

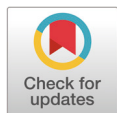
Physico-chemical attributes, sensory evaluation and oxidative stability of leg meat from broilers supplemented with plant extracts

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Competing interests

No potential conflict of interest relevant
to this article was reported.

Abstract

This feeding trial was conducted to investigate the effects of *Mentha arvensis* (MA) and *Geranium thunbergii* (GT) in drinking water on physicochemical attributes, sensory qualities, proximate analysis and oxidative stability of broiler leg meat. One hundred and twenty broiler chicks were assigned to 1 of 4 dietary treatments for 5 weeks. The dietary treatments were 1) control, 2) T1 (0.1% 1 MA:1 GT), 3) T2 (0.1% 1 MA:4 GT), 4) T3 (0.1% 4 MA: 1 GT). The water holding capacity and cooking loss were improved ($p < 0.05$) in T2 and T3. The flavor, texture and acceptability of leg meat by consumers were significantly increased in T2 relative to the control ($p < 0.05$). The crude protein content was increased in T3 while the crude fat decreased in T2 ($p < 0.05$). Moreover, broilers supplemented with plant extracts had the lowest leg meat TBARS (thiobarbituric acid reactive substances) values after 2 weeks of storage as compared with the control. Total phenolic contents and 1-1-diphenyl 2 picrylhydrazyl (DPPH) activity were also better in the T2 group ($p < 0.05$) compared with the control, whereas 2,2-Azinobis-3 ethylbenzothiazoline-6-sulfonic acid (ABTS⁺) remained unaffected. Overall, these results demonstrate that broiler drinking water with the inclusion of plant extract combination can be used to enhance the oxidative stability, shelf life and quality characteristics of broiler leg meat without compromising the growth performance.

Keywords: Broiler leg meat, Oxidative stability, Plant extracts, Shelf life

INTRODUCTION

Poultry meat quality is determined by not only physical and chemical properties but also by consumer preference. As the consumption of meat is increasing, consumer interest in healthy food is also increasing worldwide, as is the demand for high-quality products with safety and better shelf life [1]. Meat quality traits can be classified into three groups i) appearance quality traits including drip loss, color and texture of meat; ii) eating quality trait including tenderness, juiciness, succulence and flavor of cooked meat [2]; and iii) reliance quality traits including safety, nutritive value, animal welfare, market price,

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Availability of data and material

Upon reasonable request, the datasets of this study can be available from corresponding author.

Authors' contributions

Conceptualization: Yang EJ, Seo YS, Yang CJ.
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Formal analysis: Yang EJ, Seo YS, Dilawar MA, Mun HS, Park HS.

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Investigation: Yang EJ, Seo YS, Dilawar MA, Mun HS, Park HS.

Writing - original draft: Dilawar MA, Yang CJ.

Writing - review & editing: Yang EJ, Seo YS, Dilawar MA, Mun HS, Park HS, Yang CJ.

Ethics approval and consent to participate

The experimental protocols and management and care of broilers were approved and reviewed by the Institutional Animal Care and Use Committee (IACUC), Suncheon National University (SCNU IACUC 2019-05).

ethics, product packaging, brand and origin of meat products [3].

The oxidative process has a negative impact on the growth and performance of animals and deteriorates meat quality. Unfortunately, chicken meat is highly susceptible to oxidation reactions because of a high degree of unsaturation in muscles, which results in loss of flavor, appearance, and nutritive value [4]. During recent years, people have had many concerns regarding the safety of meat and its effect on their health, ageing and oxidative processes. Therefore, increased attention is being given to the rearing of birds without the use of synthetic antioxidants, antibiotics or chemicals [5]. Plant extracts possess a variety of physiologically active substances that exhibit antioxidant activity. Different kinds of plant extracts have been shown to increase animal feed intake, endogenous digestive enzyme secretions and boosting the immune system. As a result, providing birds with feed amended with such extracts leads to increased poultry productivity and meat quality characteristics [6].

Mentha arvensis (MA) is a species of herbal plant belongs to the *Lamiaceae* family and the extracts of this plant has been used in folk medicine for several therapeutic purposes. This plant yields 40%–50% menthol, which is a primary phenolic compound having antioxidant, antibacterial and antiseptic properties. The contents of antioxidant compounds in this plant are as follows: Vit C, 12.8 ± 0.08 mg%; Vit E, 0.0294 ± 0.0015 mg%; carotenoid, 4.48 ± 0.06 mg%; total content of phenolics, 70.0 ± 0.13 mg% [7]. The other plant of interest is *Geranium thunbergii* (GT), which belongs to the *Geraniaceae* family. This plant has been reported to exhibit anti-oxidative, anti-inflammatory, anti-mutagenic, antibacterial, anti-hypertensive and antifungal activities [8]. The leaves of this plant contain a crystalline tannin called geraniin (10% of total dry weight), which is used in the treatment of diarrhoea. The total phenolics of this plant are 104 ± 2.4 mg GAE/g and the Gallic acid content is $2,313 \pm 10.8$ mg/100 g dried sample, which indicates that it has good antioxidant activity [9].

A way of enhancing the efficacy of plant extracts may be the water supplementation, which ensures uniform mixing into water, uniform intake by birds and to avoid wastage [10]. Skomorucha and Sosnowka-czajka [11] also reported that the response of broilers to the water supplementation with certain herbs was positive in terms of growth performance, physiological response to stress and welfare. Therefore, this study was conducted to meet consumer preference for safe, hygienic, less prone to oxidative processes and antibiotic-free poultry meat. The present study investigated if the plant extracts in drinking water would improve carcass color coordination, physio-chemical attributes, sensory evaluation and oxidative stability of broiler leg meat.

MATERIALS AND METHODS

The experimental protocols and management and care of broilers were approved and reviewed by the Institutional Animal Care and Use Committee (IACUC), Suncheon National University, Korea (SCNU IACUC 2019-05).

Manufacture of plant extracts

Two plants, MA and GT, were purchased from Bonghwa, South Korea. The leaves were thoroughly washed, dried and ground, after which the extract of both plants were prepared according to the method described by Dilawar et al. [10]. Briefly, MA and GT extracts were prepared separately by mixing 100 g of leaves with 5 L distilled water and kept for 2 h in the dark at room temperature, with occasional shaking. This method was repeated for the extraction of 2 kg dried leaves of both plants, after which the samples were filtered with the help of Whatman No. 1 filter paper. The combination treatments were prepared in the broiler house before adding to the drinking water.

Birds and housing

A total of 120, day-old male “Ross” broiler chickens were reared and housed according to the guidelines set on the Aviagen [12]. A feeder at the front side and a nipple drinker at the back were placed in the cage for free access to feed and water (with dietary treatment inclusion) throughout the whole experiment.

Dietary treatments

The ingredients, vitamin and mineral content and calculated chemical composition of the basal diets are presented in Table 1. Commercially available poultry feed (Nonghyup feed, Gyeongsangnam-do, Korea) were fed to the birds as basal diet. A preliminary experiment was conducted by Dilawar et al. [10] to identify the percentage and ratio of two plant extracts on broiler performance and feed conversion ratio (data not shown). The broiler leg meat samples from the treatments which performed best were further evaluated in this experiment. The treatments used in this study were 1) control, 2) T1 (0.1% 1 MA:1 GT), 3) T2 (0.1% 1 MA:4 GT), 4) T3 (0.1% 4 MA: 1 GT). Birds were weighed individually and randomly divided into four treatment groups in five replicates with six birds each.

Table 1. Feed ingredients and chemical composition of diets

Ingredient (% as-fed basis)	Starter	Finisher
Corn	50.00	56.00
Soybean meal	37.00	28.84
Corn gluten meal	0.50	1.00
Wheat 10%	6.00	7.00
Limestone-small	2.03	1.92
Salt-Proc	0.25	0.25
DCP 18%	0.40	0.46
L-Lys sulfate 70%	0.30	0.18
Minemix ¹⁾	0.20	0.20
Vitamix ²⁾	0.05	0.05
L-Threonine 98%	-	0.01
MHA-Liquid	0.26	0.29
Sunphase5000FTU	0.01	0.01
Soybean oil	3.00	3.80
Total	100.00	100.00
Calculated composition (%DM)		
ME (kcal/kg)	3,090.97	3,207.91
Crude protein (%)	22.04	19.00
Crude fat (%)	5.35	6.23
Crude ash (%)	5.71	5.26
Crude fibre (%)	2.59	2.39
Ca (%)	1.09	1.04
Phosphorus (%)	0.45	0.43
Lysine (%)	1.34	1.07
Methionine (%)	0.57	0.55

^{1,2)}Vitamin–mineral mixture provided the following nutrients per kilogram of diet: vitamin A 12,061.00 IU (starter) and 12,122.00 IU (finisher); vitamin D₃ 3,000.00 IU; vitamin E 28.06 ppm (starter) and 29.35 ppm (finisher); vitamin K 2.10 ppm (starter) and 2.11 ppm (finisher); choline chloride 1,329.10 ppm (starter) and 1,146.20 ppm (finisher); copper 73.02 ppm (starter) and 72.07 ppm (finisher); manganese 77.92 ppm (starter) and 75.80 ppm (finisher); zinc 73.75 ppm (starter) and 71.57 ppm (finisher); iodine 0.94 ppm; selenium 0.30 ppm; iron 148.63 ppm (starter) and 4,141.21 ppm (finisher).

Sampling procedure and analysis

At 36 days of age, two birds were randomly selected from every replicate cage (10 birds/ treatment) and slaughtered by cutting the jugular veins. The whole leg portion (drumstick and thigh) was excised from the carcass, after which the meat from the leg was separated by removing the bones, skin and connective tissues. Leg meat samples from each bird (3 replicates) were refrigerated at 4 °C for TBARS (thiobarbituric acid reactive substances), pH, sensory evaluation, water holding capacity (WHC) and cooking loss determination and -20 °C for other analysis.

The color coordination was determined with the help of a Chroma meter (CR-410, Konika Minolta Sensing, Tokyo, Japan) and presented in CIE unit (The International Commission of Illumination, 1978) of a^* , L^* , and b^* . The chroma meter was calibrated using a white ceramic tile (as standard) throughout the study.

The pH of leg meat sample was measured with a pH meter (Seven Excellence, Metler-Toledo AG, Greifensee, Switzerland) by homogenizing 1 g of minced broiler meat and 9 mL of water for 1.5 minutes at 20,000 rpm with a homogenizer (UltraTurrax T-25, Staufen, Germany).

After 24 h postmortem, leg meat samples (1.5 cm thick and 80 g weight) were cut and placed in polyethylene bags and were then placed in a water bath at 75 °C for 30 minutes. The bags were then cooled for one hour at room temperature. The samples were subsequently cooked using a Combi Oven (MCS-6, Henny Penny, Eaton, Oh, USA). Cooking loss was determined for each sample (three replicates) by calculating the percentage of the cooked sample (W2) and the weight of the uncooked sample (W1). The percentage of cooking loss was calculated according to the following formula: $\text{Cooking loss (\%)} = [(W1 - W2) / W1] \times 100$.

The WHC was determined in three replicates per sample using the procedure described by Bostami et al. [13]. In a short, a 300 mg leg meat sample was compressed in a filter-press device for 2 min. After the filter press and compression, meat samples were individually weighed. The amount of expelled water was calculated by evaluating the initial to the final weight of compressed and filter pressed samples. A lower water expulsion indicated the higher WHC and vice versa. The WHC was calculated and expressed as a percentage.

Sensory evaluation was conducted by 10 trained judges. Chicken leg meat samples were boiled in water before evaluation until the internal temperature raised to 70 °C. The temperature was checked by placing a thermometer in the geometric center of the meat sample. The scale of 1 to 7 was used for the evaluation of meat sample as follows: color (1: very light/pale, 7: reddish black color), flavor intensity (1: very poor, 7: excellent), tenderness (1: extremely hard, 7: very soft/tender), palatability (1: low, 7: high) juiciness (1: very dry, 7: succulent) and overall acceptability (1: extremely unaccepted, 7: highly acceptable).

The proximate composition of chicken leg meat samples was analyzed according to the AOAC guidelines and procedures [14].

The TBARS values of the leg meat samples were measured at 0, 1, and 2 weeks after storage according to the procedure explained by Ahmed et al. [15]. About 4 g leg meat was added to a 10 mL solution consisting of 20% trichloroacetic acid and homogenized in a homogenizer (UltraTurrax T-25, Staufen, Germany) at maximum speed of 25,000 rpm for 1.5 min. The mixture was then filtered through a micro no. 60 filter paper (Hyundai Seoul, Korea). Two mL of the filtered solution and 2 mL of 2-thiobarbituric acid were placed in a shaking heating water bath for 30 min at 80 °C. The absorbance was determined at 530 nm after cooling with the help of a VIS Spectrophotometer (S22 Libra, Biochrom Limited, Cambridge, UK). The TBARS value was presented as milligrams of MDA (malondialdehyde) per 100 g of meat.

The total phenolics were measured using Folin-Ciocalteu reagent. Briefly, 15 mL of distilled water was added to 5 g of chicken leg meat sample, vortexed for 1 minute and centrifuged for 10

minutes at 3,000×g. To measure the total phenolic compounds, 100 µL of 50% Folin Ciocalteu's reagent (Sigma-Aldrich, St. Louis, Mo, USA) and 2 mL of 2% Na₂CO₃ solution and were added to each 15 µL sample (three replicates) and incubated for 15 mins at 45 °C. The absorbance was subsequently measured at 710 nm using a spectrophotometer and quantification was conducted based on a curve obtained with Gallic acid.

DPPH (1-1-diphenyl 2 picrylhydrazyl) radical scavenging ability was determined according to the method explained by Jang et al. [16]. Briefly, 200 µL of each prepared sample (three replicates) by the same method as the total phenol compound. The samples were amended with 1 mL of methanolic 0.2 mM DPPH solution (Wako Pure Chemical, Osaka, Japan) and 800 µL of water and, mixed and allowed to react for 30 min, after which the absorbance was calculated at 517 nm using a spectrophotometer. A tube containing 1 mL of DPPH (0.2 mM) and 1 mL of distilled water was used as a control and the DPPH was calculated by the following equation:

$$\text{DPPH radical scavenging ability (\%)} = [1 - (\text{Absorbance of the sample} / \text{Absorbance of a control})] \times 100$$

ABTS⁺ (2,2-azinobis-3 ethylbenzothiazoline-6-sulfonic acid) was mixed in water to a 7 mM concentration and ABTS radical cations were generated by the reaction of 2.45 mM potassium persulphate and ABTS stock solution. A total of 10 µL of the sample prepared in the same manner as the total phenolic compound content was mixed with 1 mL diluted ABTS prepared solution and reacted at room temperature for 6 minutes. Finally, the absorbance was determined at 734 nm using a spectrophotometer. The ABTS radical scavenging ability of each sample (three replicates) was then calculated by the following equation:

$$\text{ABTS scavenging ability (\%)} = [1 - (\text{Absorbance of sample} / \text{Absorbance of the control})] \times 100$$

Statistical analysis

All experimental data were examined using the SPSS program (Statistics Package for Social Science, version 15.1, SPSS, Chicago, IL, USA) to determine if variables differed between groups. Each cage was used as the experimental unit for growth production parameters, whereas an individual chick served as the experimental unit for proximate composition, ABTS⁺, DPPH and total phenolic contents. The statistical equation used to test the effects of treatment was:

$$Y_{ij} = \mu + \alpha_i + e_{ij}$$

where Y_{ij} = the response variable, μ = the general mean, α_i = the effect of dietary treatments, and e_{ij} = the error. The means were determined and expressed with the SEM. All parameters were compared between groups by one-way ANOVA and subsequent Duncan's multiple range tests. A $p < 0.05$ was considered significant.

RESULTS

Table 2 shows the L*, a*, and b* color values of poultry leg meat. The L* and a* values differed significantly between groups. Specifically, the L* values of T1 and T2 was higher as compared with the control and T3 ($p < 0.05$). Additionally, the redness value of the control was significantly ($p < 0.05$) higher than T1 and T2. In the case of yellowness, there was no significant difference between treatments and the control. The pH of leg meat samples did not differ significantly between dietary

Table 2. Effects of two plant extracts on color values, pH, cooking loss and WHC of broiler meat

Item	Dietary treatments (n = 10)				SEM	p-value
	Control	T1	T2	T3		
CIE L*	52.70 ^{bc}	55.64 ^b	55.05 ^{ab}	51.24 ^c	0.48	0.036
CIE a*	9.13 ^a	5.82 ^{bc}	5.35 ^c	7.82 ^{ab}	0.12	0.021
CIE b*	15.75	16.13	17.45	16.09	0.26	0.648
pH	6.88	6.74	6.67	6.68	0.10	0.139
Cooking loss (%)	26.87 ^a	26.83 ^a	22.43 ^b	22.72 ^b	1.31	0.01
WHC (%)	37.48 ^b	39.37 ^{ab}	41.97 ^a	42.09 ^a	0.73	0.013

n, number of birds.

^{a-c}Within the same row, mean values with different superscripts are significantly different ($p < 0.05$).

WHC, water holding capacity.

treatments (Table 2).

Cooking loss was significantly reduced in T2 and T3 ($p < 0.05$), with the greatest cooking loss seen in the control (Table 2). The WHC was increased significantly ($p < 0.05$) in T2 and T3 compared with the control.

There were no differences found in the color and taste of the leg meat samples (Table 3). However, the flavor, texture, juiciness and overall acceptability of meat supplemented with T2 were preferred ($p < 0.05$) over the control by the panellists.

There was no significant difference in the moisture content of the leg meat sample among groups (Table 4). However, the crude protein (CP) contents were significantly higher ($p < 0.05$) in the broiler leg meat fed diet T3, while the crude ash content was higher ($p < 0.05$) in T2 relative to the other treatments.

On an average and after 2 weeks of storage, leg meat TBARS value was decreased significantly

Table 3. Effects of two plant extracts on sensory properties of broiler meat

Items	Dietary treatments (n = 10)				SEM	p-value
	Control	T1	T2	T3		
Color	4.25	5.00	5.50	4.75	0.20	0.524
Flavor	3.75 ^b	4.00 ^b	5.00 ^a	3.75 ^b	0.15	0.011
Taste	4.25	5.50	5.75	5.00	0.20	0.224
Texture	4.00 ^b	4.75 ^{ab}	5.25 ^a	4.25 ^{ab}	0.18	0.028
Juiciness	3.75 ^b	4.25 ^{ab}	5.50 ^a	5.25 ^a	0.16	0.024
Overall acceptability	4.00 ^b	5.00 ^{ab}	5.75 ^a	4.50 ^{ab}	0.22	0.031

n, number of birds.

^{a,b}Within the same row, mean values with different superscripts are significantly different ($p < 0.05$).

Table 4. Effects of two plant extracts on proximate composition of broiler meat

Items	Dietary treatments (n = 10)				SEM	p-value
	Control	T1	T2	T3		
Moisture	74.60	74.48	74.50	74.24	2.60	0.418
Crude protein	18.29 ^c	18.69 ^{bc}	18.57 ^{bc}	19.19 ^a	0.50	< 0.001
Crude fat	2.43 ^{ab}	2.47 ^{ab}	2.10 ^b	2.78 ^a	0.02	0.001
Crude ash	1.00 ^{bc}	0.96 ^c	1.14 ^a	1.01 ^b	0.01	0.001

n, number of birds.

^{a-c}Within the same row, mean values with different superscripts are significantly different ($p < 0.05$).

($p < 0.05$) in the plant extracts supplemented groups (Table 5). However, no significant differences were found at 0 and 1 weeks of storage.

The phenolic contents of the leg meat varied from 71.07 to 78.03 mg GAE/kg of meat (Table 6). The meat from chickens fed T2 showed significantly greater total phenols and DPPH scavenging activity compared with the control group ($p < 0.05$). In the case of ABTS⁺ scavenging, there were no differences ($p > 0.05$) among groups. Clearly, the 31.5% increase in the DPPH and 5% increase in the ABTS⁺ scavenging effect of T2 compared to the control was because of the presence of higher total phenolic contents.

DISCUSSION

The color value of meat, L^* is linked with visual color observation, the a^* value is related to oxidation state, intramuscular fat and pigment content and the b^* value is associated with redox state and intramuscular fat content [13]. In this study, the L^* color value ranged from 51.24 to 58.50, the a^* color value from 5.82 to 9.13 and the b^* color value from 15.75 to 17.45. This variation in meat color was in accordance with the results of previous studies that showed the addition of phytochemicals such as black pepper, red pepper and garlic in poultry diets influenced meat color [17].

Different authors suggested different cut off values of L^* to determine meat quality. For poultry meat, Petracci et al. [18] suggested $L^* < 50$ was dark, $50 \leq L^* \leq 56$ was normal and $L^* > 56$ was pale. In this experiment, the L^* values of the control, T1, T2, and T3 were 52.70, 55.64, 55.05, and 51.24, respectively, which indicates that leg meat L^* value lies in the normal cut off range. Redness value decreased in response to the addition of extract from MA and GT to the diets of birds as compared with the control. According to Amorim et al. [19], a decreased a^* value is a result of a higher percentage of fat deposition and intramuscular fat and a proportional decrease in the blood vessels; therefore, a low meat a^* value results in brighter meat (higher L^* value), which was also found in this experiment.

The pH value varied from 6.67 to 6.88 in the meat samples. In this trial, the pH values of leg

Table 5. Effects of two plant extracts on TBARS value of broiler meat

Storage period	Dietary treatments (n = 10)				SEM	p-value
	Control	T1	T2	T3		
0-wk	0.30	0.29	0.30	0.29	0.03	0.09
1-wk	0.35	0.30	0.24	0.30	0.04	0.30
2-wk	0.48 ^a	0.27 ^{bc}	0.30 ^{bc}	0.22 ^c	0.05	0.001
Average	0.34 ^a	0.26 ^{bc}	0.24 ^c	0.25 ^c	0.02	0.02

n, number of birds.

^{a-c}Within the same row, mean values with different superscripts are significantly different ($p < 0.05$).

TBARS, thiobarbituric acid reactive substances.

Table 6. Effects of two plant extracts on total phenolic contents ($\mu\text{g/g}$), DPPH (%) and ABTS (%) radical scavenging activity of broiler meat

Item	Dietary treatments (n = 10)				SEM	p-value
	Control	T1	T2	T3		
Total phenols (ppm)	71.07 ^b	77.33 ^{ab}	78.03 ^a	73.75 ^{ab}	2.45	0.041
DPPH radical scavenging activity (%)	33.37 ^b	34.80 ^b	43.90 ^a	35.59 ^b	1.15	0.031
ABTS radical scavenging activity (%)	55.47	53.73	58.33	53.86	1.50	0.135

n, number of birds.

^{a,b}Within the same row, mean values with different superscripts are significantly different ($p < 0.05$).

DPPH, 1,1-diphenyl 2 picrylhydrazyl; ABTS, 2,2-azinobis-3 ethylbenzothiazoline-6-sulfonic acid.

meat samples were same with the findings of a previous trial performed by Džinić et al. [17], in which meat samples with a pH more than 5.8 was considered as normal meat for quality purpose. The lowest pH value (6.67) was observed in T2 and the lowest a* color value was also found in T2, which is in line with the results of previous experiments that showed light color poultry meat samples had significantly lower pH [20]. A high pH and microbial count is usually an indicator of meat spoilage and it is of great significance that the pH of the meat reaches as low as possible for better shelf life. The highest pH was observed in the control (6.88) relative to supplemented groups, indicating reduced spoilage of meat because of supplementation with plant extracts. Supporting the results of the current study, different researchers also reported a decline in the pH of meat because of the addition of phytochemicals such as pomegranate by-products and 2% garlic acid [5,15].

The WHC is important for customers as it has a significant role in determining the final weight of the meat. In this study, supplementation of broilers with plant extracts increased the WHC and decreased the cooking loss ($p < 0.05$), suggesting increased retention of nutrients and better quality of meat. Cooking loss is very important to the meat industry as the main point of the profit is water retention. The relationship between WHC, muscle pH and meat color is well established. Positive influences of plants extract on meat quality of chickens have been observed by many scientists using different supplements and similar to our findings, Džinić, et al. [17] reported the lowest cooking and drip-loss of meat after feeding animals hot red pepper.

According to the consumer's point of view, juiciness, flavor and tenderness are the most critical factors for eating satisfaction [1]. Supplementation of broilers with MA and GT increased the flavor, texture, juiciness and acceptability of the poultry meat. Specifically, the overall acceptability of T1, T2, and T3 were 5, 5.75, and 4.50, respectively, on a scale of 7, while that of the control was only 4. Some authors reported that the supplementation of natural anti-oxidants to the lamb, pigs and poultry did not have adverse or beneficial effects on sensory characteristics of meat [21]. Furthermore, Džinić et al. [17] reported a characteristic pungent smell and taste being transferred to the meat due to the supplementation of poultry feed with 2% garlic. This characteristic of flavor can be beneficial or non-beneficial depending on consumer preference. Conversely, an overall improvement in meat quality attributes without any atypical smell was observed in this study in response to the addition of plant extracts.

In general, the proximate composition and nutritive value of meat will depend on the diet, age, genetics, sexual maturity, management and environmental conditions of the source animal. In the present study, the non-significant moisture content is consistent with the findings of Gardzielewska et al. [22], who reported that dietary feed of broiler chickens supplemented with echinacea (*Echinacea purpurea*), ginger (*Zingiber officinale*) and garlic (*Allium sativum*) did not show any effect on the moisture content of meat. In our study, moisture content was lowest (74.24%) and crude fat content was highest (2.78%) in birds supplemented with T3. This might have been because of the inverse relationship between fat content and meat moisture, which is directly linked with meat juiciness [23]. The CP content of leg meat was higher in T3 (19.19%) than the control (18.29%), which was related to the high meat quality in birds supplemented with plant extract. In previous trials by Puvača et al. [5], there was a significant improvement in the protein content of poultry meat because of the dietary supplementation of garlic, red and black pepper. In short, supplementation of the feed with plant extracts showed beneficial effects on the proximate composition of chicken meat and had the ability to increase the nutritive value of meat. This may be due to the reason that muscles of animals are the main cause of deterioration of meat quality and oxidation of these muscles affect the nutritional and organoleptic properties [24]. The phenolics in MA and GT have the ability to stop these reactions and enhance the meat quality.

During the processing and storage of chicken meat, oxidative deterioration is responsible for

rancid odor and flavor. It is understood that the free radicals produced during lipid oxidation can cause ageing of cells, cancer, cardiovascular diseases and neurodegenerative disorders [25]. The potential of the phenolics to act as antioxidant depends mainly on the redox effects of phenolic hydroxyl groups, which allows them to quench free radicals because of their high radical-absorbance or H⁺-donating ability [26]. Moreover, the shelf life of packed chicken meat is short because of rapid microbial growth and lipid oxidation. In the present study, supplementation of feed with different proportions of MA and GT significantly decreased the lipid oxidation, as represented by the decreased meat TBARS value. These values are consistent with the findings of Biswas et al. [27], showing the presence of natural antioxidants in MA. Furthermore, a 9.80% increase in total phenolic contents in the supplemented group was observed because of high phenolic, flavonoid and tannin chemical contents present in the Geraniaceae and Lamiaceae family [28]. Phenolic compounds in both plants (MA and GT) have antioxidant activities and therefore have the ability to improve the meat quality and increase the shelf life of stored meat. Similar beneficial effects of both plants on the oxidative stability has been reported in broiler meat [10,29].

Free stable radical DPPH is commonly used to estimate the efficiency of plant extracts as oxidants. The results of our study indicated that the supplementation of dietary plant extracts improved the radical scavenging activity in leg meat. Similar to our findings, Jang et al. [16] reported that the free radical scavenging effect of chicken meat increased because of supplementation with medicinal herbal extract mix). In the present trial, better scavenging activity in the chicken meat supplemented with MA and GT was because of the presence of polyphenols in natural antioxidants. In addition, a feeding trial conducted by Wong et al. [25], MA had the second-highest DPPH free radical capturing activity among 25 plants and the third-highest antioxidant index (10.9) among 43 plants [7].

It has been suggested by Nagendra Prasad et al. [30] that the polyphenolic content of plant extracts were closely related to the antioxidant capacity ($R^2 = 0.9773$). In addition, the phenolic components in plant extracts react with hydroxyl radicals and lipid to form stable products that may increase scavenging ability [16]. Similar to our findings, Luna et al. [31] and Goñi et al. [32] reported that the addition of dietary phenolic sources led to significant anti-oxidation activities in chicken and lamb meat.

CONCLUSION

In conclusion, supplementation of plant extracts improved the nutritional value of broiler leg meat and a combination of MA and GT in T2 produced the most promising effects among all treatments. The combination of plant extracts in T2 improved the nutritive value and composition of broiler leg meat by increasing the mineral content (total ash) and decreasing the ether extract. In addition to the good WHC and minimum cooking loss in T2, the leg meat was highly acceptable by consumers because of its better juiciness, color, flavor and texture. The higher total phenolic contents, better DPPH and ABTS⁺ radical scavenging ability and decreased meat TBARS value indicate that plant extracts combination in T2 is capable of improving oxidative stability, shelf life and quality of broiler leg meat without having a negative impact on growth performance.

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