sulphur amino acids (g/kg)	9.20

[1]Provides per kg of diet: Vitamin A, 12,000 I.U; Vitamin D3, 5000 I.U; Vitamin E, 130.0 mg; Vitamin K3, 3.605 mg; Vitamin B1 (thiamin), 3.0 mg; Vitamin B2 (riboflavin), 8.0 mg; Vitamin B6, 4.950 mg; Vitamin B12, 17.0 mg; Niacin, 60.0 mg; D-Biotin, 200.0 mg; Calcium D-pantothenate, 18.333 mg; Folic acid, 2.083 mg; manganese, 100.0 mg; iron, 80.0 mg; zinc, 80.0 mg; copper, 8.0 mg; iodine, 2.0 mg; cobalt, 500.0 mg; and selenium, 150.0 mg.

Growth Performance and Carcass Measurements

All parameters related to growth rate (live body weight [**BW**] and body weight gain [**BWG**]) and feed utilization (feed intake [**FI**], and feed conversion ratio [**FCR**]) were evaluated at 1, 3, and 5 wk of age. For carcass evaluation, at the end of the experimental period, 25 quail birds were randomly weighed, and slaughtered after fasting for 6 h. All the edible organs and parts including liver, heart, gizzard, and eviscerated carcass were weighed, and the results were expressed as a percentage of the final body weight.

Blood Chemistry

Blood samples were collected at the end of the trial from the slaughtered quails. Blood samples were collected in heparinized tubes to obtain plasma after centrifugation for 15 minutes at 3,000 rpm. Plasma metabolites including protein and its fraction, aspartate aminotransferase, alanine aminotransferase, lactate dehydrogenase, creatinine, urea, triglycerides, total cholesterol and its fractions (high density lipoprotein, low density lipoprotein **[LDL]**, and very-low-density lipoprotein**[VLDL]**), and immunoglobulins (IgG, IgA and IgM) were determined using an automatic analyzer with a commercial kits from Bio-diagnostic Company (Giza, Egypt) according to the manufacture procedure. Plasma lysosomal activity was assessed with a 96-well microplate turbidity assay. Malondialdehyde (**MDA**), superoxide dismutase, catalase, total antioxidant capacity, and reduced glutathione (**GSH**) colorimetrically using microplate spectrophotometer with a commercial detection kit (Bio-diagnostic, Egypt) following the manufacturer's instructions.

Microbiological Analysis

Samples (~10 g) were collected from the quail cecum (5 samples per treatment) at the end of experiment and were transferred to a 250 mL Erlenmeyer flask containing 90 mL of peptone (0.1% peptone) in a saline solution (0.85% NaCl) and were thoroughly mixed. The total bacterial count, *Enterobacter* spp. count, total count of molds and yeasts, *Salmonella* spp. count, Coliform, lactic acid bacteria count, and *E. coli* count were estimated according to Xia et al. (2004) and Reda et al. (2020a,b).

Digestive Enzymes

The digestive enzymes (amylase, lipase, and protease) activities were determined in the ileal digesta of quails at the end of the experimental period (1 bird per replicate). The quail ileum from Meckel's diverticulum to 2 cm above the junction of ileocecal region was dissected, and the ileal contents were aseptically collected in screw-capped sterile specimen vials. Activities of amylase, lipase and protease were determined in the digestive samples according to the procedure of Najafi et al. (2005; 2006).

Statistical Analysis

Data of growth, carcass, feed utilization, lipid profile, liver and kidney function, and antioxidant and immune parameters, intestinal microbiota growing quails were analyzed with a generalized linear model using a normal distribution and the identity link function (SAS Institute Inc., 2001).

RESULTS

Growth Performance

The effects of LGEO supplementation on growth performance of growing quails during the experimental periods are displayed in Table 2. The birds fed diets containing LGEO had a significantly higher BW at 3 wk of age and BWG from 1 to 3 wk (linear, $P < 0.05$) compared with that in the control group. All levels of LGEO (except 600 mg/ kg diet) increased BW at 5 wk of age (quadratic, $P < 0.05$) and BWG from 3 to 5 (linear and quadratic, $P < 0.05$) and 1 to 5 wk (quadratic, $P < 0.05$) compared with that in the control group. FI during the period from 1 to 3 wk was lowered (linear and quadratic, $P < 0.001$) in the quail fed 150 and 300 mg LGEO/kg diet compared with that in the control group. During the period from 3 to 5 wk of age, FI was significantly decreased in the birds received LGEO (600 mg/kg diet) diets compared with that of the control. However, there were no statistical differences in FI between the treatments during the period from 1 to 5 wk of age. Feed conversion ratio was improved with addition of LGEO in quail diet during the periods (from 1 to 3 wk and from 1 to 5 wk). During the period of 3 to 5 wk of age, the quails fed LGEO (300 and 450 mg/kg diet) had better FCR than the control and other treatments.

Carcass Traits

The results in Table 3 demonstrated no significant effects (linear and quadratic, $P > 0.05$) of dietary LGEO on the percentages of the carcass, heart, gizzard, liver, giblets, and dressing for the preslaughter weight.

Liver and Kidney Function

Liver and kidney function results are summarized in Table 4. The globulin, alanine aminotransferase and urea values were not affected ($P > 0.05$) by dietary

Table 2. Growth performance of growing Japanese quail as affected by dietary lemongrass essential oil (LGEO).

	LGEO (mg/kg diet)						*P* value[2]	
Items	0	150	300	450	600	SEM[1]	Linear	Quadratic
Body weight (g)								
1 wk	30.02	29.84	30.06	30.04	30.03	0.100	0.5078	0.7870
3 wk	97.17	104.56	106.56	103.03	109.01	1.454	0.0009	0.1674
5 wk	185.05	199.70	202.63	200.67	188.38	1.416	0.1318	<0.0001
Body weight gain (g / day)								
1−3 wk	4.80	5.34	5.46	5.21	5.64	0.106	0.0011	0.1747
3−5 wk	6.28	6.80	6.86	6.97	5.67	0.085	0.0048	<0.0001
1−5 wk	5.54	6.07	6.16	6.09	5.66	0.051	0.1511	<0.0001
Feed intake (g / day)								
1−3 wk	15.07	13.59	12.43	14.42	15.15	0.233	0.2526	<.0001
3−5 wk	20.56	21.48	20.34	19.98	18.79	0.421	0.0041	0.0573
1−5 wk	17.81	17.54	16.38	17.20	16.97	0.294	0.0594	0.0949
Feed conversion ratio (g feed/ g gain)								
1−3 wk	3.14	2.55	2.28	2.77	2.69	0.063	0.0092	<0.0001
3−5 wk	3.27	3.16	2.97	2.87	3.32	0.047	0.2426	0.0001
1−5 wk	3.21	2.89	2.66	2.82	3.00	0.043	0.0059	<0.0001

[1]Standard error means.
[2]Linear and quadratic effects.

Table 3. Carcass traits and relative organs of growing Japanese quail as affected by dietary lemongrass essential oil (LGEO).

	LGEO (mg/kg diet)						P value[2]	
Items	0	150	300	450	600	SEM[1]	Linear	Quadratic
Carcass %	71.21	73.69	74.81	68.51	74.33	2.362	0.9044	0.9427
Liver %	2.61	2.51	3.5	3.08	2.31	0.287	0.9750	0.0484
Gizzard %	2.88	2.13	3.27	2.35	2.76	0.212	0.9888	0.7670
Heart %	1.02	0.93	1.03	0.84	0.99	0.052	0.4678	0.4357
Giblets %	6.50	5.58	7.80	6.28	6.06	0.386	0.8970	0.1855
Dressing %	77.71	79.27	82.6	74.79	80.38	2.414	0.9215	0.7657

[1]Standard error means.
[2]Linear and quadratic effects.

Table 4. Liver and kidney function of growing Japanese quail as affected by dietary lemongrass essential oil (LGEO).

	LGEO (mg/kg diet)						P value[3]	
Items[1]	0	150	300	450	600	SEM[2]	Linear	Quadratic
Total protein (g/dL)	2.75	2.95	3.16	3.05	2.74	0.099	0.8160	0.0060
Albumin (g/dL)	1.58	2.04	1.71	1.70	1.51	0.087	0.1478	0.0272
Globulin (g/dL)	1.17	0.91	1.45	1.35	1.23	0.070	0.1509	0.0591
AST (IU/L)	211	193	181	163	169	11.33	0.0193	0.3971
ALT (IU/L)	11.35	12.10	9.19	10.44	11.22	0.535	0.3142	0.0787
LDH (IU/L)	232	222	188	179	166	7.11	0.0002	0.5824
Creatinine (mg/dL)	0.34	0.35	0.36	0.35	0.30	0.010	0.0327	0.0073
Urea (mg/dL)	7.82	7.67	7.87	6.88	7.48	0.197	0.0690	0.7235

[1]Abbreviations: A/G, albumin/ globulin ratio; AST, aspartate aminotransferase; ALT, alanine aminotransferase; LDH, lactate dehydrogenase.
[2]Standard error means.
[3]Linear and quadratic effects.

LGEO levels. The total protein and albumin values were highest (quadratic, $P < 0.05$) in the LGEO levels of 150, 300 and 450 mg/kg compared with that in the control group. The quails fed diets containing LGEO levels had lower aspartate aminotransferase (linear, $P < 0.05$) than those in the control group. Dietary LGEO levels (300, 450, and 600 mg/kg) reduced lactate dehydrogenase values compared with the control group. The highest creatinine value was observed in quails fed 600 mg LGEO/kg diet (linear and quadratic, $P < 0.05$).

Lipid Profile

Data presented in Table 5 show the impact of different LGEO levels on plasma lipid profile. Total cholesterol, triglyceride, LDL and VLDL were significantly lowered (linear and quadratic, $P < 0.05$) in LGEO-treated quails compared to those in the control. The dietary supplementation of LGEO (300, 450, and 600 mg/kg) increased high density lipoprotein (linear, $P < 0.05$) compared with the control group.

Antioxidant and Immunological Indices

As shown in Table 6, dietary supplementation of LGEO increased (linear and quadratic, $P < 0.05$) plasma immunoglobulins (IgM, IgG and IgA) levels and lysozyme values compared with the control group. The activities of superoxide dismutase, total antioxidant capacity, GSH, and catalase were significantly augmented (linear and quadratic, $P < 0.05$) by the dietary supplementation of LGEO levels compared with those in the control. However, the inclusion of the different levels LGEO in quail diets decreased MDA levels (linear and quadratic, $P < 0.0001$) compared with the control group.

Digestive Enzymes

The effects of LGEO inclusion in diets on digestive enzymes (protease, amylase and lipase) of growing quails are presented in Table 7. The intestinal digestive enzyme activities were significantly higher in birds fed

Table 5. Lipid profile of growing Japanese quail as affected by dietary lemongrass essential oil (LGEO).

	LGEO (mg/kg diet)						P value[3]	
Items[1]	0	150	300	450	600	SEM[2]	Linear	Quadratic
TC (mg/dL)	217.33	190.95	193.14	182.50	192.83	2.793	0.0002	0.0004
TG (mg/dL)	242.23	138.85	158.85	169.50	166.85	8.836	0.0066	0.0010
HDL (mg/dL)	53.52	55.50	60.60	56.36	62.30	1.648	0.0088	0.8377
LDL (mg/dL)	115.37	107.68	100.77	92.24	97.16	1.956	<0.0001	0.0168
VLDL (mg/dL)	48.45	27.77	31.77	33.90	33.37	1.767	0.0066	0.0010

[1]Abbreviations: HDL, high density lipoprotein; LDL, low density lipoprotein; TC, total cholesterol; TG, triglycerides; VLDL, very low density lipoprotein.
[2]Standard error means.
[3]Linear and quadratic effects.

Table 6. Antioxidant and immunological indices of growing Japanese quail as affected by dietary lemongrass essential oil (LGEO).

Items[1]	LGEO (mg/kg diet)					SEM[2]	P value[3]	
	0	150	300	450	600		Linear	Quadratic
IgM (mg/dL)	0.42	0.63	0.86	0.88	0.61	0.072	0.0340	0.0033
IgG (mg/dL)	0.68	1.09	1.31	1.36	1.05	0.051	0.0003	<0.0001
IgA (mg/dL)	0.48	0.72	0.91	0.93	0.67	0.033	0.0016	<0.0001
Lysozyme (U/mL)	0.08	0.23	0.28	0.23	0.13	0.009	0.0111	<0.0001
SOD (U/mL)	0.09	0.23	0.29	0.24	0.24	0.013	<0.0001	<0.0001
MDA (nmol/mL)	0.42	0.23	0.17	0.20	0.23	0.009	<0.0001	<0.0001
TAC (ng/mL)	0.07	0.21	0.28	0.20	0.12	0.021	0.3655	0.0002
CAT (ng/mL)	0.08	0.23	0.29	0.22	0.18	0.011	0.0006	<0.0001
GSH (ng/mL)	0.09	0.19	0.31	0.24	0.19	0.015	0.0009	<0.0001

[1]Abbreviations: CAT, catalase; y; GSH, reduced glutathione; IgM, IgG and IgA, immunoglobulin M, G, and A; MDA, malondialdehyde; SOD, superoxide dismutase; TAC, total antioxidant capacit.
[2]Standard error means.
[3]Linear and quadratic effects.

Table 7. Digestive enzymes of growing Japanese quail as affected by dietary lemongrass essential oil (LGEO).

Items	LGEO (mg/kg diet)					SEM[1]	P value[2]	
	0	150	300	450	600		Linear	Quadratic
Protease (U/l)	0.19	0.84	1.24	1.38	0.78	0.109	0.0019	0.0002
Amylase (U/l)	7.54	23.33	24.50	17.50	12.82	1.471	0.3501	<0.0001
Lipase (U/l)	4.89	8.50	13.25	10.50	10.03	1.134	0.0108	0.0072

[1]Standard error means.
[2]Linear and quadratic effects.

Table 8. Bacteriology of growing Japanese quail as affected by dietary lemongrass essential oil (LGEO).

Items	LGEO (mg/kg diet)					SEM[1]	P value[2]	
	0	150	300	450	600		Linear	Quadratic
Microbiological count (Log CFU/g)								
Total bacterial count	9.10	8.87	9.19	9.18	8.56	0.015	<0.0001	<0.0001
Lactobacillus	7.45	7.52	8.19	8.23	7.55	0.032	<0.0001	<0.0001
Coliform	5.61	4.18	3.76	3.38	4.03	0.048	<0.0001	<0.0001
E. coli	4.57	3.11	2.64	2.54	3.21	0.048	<0.0001	<0.0001
Salmonella	2.72	2.25	1.56	2.20	2.10	0.059	0.0001	<0.0001

[1]Standard error means.
[2]Linear and quadratic effects.

diet supplemented with LGEO levels than those fed the control diet.

Microbiological Analysis

The results of the caecal microbiota of growing Japanese quail as affected by dietary treatments are shown in Table 8. The dietary supplementation of LGEO levels (300 and 450 mg/kg) increased total bacterial count and *Lactobacillus* count (linear and quadratic, $P < 0.0001$) compared with the control group. However, the groups fed a diet supplemented with LGEO exhibited lower *Coliform, E. coli, Salmonella* colonization (linear and quadratic, $P < 0.0001$) than those in the control group.

DISCUSSION

The growth and feed utilization of growing quails were improved by supplementation of LGEO. Similar to our results, Mukhtar et al. (2012) clarified that the addition of LGEO in the broiler chicks' diet significantly improved performance indices (BWG, FI, and FCR) compared to the control group. Khattak et al. (2014) stated that the inclusion of lemongrass in the diet enhanced BWG with positive effects on FCR of broiler chicks. Tiwari et al. (2018) detected that BWG was higher in the LGEO-received birds compared to the control group without LGEO. This improvement may be attributed to the active compounds, antioxidant and antimicrobial activities of the LGEO. Additionally, this positive effect of LGEO on performance may due to that this oil lead to the better digestion of nutrients.

The current results showed no significant changes in carcass traits, which agreed with that described by Mukhtar et al. (2012) who observed no significant differences regarding percentages of carcass, dressing and giblets in response to the dietary LGEO. However, LGEO levels had no detrimental effect on carcass traits of growing quails at 5 wk of age.

The blood biochemistry of poultry suggests their physiological disposition in the nutritional plane. The improvement of biochemical parameters indicates a better physiological status of the birds. In the current study, dietary supplementation of LGEO boosted the total protein, albumin and reduced liver enzyme activities. The results were consistent with previous investigations, Alzawqari et al. (2016) illustrated that serum total protein and globulin were significantly increased with the addition of lemongrass leaves in the diet compared to the control group. The dietary inclusion of lemongrass in broiler diet lowered liver enzyme activities (Gibson et al., 2017). The low levels of liver enzymes in birds administered with the LGEO might be owing to it could repair hepatic injury or restore the cellular permeability that can be caused by cytotoxic and mutagenic compounds. Therefore, this was consistent with the results of Tiwari et al. (2010) and Bidinotto et al. (2011) who indicated that lemongrass has a cytoprotective influence due to its phenolic components.

The presence of antihypertensive components such as alkaloids and flavonoids present in lemongrass has decreased serum cholesterol, thereby preventing cardiovascular disease (Gibson et al., 2017). Mukhtar et al. (2012) stated that supplementation of various levels of LGEO in the broiler diets significantly reduced serum cholesterol compared to the control group. Olorunnisola et al. (2014) indicated that lemongrass extracts were successful with declining levels of the cholesterol in the blood stream. Alzawqari et al. (2016) illustrated that serum triglyceride, LDL and VLDL were significantly decreased in the birds fed diets containing lemongrass leaves compared to the control group. The hypocholesterolemic impact of LGEO is due to the inhibition of 3-hydroxy-3-methylglutaryl-coenzyme A (HMG-CoA) reductase activity (Krishan and Narang, 2014) that acts as a basic regulatory enzyme in the cholesterol synthesis process (Crowell, 1999).

Natural antioxidants are widely distributed in medicinal plants, possessing various biological activities (Abd El-Hack et al., 2020b). Bioactive plant constituents have been related to favorable therapeutic effects and boosting the health and physiological status (Elwan et al., 2019; Alagawany et al., 2020a,b,c; Ismail et al., 2021). Plant oils are very good sources of natural antioxidants. The oils of lemongrass have antioxidant activity due to its content of flavonoids and phenol (Nambiar and Matela, 2012). Daader et al. (2018) clarified that dietary LGEO supplementation enhanced antioxidant indices (reduced GSH content and catalase activity) of growing rabbits. Also, MDA level was declined in response to LGEO (Al-Sagheer et al., 2018). Extracts of lemongrass inhibited the oxidative stress, particularly lipid peroxidation by preventing free radical attacks on biomembranes (Ojo et al., 2006).

The dietary LGEO supplementation improved the immune responses and disease resistance (Al-Sagheer et al., 2018). It is suggested that LGEO modulatory impact on indigenous intestinal flora could play a beneficial role in the development of the gut immune system (Harikrishnan et al., 2011). Citral is the main component of LGEO and has been known for its immunomodulatory and antiinflammatory properties (Bachiega and Sforcin, 2011). Al-Sagheer et al. (2018) indicated that LGEO provoked a significant increment in immunoglobulins level. These increases in serum immunoglobulins level may be owing to higher levels of B-cell proliferation (Zeng et al., 2015). The increased lysozyme activity was reported after supplementation of essential oils in the feed (Zheng et al., 2009).

In poultry, the production and growth depend upon the digestion and absorption of the feed accomplished by the intestinal health (Elnesr et al., 2019; 2020). Increased activity of intestinal digestive enzymes in quail fed LGEO may be an indicator for improving nutrient digestibility and increasing the productive performance. The medicinal plants produced a pronounced stimulation of a majority of digestive enzymes in the small intestine and pancreas (Platel and Srinivasan, 2001). To our knowledge, the enhancement mechanisms of LGEO on the activities digestive enzymes are not yet clearly identified and needs further studies.

The antimicrobial properties of essential oils arise mainly from aldehydes, terpenes and phenols that are able to disturb the function and integrity of bacterial cell membranes (Di Pasqua et al., 2007; Abd El-Hack et al., 2016; Mohamed et al., 2019). Lemongrass is an important plant because of its rich composition of phytochemicals phenols, tannins, and flavonoids (Olorunnisola et al., 2014). Also, one of the main compounds of LGEO is citral, a component found to act as an antimicrobial (a substance that suppresses or destroys the microorganisms (bacteria and fungi) growth. Also, LGEO contains limonene, a component shown to decrease inflammation (De souza et al., 2019). LGEO contains pinene that has displayed a wide spectrum of antimicrobial activities (Leite et al., 2007).

Finally, there are potential ways for the action of LGEO in improving the growth performance and physiological status: the first is an enhancing of the antioxidant system due to phytochemicals constituents, the second is a reduction of harmful microbiota, and the third may be due to enhancing the immunity and increasing feed utilization.

CONCLUSION

In conclusion, this study suggests for the utilization of a new feed additive from natural plants in the form of LGEO in poultry production. Results of the study showed that dietary supplementation of LGEO can improve the performance, lipid profile, immunity and antioxidant indices and decline intestinal pathogens and thus boost the health status of growing quail.

DISCLOSURES

The authors declare that they have no conflict of interest.

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