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Original study

Effects of dietary thyme and rosemary essential oils on performance parameters with lipid oxidation, water activity, pH, colour and microbial quality of breast and drumstick meats in broiler chickens

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Abstract. This study was aimed at determining the effects of different doses of thyme essential oil (TEO) and rosemary essential oil (REO) incorporated into broiler rations on performance parameters, including body weight gain, feed intake and feed conversion rate, as well as on the quality criteria of breast and drumstick meat. The study material comprised of 400 three-day-old male Ross 308 chicks, which were assigned to five groups, each of 80 broilers. Each group was divided into four sub-groups of 20 animals. In this study, the feed rations provided to the control group and groups TEO-150, TEO-300, REO-100 and REO-200 were supplemented with 0, 150 $mg\,kg^{-1}$ TEO, 300 $mg\,kg^{-1}$ TEO, 100 $mg\,kg^{-1}$ REO and 200 $mg\,kg^{-1}$ REO, respectively. Fattening performance parameters were statistically similar in the control group and all trial groups ($P > 0.05$). It was determined that, while dietary supplementation with TEO and REO significantly reduced total mesophilic aerobic bacteria (TMAB) counts throughout storage in drumstick meat and on days 0 and 8 of storage in breast meat ($P < 0.01$), it showed variable effects on other microbial counts and during other time points in both breast meat and drumstick meat. Dietary supplementation with TEO and REO was ascertained not to affect the pH value of breast and drumstick meat and to show limited and variable effects on colour parameters and water activity throughout the storage period of breast and drumstick meat. In all groups supplemented with TEO and REO, the thiobarbituric acid reactive substance (TBARS) levels of drumstick meat were observed to have significantly decreased on days 0, 2 and 4 of storage ($P < 0.01$). As a result, dietary supplementation with TEO and REO was determined to have a limited effect on performance parameters, but to improve the microbial quality of meat.

1 Introduction

In parallel with the increased importance of ecological agriculture, today, the use of natural substances has gained prominence in the livestock sector. The plant essential oils and extracts prevent the invasion of the digestive tract by pathogenic microorganisms, increase the effects of digestive enzymes, strengthen immunity, and improve both the feed conversion rate and palatability of feed (Demir et al., 2005; Gumus et al., 2017a). In view of these effects, feed supplements of plant origin have gained popularity in livestock and poultry production for their growth promoting, production increasing, immunity boosting and health protective effects (Zhang et al., 2021). Two important plant supplements, which have found use in poultry production for their growth promoting and antioxidant effects, are thyme (*Thymus vulgaris* L.) and rosemary (*Rosmarinus officinalis*), both of which are environmentally friendly plants that belong to the family Lamiaceae (Soncu et al., 2020; Zhang et al., 2021).

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The main pharmacological effects of thyme (*Thymus vulgaris* L.) are attributed to thymol and carvacrol, which are the most important bioactive compounds found in the structure of this plant (Grigore et al., 2010). The active substances found in thyme improve the digestive activity of several enzymes, such as protease, amylase and lipase, and thereby increase the feed conversion rate (Abdel-Wareth et al., 2012). Previous studies have pointed out to various biological and protective effects of thyme, including among others, antioxidant, antibacterial, anti-inflammatory, immunostimulatory and health protective activity (Gumus et al., 2017a; Zhang et al., 2021). While some reports have indicated dietary thyme supplementation to improve the performance parameters of poultry (El-Ghousein and Al-Beitawi, 2009; Toghyani et al., 2010), it has also been suggested that dietary thyme has no such effect (Saleh et al., 2014). It has also been reported that thyme essential oil improves meat quality (Bahrami et al., 2021).

Owing to its strong antioxidant activity, rosemary (*Rosmarinus officinalis*) is commonly used for both food aromatization and medicinal purposes (Demir et al., 2005; Soncu et al., 2020). Demir et al. (2005) reported that natural plant supplements, including thyme and rosemary, significantly increase the performance of broiler chickens and, thus, suggested that consumers could benefit from the antioxidant effect of these poultry products. It has also been indicated that the phenolic substances found in thyme and rosemary show a protective effect against oxidative stress by means of free radical scavenging activity (Gumus et al., 2017a; Zhang et al., 2021).

This study was aimed at determining the effects of different doses of thyme and rosemary essential oils incorporated into broiler rations on fattening performance parameters (body weight gain, feed intake and feed conversion rate) as well as on the quality criteria of breast and drumstick meat.

2 Materials and methods

2.1 Animals, experimental design and diet

A total of 400 three-day-old male Ross 308 broilers were divided into five treatments with four replicates of 20 birds each. The feeding period was divided in starter diets, fed from 3 to 21 d of age, and finisher diets, fed from 22 to 42 d of age (Table 1). The experimental diets were based on a standard commercial feed used as a control group which was supplemented with 150 mg kg^{-1} thyme essential oil (TEO-150 group), 300 mg kg^{-1} thyme essential oil (TEO-300 group), 100 mg kg^{-1} rosemary essential oil (REO-100 group) and 200 mg kg^{-1} rosemary essential oil (REO-200 group). The animals were housed in 20 floor pens measuring 180 × 180 × 85 cm. Feed and water were supplied ad libitum. The ambient temperature was gradually decreased from 33 °C in the first week to 22 °C on day 14 and was then kept constant afterwards. The lighting program applied was a continuous 23 h light. Diets were formulated and considered as control according to the recommendation of NRC (1994) (Table 1). The nutritional composition of the diets was determined according to the AOAC (2005).

Table 1. Ingredients and nutrient composition of broiler starter and grower diets in the study (g kg^{-1}).

Ingredients (g kg^{-1})	Starter (3 to 21 d)	Grower (22 to 42 d)
Maize	538.9	603
Soybean meal	361.9	318.6
Fish meal	30	30
Vegetable oil	37.3	24.4
Antioxidant	0.125	0.125
DL-Methionine	1.775	0.375
Limestone[a]	13	13
Dicalcium phosphate	11.5	6.5
Choline chloride	2.5	2
Antioxidant	0.125	0.125
Salt	2	1
Vit–Min. Premix[b]	1	1
Nutrient content		
Crude protein (g kg^{-1})	220	198.2
Crude fat (g kg^{-1})	63.1	52.2
Crude fibre (g kg^{-1})	38	36.5
Calcium (g kg^{-1})	10.2	9
Phosphorous (g kg^{-1})	4.5	3.5
Metabolic energy (MJ kg^{-1})	12.06	13.23

[a] Thyme and rosemary essential oils have replaced limestone in the same amount in the groups which TEO and REO have been included. [b] Supplied per kg of diet: vitamin A: 10 000 IU; vitamin D3: 3500 IU; vitamin E: 60 mg; vitamin K3: 3 mg; vitamin B12: 0.1 mg; thiamine: 3 mg; riboflavin: 6 mg; niacin: 40 mg; pyridoxine: 5 mg; pantothenic acid: 11 mg; folic acid: 1 mg; biotin: 0.15 mg; choline chloride: 500 mg; ethoxyquin: 150 mg; Fe: 60 mg; Zn: 60 mg; Mn: 100 mg; Cu: 10 mg; I: 1.6 mg and Se: 0.15 mg.

2.2 Herbal additives

Thyme essential oil (%) was fortified with thymol 82.05, carvacrol 5.48, para-cymen 4.78, β-bisabolene 2.98, trans-caryophyliene 2.54, α-pinene 1.02, α-terpinen 0.85 and beta-myrcene 0.3 (Talya Herbal Products Co. Ltd., Antalya, Türkiye).

Rosemary essential oil (%) was fortified with limonene 58.75, terpinoinene 9.53, para-cymen 3.9, cineol 3.78, eucalyptol 2.94, geraniol 2.22, citral 2.08, α-pinene 1.96, isopropyl myristate 1.68, gamma-terpinen 1.54, beta-myrcene 0.96, menthonomethene 0.64, linalool 0.44, geranyl nitrile 0.39, camphene 0.36, α-terpineol 0.34, dihydromycenol 0.33, menthnone 0.3, nerli nitrile 0.29, α-phellandrene 0.27, para-cymen-8-ol 0.24, isoterpinolene 0.23, epoxyterpinolene 0.16, sabinene 0.13 and other 6.54 (Talya Herbal Products Co. Ltd., Antalya, Türkiye).

2.3 Fattening performance parameters

Body weight (BW), body weight gain (BWG) and feed intake (FI) were measured at 3, 10, 17, 24, 31 and 42 d of age. The animals were provided with feed between 08:00 and 17:00 LT each day. In order to determine the daily feed consumption of the animals, throughout the study period, weighed quantities of feed were provided in the morning and evening; the remainder collected the following day was weighed and subtracted from the amount of feed provided. The body weight of the animals was measured at the beginning of the trial (3 d of age), and on days 10, 17, 24, 31 and 42 in the morning, before they were given feed. Feed conversion ratio (FCR) was calculated as total FI (g) / total BWG (g). Mortality was recorded when it occurred.

2.4 Meat quality parameters

At the end of the experimental period (42 d), a total of 60 animals, including 12 animals from each group, were slaughtered. Prior to slaughter, the chickens were fasted for 10 h. The slaughtered animals were bled for 120 s. The feathers of the animals were plucked manually. The chicken drumsticks and breast meat were placed on polyethylene plates, covered with stretch film and stored at 4±1 °C for 10 d. Subsequently, the samples were analysed on days 0, 2, 4, 6, 8 and 10 for pH, water activity (aw), and colour (L* (lightness), a^* (redness), b^* (yellowness)) analyses and microbial counts (Enterobacteriaceae, total psychrotrophic aerobic bacteria (TPAB), total mesophilic aerobic bacteria (TMAB), *Staphylococcus* spp., *Lactobacillus* spp. and *Pseudomonas* spp.). Microbiological analyses of the samples preceded the other analyses.

Water activity values were measured using an AQUALAB 4TE (USA) device. Meat samples were placed in the container of the device for the reading of the aw values.

The pH values of the samples were measured as described by Gökalp et al. (2001). Accordingly, 10 g portions of the homogenized samples were weighed and each portion was added 100 mL of distilled water. Homogenization was performed for 1 min using an Ultra-Turrax (IKA Werk T 25, Germany) homogenizer, and the pH values were measured using a pH meter (WTW Inolab, Germany).

The colour intensities (L*, a^*, b^*) of the cross sectional areas of the drumstick and breast meat samples were determined using a Minolta colorimeter (CR-200, Minolta Co, Osaka, Japan). Colour measurements were performed directly on the surface of muscle tissue by removing the skin.

The microbiological analyses of the samples were performed in compliance with the method described by Baumgart et al. (1993). Accordingly, 25 g of the meat samples was homogenized in 225 mL of sterile Ringer's solution. Subsequently, the other solutions were prepared. Inoculations were made using the spread plate technique. The TMAB count was determined using Plate Count Agar (PCA, Merck). The petri dishes were incubated under aerobic conditions at 30 ± 1 °C for 72 ± 1 h. The TPAB count was also determined using the Plate Count Agar (PCA, Merck), and the petri dishes were incubated under aerobic conditions at 7 ± 1 °C for 10 d. For the determination of Enterobacteriaceae counts, 1 mL of the appropriate dilutions was inoculated into Violet Red Bile Dextrose Agar (VRBDA, Merck). The petri dishes were incubated at 30 °C under anaerobic conditions for 2 d. *Staphylococcus* spp. counts were determined using mannitol salt agar (MSA). The plates were incubated under aerobic conditions at 30 ± 1 °C for 48 ± 1 h. *Pseudomonas* spp. counts were determined using Pseudomonas Agar (Oxoid CM 0559) supplemented with CFC supplement (Oxoid SR 0103), and the plates were incubated under aerobic conditions at 25 ± 1 °C for 48±1 h. *Lactobacillus* spp. counts were determined using MRS Agar (De Man Rogosa and Sharpe) (Oxoid CM 1153), and the plates were incubated under anaerobic conditions at 37 ± 1 °C for 48 ± 1 h. Bacterial counts were expressed in log cfu g^{-1}.

For thiobarbituric acid reactive substance (TBARS) value analysis, taking 2 g of homogenized samples, 12 mL TCA solution (7.5 % TCA, 0.1 % EDTA, 0.1 % propyl gallate (dissolved in 3 mL ethanol)) was added, and after homogenization in Ultra-Turrax for 15–20 s, it was filtered through Whatman 1 paper filter; 3 mL of the filtrate was taken and transferred to the test tube, and 3 mL of TBA (0.02 M) solution was added and made homogeneous. The test tubes were kept in a water bath at 100 °C for 40 min and then cooled in cold water for 5 min. After centrifugation (5 min at 2000 g) absorbance values were read at 530 nm in a spectrophotometer (Aquamate, Thermo Electron Corporation, England). Results are given in µmol malonaldehyde kg^{-1} (Lemon, 1975).

$$\text{TBARS} = ((\text{absorbance}/k(0.06) \times 2/1000) \times 6.8) \times 1000/\text{sample weight}$$

2.5 Statistical analyses

All statistical analyses were performed using the SPSS 20.00 software (SPSS, 2011). For performance parameters differences between the groups were determined with the one-way analysis of variance (ANOVA) test and Duncan's post-test.

Water activity, pH, TBARS, colour parameters (L*, a^* and b^*) and microbial counts (log cfu g^{-1}) were analysed using general linear model:

$$Yijk = \mu + di + gj + dgij + eijk,$$

where $Yijk$ is the response variable, μ the population mean, di the storage time (0th, 2nd, 4th, 6th, 8th and 10th days) (water activity, pH, TBARS, L*, a^*, b^*, microorganism), gj the treatment group (control, TEO-150, TEO-300, REO-100, REO-200), $dgij$ the storage time × treatment group interaction and $eijk$ the experimental error. The data were expressed as mean ± standard error of mean (SEM). Differences were considered to be significant at $P < 0.05$ and $P < 0.01$.

3 Results

3.1 Fattening performance

Study data on performance parameters, including body weight, daily body weight gain, feed intake and feed conversion rate, are presented in Table 2. Accordingly, as shown in Table 2, body weight, daily body weight gain, daily feed intake and feed conversion rates were statistically similar in the control group and all trial groups that received dietary supplementation with TEO and REO ($P > 0.05$).

3.2 Meat quality

Breast meat TMAB counts were determined to have significantly decreased on days 0 and 8 of storage in groups TEO-150, TEO-300, REO-100 and REO-200, and on day 10 of storage in groups TEO-300 and REO-100 ($P < 0.01$), but they did not differ between the groups on the other days ($P > 0.05$) (Table 3). Enterobacteriaceae counts had significantly decreased on day 2 of storage in groups TEO-150, TEO-300 and REO-200 ($P < 0.01$), but they were statistically similar in all groups on the other days of storage ($p > 0.05$) (Table 3). *Micrococcus/Staphylococcus* counts had significantly increased on days 6 and 10 of storage in groups TEO-150 and REO-200 ($P < 0.05$) and were observed to have decreased on day 10 of storage in group REO-100 ($P < 0.01$) (Table 3). *Pseudomonas* spp. counts were determined to have increased on day 0 of storage in groups TEO-150, TEO-300, REO-100 and REO-200, on day 2 in groups TEO-150, TEO-300 and REO-200 ($P < 0.01$), and on day 4 in group TEO-150, but they were determined to have decreased on day 4 in group REO-100 ($P < 0.05$) and to have significantly increased on days 6 and 8 of storage in groups TEO-150, TEO-300 and REO-100 ($P < 0.05$) (Table 3). Furthermore, significantly decreased TPAB levels were detected on day 8 of storage in groups REO-100 and REO-200 and on day 10 in only group REO 2 ($P < 0.05$). *Lactobacillus* spp. counts were statistically similar in all groups throughout the storage period ($P > 0.05$) (Table 3).

Drumstick meat analyses demonstrated that, overall, TMAB counts had significantly decreased on days 0, 2, 4, 6, 8 and 10 of storage in all groups that received dietary TEO and REO, when compared to the control group ($P < 0.05$) (Table 4). Furthermore, drumstick meat Enterobacteriaceae counts were ascertained to have decreased on days 0 and 2 of storage in groups TEO-300 and REO-200 ($P < 0.05$) but showed no statistically significant difference between the groups on the other days of storage ($P > 0.05$) (Table 4). *Lactobacillus* spp. counts had decreased on day 0 of storage in group TEO-300 and on day 2 in groups TEO-150, TEO-300 and REO-200 ($P < 0.05$), but they had increased on day 8 in group TEO-150 and on day 10 in groups TEO-150 and REO-100 ($P < 0.05$) (Table 4). Increases were detected in *Micrococcus/Staphylococcus* counts on day 8 of storage in only group REO-100 and in *Pseudomonas* spp. counts on day 2 of storage in only group REO-200 ($P < 0.05$), whilst these counts were statistically similar in all groups on the other days of storage ($P > 0.05$) (Table 4). TPAB levels had decreased in groups TEO-300 and REO-100 and had increased in group REO-200 ($P < 0.01$) on day 4 of storage, and they were observed to have increased in groups TEO-150 and REO-200 on days 6 and 8 of storage ($P < 0.01$) and to have decreased in group REO-100 on days 8 and 10 and in groups TEO-300 and REO-200 on day 10 of storage ($P < 0.01$) (Table 4).

Breast meat analyses showed that, of the colour parameters, the L* value had significantly increased on day 6 of storage in group REO-200 and on day 10 of storage in groups TEO-150, REO-100 and REO-200 ($P < 0.05$). Differences between the groups on the other days of storage were only mathematical ($P > 0.05$) (Table 5). Another colour parameter, the a^* value, was determined to have significantly decreased on only day 10 of storage in group REO-200 ($P < 0.05$). The a^* value was statistically similar in all groups on the other days of storage, whilst the b^* values of the groups were statistically similar throughout the storage period ($P > 0.05$) (Table 5).

Of the drumstick meat colour parameters, the a^* value had significantly increased on day 2 of storage in group TEO-300, whilst the b* value had significantly increased on day 6 of storage in group REO-100 ($P < 0.05$). On the other days, no statistically significant difference was determined between the groups for the a^* and b^* values ($P > 0.05$) (Table 6). While the L* value and pH level were statistically similar in all groups throughout storage, the aw value had decreased on only day 6 of storage in groups REO-100 and REO-200 ($P < 0.05$), and it was similar in all groups on the other days of storage ($P > 0.05$) (Table 6).

Breast meat TBARS levels were statistically similar in all groups ($P > 0.05$), but they were observed to be mathematically low in particular on days 0, 2 and 4 of storage in the groups that received dietary TEO and REO (Table 5). On the other hand, drumstick meat TBARS levels were determined to have significantly decreased on days 0, 2 and 4 of storage in groups TEO-150, TEO-300, REO-100 and REO-200, in comparison to the control group ($P < 0.01$). While a mathematical decrease was observed on the other days of storage, no statistically significant difference existed between the groups ($P > 0.05$) (Table 6).

4 Discussion

The search for natural supplements as an alternative to synthetic growth promoters has accelerated research on medicinal and aromatic plants and their extracts. Essential oils are listed among natural, safe and non-residual alternative dietary supplements of plant origin. Essential oils are reported to have antioxidant, anti-inflammatory and antimicrobial ef-

Table 2. Effects of basal ration supplemented with thyme and rosemary essential oils on body weight, body weight gain, feed intake and feed conversion rate in broilers.

Parameters	Groups					P values
	Control	TEO-150	TEO-300	REO-100	REO-200	
Body weight (g)						
3 d age	77.61 ± 2.48	73.76 ± 0.61	74.11 ± 0.46	73.04 ± 1.15	74.34 ± 1.48	0.243
10 d age	254.54 ± 2.18	251.71 ± 0.45	253.79 ± 5.54	251.00 ± 4.42	262.00 ± 6.37	0.437
17 d age	342.75 ± 2.26	337.30 ± 4.15	331.47 ± 9.37	328.83 ± 7.05	335.45 ± 7.68	0.628
24 d age	585.43 ± 8.21	578.93 ± 3.46	549.41 ± 16.61	534.73 ± 15.08	571.88 ± 16.41	0.074
31 d age	1161.12 ± 11.49	1154.83 ± 21.08	1164.01 ± 15.14	1111.26 ± 8.92	1135.88 ± 37.17	0.406
42 d age	2557.41 ± 29.45	2520.21 ± 120.99	2552.63 ± 161.93	2517.16 ± 51.59	2327.58 ± 160.60	0.637
Body weight gain (g d^{-1})						
3–10 d	25.28 ± 0.57	25.42 ± 0.07	25.67 ± 0.75	25.42 ± 0.48	26.81 ± 0.77	0.373
11–17 d	47.27 ± 0.93	46.75 ± 0.49	42.23 ± 2.53	40.53 ± 1.99	44.27 ± 1.74	0.060
18–24 d	82.24 ± 1.67	82.27 ± 2.96	87.80 ± 3.08	82.36 ± 3.12	80.57 ± 3.72	0.514
25–31 d	59.86 ± 3.60	65.73 ± 3.05	54.88 ± 7.88	64.61 ± 2.32	66.63 ± 5.12	0.417
32–42 d	97.73 ± 4.81	90.53 ± 9.30	100.45 ± 18.96	95.36 ± 4.98	90.07 ± 8.32	0.952
3–42 d	70.85 ± 0.79	69.90 ± 3.46	70.81 ± 4.62	69.83 ± 1.46	64.38 ± 4.59	0.639
Feed intake (g d^{-1})						
3–10 d	35.23 ± 0.34	36.31 ± 0.33	35.40 ± 0.36	36.10 ± 0.47	35.32 ± 0.29	0.170
11–17 d	108.55 ± 1.41	111.37 ± 1.41	108.55 ± 1.41	108.55 ± 1.41	107.14 ± 0.00	0.252
18–24 d	128.29 ± 1.90	135.63 ± 4.75	133.99 ± 5.45	135.23 ± 2.11	153.86 ± 24.52	0.601
25–31 d	159.90 ± 7.05	162.50 ± 1.41	177.66 ± 6.68	185.43 ± 16.46	173.26 ± 12.73	0.408
32–42 d	171.76 ± 4.30	191.60 ± 13.30	190.40 ± 9.24	195.71 ± 7.69	214.07 ± 28.25	0.438
3–42 d	120.75 ± 0.98	127.48 ± 3.97	129.20 ± 3.43	132.20 ± 3.73	136.73 ± 9.75	0.324
Feed conversion rate (g g^{-1})						
3–10 d	1.40 ± 0.04	1.43 ± 0.08	1.38 ± 0.05	1.42 ± 0.04	1.32 ± 0.04	0.400
11–17 d	2.30 ± 0.05	2.39 ± 0.04	2.60 ± 0.15	2.70 ± 0.18	2.43 ± 0.09	0.148
18–24 d	1.56 ± 0.05	1.66 ± 0.11	1.53 ± 0.05	1.65 ± 0.08	1.95 ± 0.39	0.542
25–31 d	2.69 ± 0.19	2.49 ± 0.13	2.87 ± 0.18	2.66 ± 0.22	2.43 ± 0.04	0.411
32–42 d	1.75 ± 0.05	2.11 ± 0.31	1.89 ± 0.31	2.05 ± 0.09	2.37 ± 0.31	0.519
3–42 d	1.71 ± 0.02	1.85 ± 0.16	1.85 ± 0.15	1.90 ± 0.09	2.15 ± 0.20	0.285

All values are given as mean ± standard error of mean (SEM) ($n = 80$). $P > 0.05$: nonsignificant. Control: basal ration alone, TEO-150: basal ration + 150 mg kg^{-1} of TEO, TEO-300: basal ration + 300 mg kg^{-1} of TEO, REO-100: basal ration + 100 mg kg^{-1} of REO and REO-200: basal ration + 200 mg kg^{-1} of REO.

fects and to increase the activity of digestive enzymes and, thus, are suggested to be used as dietary supplements either alone or in combination, for the economical and safe production of animal products, the maintenance of animal health, and the increase of yields (Gumus et al., 2017a; Soltani et al., 2016).

The present study demonstrated that, overall, by the end of the study period, no statistically significant effect had occurred on the body weight, body weight gain, feed intake and feed conversion rate of broiler chickens that had received dietary TEO and REO supplementation. These results are in agreement with previous reports indicating no statistically significant difference to have occurred in the body weights and daily body weight gain of broiler chickens given 100 and 200 mg kg^{-1} of dietary TEO (Saleh et al., 2014) and 100 mg kg^{-1} of dietary REO (Abd El-Latif et al., 2013). Similar to the results of the present study, previous reports have also indicated no effect to have been achieved with dietary REO supplementation on body weight (Franciosini et al., 2016), daily body weight gain (Franciosini et al., 2016; Norouzi et al., 2015), feed intake (Franciosini et al., 2016; Norouzi et al., 2015; Rostami et al., 2015; Soltani et al., 2016) and feed conversion rate (Franciosini et al., 2016; Soltani et al., 2016) in broiler chickens. Likewise, the incorporation of thymol into broiler rations has also been reported not to have affected feed intake (Saadat Shad et al., 2016). On the other hand, there are also reports that differ from the present study and suggest that the supplementation of broiler rations with 250 mg kg^{-1} of thymol significantly increases body weight gain and the feed conver-

Table 3. Effects of dietary thyme and rosemary essential oils supplementation and storage time on TMAB, Enterobacteriaceae, *Lactobacillus* spp., *Micrococcus/Staphylococcus* spp., *Pseudomonas* spp. and TPAB counts in chicken breast meat (log cfu g^{-1}).

Days	Groups	TMAB	Enterobacteriaceae	*Lactobacillus* spp.	*Micrococcus/ Staphylococcus*	*Pseudomonas* spp.	TPAB
0	Control	4.12 ± 0.08^a	2.48 ± 0.48	3.61 ± 0.09	2.22 ± 0.18	2.26 ± 0.22^b	2.28 ± 0.21
	TEO-150	3.58 ± 0.02^b	2.10 ± 0.18	2.80 ± 0.10	2.42 ± 0.04	3.00 ± 0.00^a	2.79 ± 0.21
	TEO-300	3.42 ± 0.28^{bc}	2.39 ± 0.09	3.36 ± 0.32	2.41 ± 0.20	3.27 ± 0.27^a	2.61 ± 0.31
	REO-100	3.04 ± 0.04^c	2.56 ± 0.11	3.30 ± 0.29	2.44 ± 0.10	3.44 ± 0.16^a	2.76 ± 0.28
	REO-200	3.21 ± 0.00^{bc}	2.21 ± 0.17	3.50 ± 0.05	2.46 ± 0.02	3.58 ± 0.02^a	2.24 ± 0.24
	P values	0.013	0.697	0.179	0.703	0.015	0.462
2	Control	4.45 ± 0.15	3.16 ± 0.08^a	3.60 ± 0.14	2.57 ± 0.37	3.13 ± 0.10^d	2.92 ± 0.03^{ab}
	TEO-150	4.56 ± 0.20	2.39 ± 0.14^b	3.87 ± 0.03	3.54 ± 0.31	4.27 ± 0.13^a	2.98 ± 0.01^a
	TEO-300	4.05 ± 0.05	2.37 ± 0.11^b	3.82 ± 0.17	2.80 ± 0.08	4.06 ± 0.06^{ab}	3.52 ± 0.31^a
	REO-100	3.79 ± 0.12	3.15 ± 0.04^a	3.82 ± 0.09	2.66 ± 0.14	3.49 ± 0.03^{cd}	3.33 ± 0.18^a
	REO-200	4.53 ± 0.34	2.62 ± 0.17^b	3.65 ± 0.13	2.58 ± 0.17	3.63 ± 0.22^{bc}	2.32 ± 0.11^b
	P values	0.126	0.010	0.461	0.136	0.007	0.025
4	Control	5.49 ± 0.26	3.56 ± 0.33	4.24 ± 0.19	3.46 ± 0.29	3.89 ± 0.01^{bc}	3.89 ± 0.04
	TEO-150	5.66 ± 0.18	2.87 ± 0.09	4.40 ± 0.26	3.85 ± 0.00	4.80 ± 0.09^a	3.74 ± 0.06
	TEO-300	4.60 ± 0.10	3.36 ± 0.24	4.13 ± 0.05	3.46 ± 0.13	4.57 ± 0.24^{ab}	3.67 ± 0.29
	REO-100	4.59 ± 0.31	3.24 ± 0.18	4.26 ± 0.22	3.39 ± 0.13	3.68 ± 0.32^d	3.75 ± 0.07
	REO-200	5.24 ± 0.24	3.19 ± 0.17	4.42 ± 0.42	3.73 ± 0.04	4.10 ± 0.03^{bc}	3.46 ± 0.24
	P values	0.061	0.318	0.911	0.278	0.031	0.566
6	Control	6.34 ± 0.19	4.21 ± 0.07	4.55 ± 0.35	3.52 ± 0.05^c	3.73 ± 0.30^c	4.96 ± 0.01
	TEO-150	6.07 ± 0.01	3.68 ± 0.06	4.64 ± 0.34	4.44 ± 0.35^{ab}	4.92 ± 0.06^a	4.81 ± 0.08
	TEO-300	5.41 ± 0.41	3.59 ± 0.06	4.48 ± 0.04	3.65 ± 0.15^{bc}	4.75 ± 0.11^{ab}	4.72 ± 0.09
	REO-100	5.73 ± 0.12	3.71 ± 0.13	4.38 ± 0.23	3.70 ± 0.28^{bc}	4.58 ± 0.18^{ab}	4.41 ± 0.41
	REO-200	5.40 ± 0.34	3.87 ± 0.08	4.61 ± 0.12	4.56 ± 0.04^a	4.21 ± 0.13^{bc}	3.88 ± 0.06
	P values	0.170	0.253	0.939	0.049	0.026	0.056
8	Control	7.06 ± 0.05^a	4.68 ± 0.13	4.75 ± 0.11	4.61 ± 0.13	4.83 ± 0.05^{bc}	5.96 ± 0.01^a
	TEO-150	6.35 ± 0.35^b	4.26 ± 0.23	5.41 ± 0.24	4.62 ± 0.30	5.19 ± 0.00^{ab}	5.69 ± 0.06^{ab}
	TEO-300	5.58 ± 0.08^c	4.16 ± 0.10	5.35 ± 0.20	4.56 ± 0.01	5.18 ± 0.20^{ab}	5.68 ± 0.13^{ab}
	REO-100	5.85 ± 0.00^{bc}	4.65 ± 0.29	5.20 ± 0.12	4.26 ± 0.02	5.51 ± 0.04^a	5.35 ± 0.27^b
	REO-200	6.17 ± 0.09^{bc}	4.56 ± 0.33	5.01 ± 0.03	5.51 ± 0.34	4.75 ± 0.11^c	4.61 ± 0.04^c
	P values	0.010	0.466	0.135	0.055	0.021	0.006
10	Control	7.20 ± 0.00^a	4.78 ± 0.12	5.61 ± 0.15	5.17 ± 0.13^b	5.00 ± 0.20	6.52 ± 0.01^a
	TEO-150	7.46 ± 0.08^a	5.25 ± 0.05	5.41 ± 0.19	5.68 ± 0.07^a	5.61 ± 0.08	6.81 ± 0.02^a
	TEO-300	6.52 ± 0.02^b	5.13 ± 0.25	5.50 ± 0.12	4.92 ± 0.04^b	5.61 ± 0.39	6.57 ± 0.01^a
	REO-100	6.35 ± 0.01^b	5.2 ± 0.14	5.64 ± 0.23	4.37 ± 0.07^c	5.60 ± 0.39	6.50 ± 0.01^a
	REO-200	7.58 ± 0.28^a	5.35 ± 0.20	5.26 ± 0.01	5.91 ± 0.06^a	5.36 ± 0.09	5.66 ± 0.32^b
	P values	0.004	0.276	0.515	0.000	0.493	0.016

All values are given as mean ± SEM ($n = 12$). $^{a–d}$ Means in the same column with different superscripts differ ($P < 0.05$, $P < 0.01$). Control: basal ration alone, TEO-150: basal ration + 150 mg kg^{-1} of TEO, TEO-300: basal ration + 300 mg kg^{-1} of TEO, REO-100: basal ration + 100 mg kg^{-1} of REO and REO-200: basal ration + 200 mg kg^{-1} of REO. TMAB; total mesophilic aerobic bacteria, TPAB; total psychrotrophic aerobic bacteria.

sion rate (Saadat Shad et al., 2016); dietary supplementation with 1 % of REO significantly increases daily body weight gain and daily feed intake and improves the feed conversion rate (Al-Kassie, 2008). Furthermore, there are literature reports that suggest the supplementation of broiler rations with thyme to have significantly increased body weight and daily body weight gain (El-Ghousein and Al-Beitawi, 2009; Toghyani et al., 2010) and with 100 and 200 mg kg of REO to have significantly increased feed intake (Abd El-Latif et al., 2013). Moreover, apart from the above-mentioned literature reports, which suggest dietary thyme and rosemary supplements to either increase or not affect performance parameters, there are also other studies, which have reported statistically significant decreases resulting from the supple-

Table 4. Effects of dietary thyme and rosemary essential oils supplementation and storage time on TMAB, Enterobacteriaceae, *Lactobacillus* spp., *Micrococcus/Staphylococcus* spp., *Pseudomonas* spp. and TPAB counts in chicken drumstick meat (log cfu g^{-1}).

Days	Groups	TMAB	Enterobacteriaceae	*Lactobacillus* spp.	*Micrococcus/ Staphylococcus*	*Pseudomonas* spp.	TPAB
0	Control	4.08 ± 0.00^{a}	2.37 ± 0.23^{a}	3.56 ± 0.10^{a}	2.52 ± 0.09	3.01 ± 0.04	2.41 ± 0.08
	TEO-150	2.05 ± 0.05^{c}	2.68 ± 0.07^{a}	3.80 ± 0.08^{a}	2.26 ± 0.12	2.73 ± 0.27	2.42 ± 0.04
	TEO-300	3.15 ± 0.15^{b}	1.57 ± 0.14^{b}	2.58 ± 0.30^{b}	2.96 ± 0.02	2.95 ± 0.25	2.30 ± 0.00
	REO-100	3.15 ± 0.15^{b}	2.58 ± 0.22^{a}	3.35 ± 0.05^{a}	2.40 ± 0.17	2.79 ± 0.06	2.84 ± 0.06
	REO-200	3.18 ± 0.00^{b}	2.07 ± 0.23^{ab}	3.45 ± 0.09^{a}	2.69 ± 0.16	3.68 ± 0.02	2.72 ± 0.42
	P values	0.000	0.043	0.015	0.058	0.052	0.356
2	Control	4.78 ± 0.01^{a}	3.47 ± 0.04^{a}	4.52 ± 0.01^{a}	3.06 ± 0.01	3.33 ± 0.23^{bc}	2.95 ± 0.00^{abc}
	TEO-150	2.62 ± 0.31^{d}	3.04 ± 0.04^{ab}	4.06 ± 0.02^{b}	2.63 ± 0.21	3.17 ± 0.11^{bc}	2.61 ± 0.23^{bc}
	TEO-300	3.29 ± 0.04^{cd}	2.42 ± 0.10^{bc}	3.19 ± 0.15^{c}	3.55 ± 0.12	3.59 ± 0.11^{b}	2.54 ± 0.01^{c}
	REO-100	3.47 ± 0.40^{bc}	3.36 ± 0.00^{a}	4.28 ± 0.10^{ab}	3.27 ± 0.24	2.90 ± 0.10^{c}	3.12 ± 0.11^{ab}
	REO-200	4.14 ± 0.00^{ab}	2.17 ± 0.15^{c}	3.47 ± 0.19^{c}	3.50 ± 0.24	4.37 ± 0.11^{a}	3.47 ± 0.21^{a}
	P values	0.007	0.017	0.002	0.079	0.005	0.029
4	Control	5.32 ± 0.04^{a}	3.54 ± 0.24	5.38 ± 0.28	3.49 ± 0.11	3.52 ± 0.44	3.89 ± 0.01^{b}
	TEO-150	3.51 ± 0.28^{c}	3.40 ± 0.10	5.08 ± 0.18	3.43 ± 0.39	3.89 ± 0.01	3.80 ± 0.06^{b}
	TEO-300	4.35 ± 0.10^{b}	3.30 ± 0.13	4.05 ± 0.06	3.61 ± 0.06	4.40 ± 0.01	3.23 ± 0.03^{d}
	REO-100	4.59 ± 0.29^{b}	3.73 ± 0.13	4.54 ± 0.40	3.78 ± 0.21	3.23 ± 0.03	3.53 ± 0.03^{c}
	REO-200	4.15 ± 0.15^{bc}	3.41 ± 0.29	4.33 ± 0.15	4.20 ± 0.03	4.55 ± 0.43	4.23 ± 0.02^{a}
	P values	0.010	0.606	0.053	0.188	0.076	0.000
6	Control	6.18 ± 0.06^{a}	4.16 ± 0.00	5.48 ± 0.48	3.78 ± 0.18	4.13 ± 0.12	4.00 ± 0.00^{b}
	TEO-150	4.58 ± 0.12^{c}	3.82 ± 0.09	5.46 ± 0.10	4.20 ± 0.14	4.46 ± 0.48	4.90 ± 0.03^{a}
	TEO-300	5.25 ± 0.25^{b}	3.47 ± 0.42	4.75 ± 0.11	4.47 ± 0.15	4.72 ± 0.23	3.81 ± 0.13^{b}
	REO-100	4.58 ± 0.12^{c}	4.34 ± 0.34	4.95 ± 0.05	4.53 ± 0.41	4.46 ± 0.21	3.89 ± 0.08^{b}
	REO-200	5.38 ± 0.13^{b}	4.10 ± 0.05	4.73 ± 0.05	4.44 ± 0.15	5.20 ± 0.07	4.77 ± 0.08^{a}
	P values	0.003	0.246	0.152	0.263	0.196	0.000
8	Control	7.05 ± 0.01^{a}	4.47 ± 0.26	5.25 ± 0.24^{bc}	4.57 ± 0.02^{bc}	4.91 ± 0.00	5.06 ± 0.02^{b}
	TEO-150	5.21 ± 0.13^{c}	4.19 ± 0.01	6.00 ± 0.00^{a}	4.38 ± 0.19^{c}	4.69 ± 0.09	5.80 ± 0.04^{a}
	TEO-300	6.02 ± 0.02^{b}	4.50 ± 0.10	4.74 ± 0.90^{c}	4.73 ± 0.22^{bc}	4.94 ± 0.05	4.86 ± 0.01^{b}
	REO-100	5.32 ± 0.28^{c}	4.56 ± 0.36	5.69 ± 0.21^{ab}	5.57 ± 0.27^{a}	4.55 ± 0.39	4.50 ± 0.16^{c}
	REO-200	6.13 ± 0.17^{b}	4.29 ± 0.11	5.42 ± 0.12^{ab}	5.23 ± 0.02^{ab}	5.44 ± 0.36	5.73 ± 0.02^{a}
	P values	0.002	0.707	0.016	0.024	0.256	0.000
10	Control	7.37 ± 0.02^{a}	5.39 ± 0.39	5.85 ± 0.02^{b}	5.43 ± 0.26	4.94 ± 0.09	6.59 ± 0.01^{a}
	TEO-150	6.81 ± 0.10^{bc}	4.67 ± 0.03	6.42 ± 0.04^{a}	5.26 ± 0.19	5.15 ± 0.21	6.74 ± 0.03^{a}
	TEO-300	6.62 ± 0.01^{bc}	4.88 ± 0.02	5.25 ± 0.10^{c}	5.20 ± 0.07	5.22 ± 0.17	5.53 ± 0.05^{c}
	REO-100	6.33 ± 0.27^{c}	4.60 ± 0.30	6.21 ± 0.17^{a}	6.16 ± 0.23	5.35 ± 0.17	5.26 ± 0.18^{c}
	REO-200	6.98 ± 0.06^{ab}	4.64 ± 0.28	5.88 ± 0.02^{b}	5.38 ± 0.21	5.53 ± 0.17	6.15 ± 0.03^{b}
	P values	0.018	0.293	0.002	0.093	0.262	0.000

All values are given as mean ± SEM ($n = 12$). $^{a-d}$ Means in the same column with different superscripts differ ($P < 0.05$, $P < 0.01$). Control: basal ration alone, TEO-150: basal ration + 150 mg kg^{-1} of TEO, TEO-300: basal ration + 300 mg kg^{-1} of TEO, REO-100: basal ration + 100 mg kg^{-1} of REO and REO-200: basal ration + 200 mg kg^{-1} of REO. TMAB; total mesophilic aerobic bacteria, TPAB; total psychrotrophic aerobic bacteria.

mentation of broiler rations with 200 mg kg^{-1} of REO in body weight, daily body weight gain and the feed conversion rate (Abd El-Latif et al., 2013), with 0.5 % and 1 % of rosemary powder in body weight gain and the feed conversion rate (Rostami et al., 2015), with 3 g kg^{-1} of rosemary powder in body weight (Soltani et al., 2016), and with 1.5 % of rosemary powder in the feed conversion rate (Norouzi et al., 2015). Based on the results obtained, it is suggested that, despite the lack of any positive effect on performance parameters, dietary supplementation with TEO and REO could provide benefits as feed supplements through antimicrobial and digestive stimulant effects, particularly in the event of unfavourable environmental conditions and malnutrition. Furthermore, differences observed between the results of stud-

Table 5. Effects of dietary thyme and rosemary essential oils supplementation and storage period on colour parameters (L*, a^* and b^*), water activity, pH and TBARS in chicken breast meat.

Days	Groups	L*	a^*	b^*	pH	a_w	TBARS
0	Control	53.33 ± 1.13	4.86 ± 0.40[ab]	6.47 ± 0.61	5.82 ± 0.06	0.990 ± 0.001[a]	1.13 ± 0.09
	TEO-150	52.98 ± 0.85	5.55 ± 0.37[a]	7.68 ± 0.34	5.89 ± 0.03	0.987 ± 0.000[b]	0.88 ± 0.05
	TEO-300	53.77 ± 1.55	3.23 ± 0.63[b]	6.43 ± 0.86	5.97 ± 0.04	0.986 ± 0001[b]	0.92 ± 0.010
	REO-100	49.28 ± 1.57	5.24 ± 0.48[ab]	6.09 ± 0.75	5.95 ± 0.11	0.988 ± 0.001[ab]	0.99 ± 0.18
	REO-200	54.05 ± 2.16	6.70 ± 1.06[a]	8.75 ± 1.25	5.74 ± 0.06	0.990 ± 0.000[a]	1.20 ± 0.26
	P values	0.215	0.024	0.173	0.214	0.022	0.566
2	Control	50.24 ± 2.37	4.62 ± 1.14	6.45 ± 1.31	5.95 ± 0.22	0.990 ± 0.000	1.82 ± 0.16[ab]
	TEO-150	49.75 ± 1.48	6.26 ± 0.61	8.06 ± 0.60	5.72 ± 0.07	0.989 ± 0.001	1.49 ± 0.11[b]
	TEO-300	49.59 ± 0.58	5.52 ± 0.80	7.26 ± 0.71	5.93 ± 0.02	0.986 ± 0.002	1.71 ± 0.20[ab]
	REO-100	53.95 ± 2.48	4.61 ± 1.12	7.25 ± 1.07	5.75 ± 0.19	0.989 ± 0.001	2.12 ± 0.09[a]
	REO-200	52.72 ± 0.30	4.38 ± 0.37	7.29 ± 0.31	5.67 ± 0.08	0.989 ± 0.002	2.15 ± 0.19[a]
	P values	0.299	0.518	0.786	0.532	0.367	0.043
4	Control	51.46 ± 0.53	3.90 ± 0.66	6.84 ± 0.61	5.83 ± 0.02	0.990 ± 0.002	2.36 ± 0.21
	TEO-150	50.12 ± 0.29	3.75 ± 0.59	6.07 ± 0.47	5.90 ± 0.14	0.989 ± 0.002	1.62 ± 0.07
	TEO-300	52.62 ± 1.39	4.71 ± 0.63	6.81 ± 1.23	5.86 ± 0.11	0.989 ± 0.000	1.97 ± 0.08
	REO-100	48.75 ± 1.02	5.02 ± 0.99	6.97 ± 0.52	5.86 ± 0.04	0.987 ± 0.000	2.20 ± 0.11
	REO-200	51.86 ± 1.31	2.59 ± 0.24	6.08 ± 0.51	5.78 ± 0.03	0.988 ± 0.001	2.26 ± 0.36
	P values	0.102	0.141	0.826	0.780	0.440	0.120
6	Control	49.33 ± 2.24[b]	3.55 ± 0.63	7.20 ± 1.22	5.90 ± 0.26	0.990 ± 0.001[a]	2.65 ± 0.07[ab]
	TEO-150	50.56 ± 0.38[b]	3.00 ± 0.42	7.01 ± 0.95	5.78 ± 0.02	0.990 ± 0.000[a]	2.29 ± 0.09[b]
	TEO-300	48.36 ± 1.31[b]	5.29 ± 0.97	7.65 ± 0.96	5.86 ± 0.09	0.989 ± 0.000[a]	1.99 ± 0.28[b]
	REO-100	48.95 ± 1.37[b]	4.28 ± 1.16	9.31 ± 1.60	5.85 ± 0.08	0.984 ± 0.002[b]	2.21 ± 0.30[b]
	REO-200	55.00 ± 0.99[a]	3.97 ± 1.36	10.21 ± 1.34	5.81 ± 0.02	0.989 ± 0.001[a]	3.15 ± 0.30[a]
	P values	0.028	0.556	0.315	0.965	0.027	0.025
8	Control	52.15 ± 1.34[ab]	5.51 ± 0.28	5.91 ± 0.73	6.21 ± 0.14	0.989 ± 0.002	2.66 ± 0.30
	TEO-150	48.41 ± 0.85[b]	4.44 ± 1.40	7.72 ± 1.31	5.90 ± 0.15	0.986 ± 0.002	3.46 ± 0.36
	TEO-300	54.94 ± 2.06[a]	2.45 ± 0.57	9.08 ± 1.32	5.85 ± 0.05	0.985 ± 0.001	2.11 ± 0.11
	REO-100	50.37 ± 0.61[b]	4.93 ± 1.31	7.05 ± 0.93	5.93 ± 0.14	0.986 ± 0.001	2.63 ± 0.79
	REO-200	50.90 ± 1.00[b]	4.08 ± 0.48	8.19 ± 0.53	5.78 ± 0.04	0.990 ± 0.002	3.22 ± 1.12
	P values	0.030	0.240	0.286	0.214	0.252	0.617
10	Control	46.91 ± 1.51[b]	5.60 ± 0.76[a]	7.91 ± 0.51	6.03 ± 0.22	0.987 ± 0.000	2.76 ± 0.06
	TEO-150	51.68 ± 1.34[a]	4.68 ± 0.31[a]	5.51 ± 0.85	6.43 ± 0.23	0.987 ± 0.001	4.04 ± 1.01
	TEO-300	50.48 ± 1.49[ab]	4.69 ± 0.40[a]	6.85 ± 0.85	6.09 ± 0.01	0.984 ± 0.001	2.22 ± 0.31
	REO-100	51.58 ± 1.00[a]	4.90 ± 0.34[a]	6.53 ± 0.86	5.82 ± 0.08	0.989 ± 0.001	2.79 ± 0.34
	REO-200	54.17 ± 0.86[a]	2.97 ± 0.39[b]	9.05 ± 0.87	5.69 ± 0.01	0.992 ± 0.004	3.42 ± 0.73
	P values	0.016	0.017	0.061	0.089	0.149	0.282

All values are given as mean ± SEM ($n = 12$). [a,b] Means in the same column with different superscripts differ ($P < 0.05$, $P < 0.01$). Control: basal ration alone, TEO-150: basal ration + 150 mg kg^{-1} of TEO, TEO-300: basal ration + 300 mg kg^{-1} of TEO, REO-100: basal ration + 100 mg kg^{-1} of REO and REO-200: basal ration + 200 mg kg^{-1} of REO. L*: relative lightness, a^*: relative redness, b^*: relative yellowness, aw: water activity, TBARS: thiobarbituric acid-reactive substances.

ies are attributed to differences in the composition, usage and doses of thyme and rosemary supplements administered, and the animal breeds used.

One of the most important factors known to affect meat quality is the microbial load of meat. Some microorganisms impair the quality and shorten the shelf life of meat and pose a risk to human health (Mastromatteo et al., 2010). It is well known that the microbial load of meat increases directly proportional to the length of the storage period of this product (Chouliara et al., 2007; Gumus et al., 2018). Thus, antimicrobial substances found in the structure of meat are highly important for the storage of it without spoilage. The antimicrobial and antioxidant activities of both TEO and REO have been known for a long time, and recently, their use for meat products has gained increased popularity (Amariei et al., 2016; Gumus et al., 2017a; Soncu et al., 2020). Indeed, pre-

Table 6. Effects of dietary thyme and rosemary essential oils supplementation and storage period on colour parameters (L*, a^* and b^*), water activity (a_w), pH and TBARS in chicken drumstick meat.

Days	Groups	L*	a^*	b^*	pH	a_w	TBARS
0	Control	53.88 ± 2.64	6.28 ± 0.29	5.71 ± 0.65	5.88 ± 0.01	0.989 ± 0.001	1.91 ± 0.07[a]
	TEO-150	52.55 ± 2.05	6.47 ± 0.52	8.13 ± 0.30	5.92 ± 0.07	0.986 ± 0.000	1.17 ± 0.13[b]
	TEO-300	54.35 ± 1.54	5.85 ± 0.57	6.41 ± 0.52	6.05 ± 0.04	0.990 ± 0.001	0.69 ± 0.16[c]
	REO-100	54.11 ± 1.69	7.45 ± 0.72	5.48 ± 1.00	6.08 ± 0.07	0.990 ± 0.001	0.68 ± 0.17[c]
	REO-200	53.63 ± 1.74	6.98 ± 1.35	6.38 ± 0.89	5.94 ± 0.08	0.987 ± 0.001	0.50 ± 0.08[c]
	P values	0.971	0.641	0.132	0.177	0.068	0.000
2	Control	58.05 ± 1.86	5.37 ± 0.29[b]	5.72 ± 1.38	5.95 ± 0.17	0.993 ± 0.000	2.55 ± 0.43[a]
	TEO-150	52.01 ± 2.78	7.22 ± 1.49[ab]	4.58 ± 0.51	6.29 ± 0.03	0.992 ± 0.000	1.51 ± 0.20[b]
	TEO-300	56.04 ± 1.66	8.43 ± 1.11[a]	5.79 ± 0.90	6.01 ± 0.02	0.990 ± 0.002	1.63 ± 0.16[b]
	REO-100	55.40 ± 1.35	5.06 ± 0.54[b]	4.56 ± 0.86	5.97 ± 0.05	0.991 ± 0.002	1.71 ± 0.18[b]
	REO-200	51.58 ± 1.75	4.57 ± 0.18[b]	4.75 ± 0.30	6.10 ± 0.09	0.990 ± 0.001	1.18 ± 0.08[b]
	P values	0.143	0.035	0.732	0.171	0.456	0.014
4	Control	53.35 ± 1.77	4.87 ± 0.34	4.91 ± 0.94	6.59 ± 0.10	0.992 ± 0.001	2.74 ± 0.39[a]
	TEO-150	52.64 ± 0.51	6.13 ± 0.37	4.13 ± 0.94	6.26 ± 0.08	0.990 ± 0.000	1.54 ± 0.23[b]
	TEO-300	50.76 ± 1.72	4.83 ± 0.61	6.98 ± 0.82	6.17 ± 0.05	0.990 ± 0.002	1.78 ± 0.09[b]
	REO-100	52.69 ± 1.14	4.99 ± 0.26	6.65 ± 0.74	6.13 ± 0.05	0.991 ± 0.001	1.99 ± 0.06[b]
	REO-200	52.27 ± 1.57	5.70 ± 0.36	7.44 ± 0.42	5.87 ± 0.23	0.988 ± 0.001	1.61 ± 0.11[b]
	P values	0.764	0.136	0.056	0.061	0.234	0.009
6	Control	49.17 ± 1.01	5.14 ± 0.62	6.24 ± 0.20[b]	6.62 ± 0.22	0.994 ± 0.002[a]	2.84 ± 0.09
	TEO-150	50.50 ± 1.20	5.32 ± 0.15	6.47 ± 0.19[b]	6.27 ± 0.13	0.992 ± 0.001[ab]	2.37 ± 1.05
	TEO-300	49.62 ± 1.73	3.96 ± 0.41	6.81 ± 0.74[ab]	6.07 ± 0.07	0.992 ± 0.001[ab]	2.50 ± 0.21
	REO-100	49.02 ± 1.42	6.34 ± 0.59	8.49 ± 0.69[a]	6.17 ± 0.08	0.989 ± 0.002[bc]	2.20 ± 0.22
	REO-200	53.26 ± 1.47	5.48 ± 0.65	5.61 ± 0.70[b]	6.44 ± 0.05	0.988 ± 0.001[c]	2.18 ± 0.18
	P values	0.230	0.072	0.029	0.122	0.037	0.880
8	Control	57.92 ± 1.62	5.78 ± 0.82	7.16 ± 0.74	6.27 ± 0.01	0.991 ± 0.001	2.97 ± 0.23
	TEO-150	55.30 ± 3.57	4.52 ± 0.67	5.64 ± 1.07	6.27 ± 0.12	0.989 ± 0.000	2.65 ± 0.41
	TEO-300	50.81 ± 1.97	6.33 ± 0.27	6.23 ± 0.35	6.32 ± 0.10	0.984 ± 0.001	2.49 ± 0.32
	REO-100	52.06 ± 2.19	7.68 ± 1.40	5.16 ± 1.29	6.55 ± 0.11	0.989 ± 0.009	2.21 ± 0.23
	REO-200	50.82 ± 3.15	4.85 ± 0.51	4.77 ± 0.52	6.51 ± 0.15	0.990 ± 0.001	2.70 ± 0.35
	P values	0.268	0.103	0.360	0.301	0.790	0.558
10	Control	50.35 ± 1.84	5.73 ± 0.25	6.54 ± 0.79	6.65 ± 0.05	0.992 ± 0.000	3.27 ± 0.81
	TEO-150	52.07 ± 1.78	5.13 ± 0.21	5.59 ± 0.99	6.45 ± 0.11	0.989 ± 0.001	2.75 ± 0.20
	TEO-300	50.61 ± 1.21	5.99 ± 0.69	4.78 ± 0.89	6.46 ± 0.16	0.991 ± 0.001	4.00 ± 1.12
	REO-100	47.54 ± 0.70	5.19 ± 0.25	5.35 ± 0.67	6.44 ± 0.11	0.989 ± 0.001	2.75 ± 0.15
	REO-200	51.12 ± 0.61	4.13 ± 0.92	7.31 ± 0.55	6.32 ± 0.16	0.994 ± 0.003	4.31 ± 0.25
	P values	0.540	0.199	0.224	0.509	0.150	0.331

All values are given as mean ± SEM ($n = 12$). [a–c] Means in the same column with different superscripts differ ($P < 0.05$, $P < 0.01$). Control: basal ration alone, TEO-150: basal ration + 150 mg kg^{-1} of TEO, TEO-300: basal ration + 300 mg kg^{-1} of TEO, REO-100: basal ration + 100 mg kg^{-1} of REO and REO-200: basal ration + 200 mg kg^{-1} of REO. L*: relative lightness, a^*: relative redness, b^*: relative yellowness, a_w: water activity, TBARS: thiobarbituric acid-reactive substances.

vious research has demonstrated that essential oils extend the shelf life of meat through their bactericidal and bacteriostatic effects (Bahrami et al., 2021; Gumus et al., 2017b; Soncu et al., 2020). A previous study in quails demonstrated that dietary supplementation with 300 and 450 mg kg^{-1} of TEO decreased breast meat coliform, *Lactobacillus* spp., *Pseudomonas* spp. counts and TPAB levels (Gumus et al., 2017b). In a similar study conducted by Chouliara et al. (2007), it was determined that 0.1 % of oregano essential oil extended the shelf life of chicken meat stored at +4 °C from 5 to 8–9 d. Furthermore, Aksoy et al. (2011) reported that thyme extract showed an antibacterial effect against *Pseudomonas* spp. and TMAB in broiler meat. Another study demonstrated that dietary supplementation with 3.5 % and 7.5 % of thyme leaves produced an antibacterial effect against psychrotrophic and lactic acid bacteria in lamb meat (Nieto et al., 2010). In agreement with the literature reports referred to above, the present study demonstrated that dietary supplementation with TEO and REO tended to reduce the microbial load of breast meat and drumstick meat throughout the storage period.

Depending on the particular structure of a food product, its water content is involved in various biochemical and microbiological reactions. Water activity refers to the capability of muscle tissue to retain moisture and constitutes a major criterion influential on the palatability of meat (Zhou et al., 2010). It is indicated that while the maintenance of this criterion within the normal reference range depends on the integrity of the cell membrane of myocytes, the flow of intracellular fluid out of the cell impairs meat quality (Amariei et al., 2016). In the event of the disruption of the membrane integrity of myocytes, the hydroxyl group of the alcohols contained by phenolic compounds may constitute a strong barrier as they show less affinity to water (Amariei et al., 2016). Mehdipour et al. (2014) indicated that the supplementation of quail rations with 100 $mg\,kg^{-1}$ of thyme extract significantly increased the water activity of drumstick meat. Amariei et al. (2016) also reported that thyme and oregano essential oils increased the water activity of minced beef and pork stored at $+4\,°C$ for 5 d. Different from these results, it has been reported that the supplementation of quail rations with 150, 300 and 450 $mg\,kg^{-1}$ of thyme essential oil showed no effect on the water activity of breast meat (Gumus et al., 2017b). The present study demonstrated that dietary supplementation with TEO and REO produced a limited and variable effect on the water activity of drumstick and breast meat.

One of the critical traits used by the meat industry for the assessment of meat quality is the pH value of meat (Bianchi et al., 2005). In broiler chickens, breast meat is the first choice for the determination of meat pH level (Glamoclija et al., 2015). The pH level of meat is reported to range between 5.2–7.0 and to be affected by several factors, including among others, genetics, sex, pre-slaughter stress, slaughter technique, and storage (Ristc and Damme, 2010; Van Laack et al., 2000). The pH level of good-quality broiler meat has been reported to range from 5.9 to 6.2 (Ristc and Dame, 2010). According to some other literature reports, while the pH value of the highest quality of poultry breast meat falls within a range of 5.7–6.0, a pH value below 5.8 is associated with a paler meat colour and softer consistency (Glamoclija et al., 2015; Van Laack et al., 2000). In a previous study in quails, it was determined that dietary supplementation with 150, 300 and 450 $mg\,kg^{-1}$ of thyme essential oil had no effect on the pH value of breast meat (Gumus et al., 2017b) In the present study carried out in broiler chickens, dietary supplementation with thyme and rosemary essential oils was ascertained to have maintained the pH level of both breast and drumstick meat within the favourable range on days 0, 2, 4, 6, 8 and 10 of storage.

Another criterion influential on the physical quality of meat is meat colour and is known to be affected, either positively or negatively, by the myoglobin content and pH value of muscle tissue (Mir et al., 2017). Depending on the postmortem temperature and pH value, the extent of protein denaturation and physical appearance of meat affect the amount of light reflected from the inner and outer surface of meat (Lawrie and Ledward, 2014). While light scattering has a minimum effect on the a and b values of meat, its effect on the L^* value is distinctive. A muscle tissue pH value of ≥ 6.0 is associated with minimal protein denaturation, low light scattering and a semi-translucent appearance, whilst a pH value of ≤ 6.0 is associated with a higher level of protein denaturation, increased light scattering and opacity in muscle tissue (Anadon, 2002). The normal reference range for the L^* value is indicated as 50–56, such that a L^* value below 50 is associated with darker meat colour and a L^* value above 56 is associated with pale meat colour (Petracci et al., 2004). In the present study, dietary supplementation with TEO and REO was observed to have maintained the L^* value of both breast meat and drumstick meat within the normal range. In a previous study in quails, the incorporation of TEO in the ration at doses of 150, 300 and 450 $mg\,kg^{-1}$ was reported not to have affected the L^*, a^* and b^* values of breast meat (Gumus et al., 2017b). Similarly, in a previous study carried out in broiler chickens, 300 $mg\,kg^{-1}$ of dietary oregano essential oil (Kirkpinar et al., 2014) and 0.5 % of a dietary mixture of thyme and oregano essential oils were observed not to have affected the L^*, a^* and b^* values of breast meat (Rimini et al., 2014). On the other hand, Al-Hijazeen et al. (2016) determined that the addition of 100, 300 and 400 $mg\,kg^{-1}$ of oregano essential oil to raw broiler breast meat did not affect the a^* value on days 0, 3 and 7 of storage but improved the L^* value on only day 7. When added at doses of 300 and 400 $mg\,kg^{-1}$, oregano essential oil was determined to have improved the b^* value on days 0 and 7. In the present study, different doses of dietary TEO and REO were observed not to have shown any adverse effect on the colour parameters, namely the L^*, a^* and b^* values of breast and drumstick meat throughout the storage period.

Free radicals generated as a result of metabolic processes cause oxidative reactions. The primary products of oxidative reactions are peroxides, whilst hydrocarbons, aldehydes, ketones, alcohols and organic acids are the secondary products of these reactions. These secondary products adversely affect the nutritional value, sensorial properties and shelf life of animal products (Cai et al., 2014). Antioxidants play an important role in the scavenging of free radicals. It is well known that antioxidants significantly reduce lipid peroxidation, which is considered the main indicator of free radical presence, in muscle tissue (Gumus et al., 2017a). The maximum tolerable level of thiobarbituric acid reactive species (TBARS), which has no adverse effect on chicken meat quality, has been reported as 4 mg malondialdehyde equivalents (MDA eq) per kg. In another study, in which chicken meat was applied TEO, TBARS levels were determined to range between 0.19–0.25 $mg\,MDA\,kg^{-1}$ on day 1 of storage and to progressively increase until day 10 of storage but still remain below the maximum tolerable limit (Majdinasab et al., 2020). In another study, thyme and oregano essential oils were reported to reduce lipid oxidation in broiler breast meat (Rimini et al., 2014). Similarly, another study determined that the supplementation of broiler chicken rations with 120 ppm of rosemary essential oil and 500 ppm of thyme essential oil reduced lipid oxidation in meat (Abbasi et al., 2020). Likewise, the present study demonstrated that, excluding day 10 of storage, dietary supplementation with TEO and REO decreased TBARS levels in breast and drumstick meat throughout the storage period.

5 Conclusions

In conclusion, the incorporation of thyme and rosemary essential oils into broiler chicken rations was determined not to show any adverse effect on the performance parameters. Furthermore, dietary TEO and REO decreased TMAB, Enterobacteriaceae and *Lactobacillus* spp. counts and TBARS levels in breast and drumstick meat and partly affected the pH, water activity and colour parameters of meat. Based on the results obtained in the present study, it is suggested that the dietary supplementation of broiler chickens with thyme and rosemary essential oils could aid in protecting these animals from oxidative stress and maintaining their health.

Ethical statement. All the experimental procedures were approved by the Local Ethics Board for Animal Experiments of Sivas Cumhuriyet University (decision number: 2020/342).

Data availability. The data presented in this study are available free of charge for any user upon reasonable request from the corresponding author.

Author contributions. RG designed the study and supervised the experiments. SUG contributed in meat quality analyses. These data were analysed by RG and SUG. Manuscript was prepared by RG and edited by RG and SUG. All authors contributed to the article and approved the submitted version.

Competing interests. The contact author has declared that neither of the authors has any competing interests.

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