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Research Article

Effect of vacuum and aerial packaging on the quality and shelf life of broiler meat treated with extra virgin olive oil

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Abstract

Extra virgin olive oil (EVOO) treatment during the vacuum and aerial packaging affected the sensory, physicochemical, biochemical, and microbiological characteristics of chicken breast meat. Meat samples were separated into four treatment groups: T_1 (aerial packaging of EVOO- treated meat), T_2 (aerial packaging of raw meat), T_3 (vacuum packaging of EVOO-treated meat), and T_4 (vacuum packaging of raw meat). The samples' sensory, physicochemical, biochemical, and microbiological characteristics were determined at the 0, 5, 10, and 15 d of preservation. Regarding sensory properties, no significant differences ($p>0.05$) were found in color, flavor, tenderness, juiciness, and overall acceptability scores of all the tested samples; still, T_3 performed best and was most preferable among those. The pH levels varied significantly ($p<0.05$) amongst the four treatment groups. In the T_2 group, the most favorable raw pH was observed. Cooking loss varied significantly ($p<0.05$) among various treatments, although water holding capacity (WHC) did not vary significantly ($p>0.05$). However, T_3 performed best in both cases. The most favorable thiobarbituric acid reactive substances (TBARS) value was found in T_3. Additionally, compared to the other groups, T_3 had significantly ($p<0.05$) lower total viable count (TVC) and total yeast mold count (TYMC) values, whereas T_4 had significantly ($p<0.05$) lower total coliform count (TCC) values. Therefore, it can be concluded that, regarding sensory, anti-oxidative, physicochemical, and microbial properties, T3 (vacuum packaging of EVOO-treated meat) was better among all treatments.

Introduction

Poultry meat has become widely popular and in high demand worldwide as a food commodity, with its consumption steadily rising over the past few decades. When compared to meat products like beef or lamb, chicken meat's relatively inexpensive production costs, low fat content, high nutritional value, and distinctive flavor are some of the factors that contribute to its popularity (Latou et al., 2014; Haque et al., 2020; Hossain et al., 2021; Rahman et al., 2022). But the perishability of poultry meat is high due to its chemical composition, which is suitable for the growth of microbes (Fung and Toldra, 2010; Islam et al., 2019). The amount of unsaturated fatty acid (UFA) in poultry meat is higher than meat from other species; this characteristic makes the poultry meat prone to oxidation. Additionally, specific microorganisms present in poultry meat have the ability to multiply under standard cold-storage conditions (+4°C) (Kozačinski et al., 2012). Lipid oxidation during meat storage leads to a reduction in nutritional value as vitamins and essential fatty acids are lost, while harmful compounds such as cholesterol oxidation products and malondialdehyde are formed (Tang et al., 2001; Rima et al., 2019). To address these issues, synthetic chemicals like butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), tertiary butyl hydroquinone (TBHQ), and others are commonly employed as antimicrobial and antioxidant agents (Valencia et al., 2007; Siddiqua et al., 2018). In recent times, there has been a growing consumer awareness of the potential side effects associated with chemical preservatives. As a result, there has been an increasing demand for the use of natural preservatives in food products (Zhang et al., 2016; Saba et al., 2018). To maintain the quality of meat, extend its shelf life, and prevent economic losses, natural preservatives with antioxidant and antimicrobial properties are being utilized. These include oregano oil, extra virgin olive oil, essential oils, green tea, clove powder, ginger, garlic, chitosan, clove, red chili, and other similar substances. A key tool for extending a product's shelf life is packaging. Common packaging methods are aerial packaging and vacuum packaging. Vacuum packaging of meat involves the removal of air from the package prior to sealing. It is a suitable packaging technique for chicken parts with mild pigmentation, and can prevent or reduce brown discoloration (Mathew et al., 2016). Aerial packaging refers to packaging that permits water to evaporate from the product and penetrate the package to the exterior environment through packaging materials that are permeable to water vapor. While this provides certain benefits, such as improved shelf life, it also creates a favorable environment for aerobic microorganism growth due to the presence of oxygen and moisture. Extra virgin olive oil (EVOO) acts as a natural preservative by creating a protective barrier that isolates the food from air, effectively preventing spoilage. This seal formed by the oil helps to delay oxidation, deterioration, and the growth of mold. Both olives (Olea europaea) and olive oil contains a wide

range of polyphenols, which possess remarkable antioxidant properties (Bermúdez-Oria et al., 2019). Olea europaea polyphenols can safeguard meat products against oxidative reactions and microbiological development (Kurt et al., 2017). This research aimed to investigate the quality of broiler meat through vacuum and aerial packaging treated with EVOO and to assess the shelf life of broiler meat through vacuum and aerial packaging.

Materials and Methods

Sample collection

Samples of broiler meat were collected from Bangladesh Agricultural University, Kamal Ronjit-market, Mymensingh. Broilers of almost the same ages were brought. The samples were taken from only the breast muscle portion, excluding the bone portion. The meat sample was then immediately brought into the "Animal Science Laboratory." A Renowned brand of extra virgin olive oil was bought from a super-shop.

Sample preparation

Visible fat and connective tissues were removed using a knife as much as feasible and the samples were divided into smaller segments. Following that, purified water was used to clean the entire sample. After straining all the water, fifty percent of the meat specimen was mixed with EVOO, while the remaining fifty percent was left untreated. Subsequently, both the EVOO-mixed and EVOO-free samples were appropriately packaged using aerial and vacuum packaging methods.

Sensory evaluation

A 5-person, trained panel assessed each meat sample in both its raw and cooked forms. For the qualities of color, flavor, tenderness, juiciness, and overall acceptability, the sensory questionnaires were scored on a 9-point hedonic scale. Based on these criteria, the judges evaluated the samples. The American Meat Science Association (AMSA, 1995) rules were followed for training the panelists, who were chosen among department employees and students. Individual booths were used for sensory evaluation, which was done in controlled environments for humidity, temperature, and light. All panelists took part in orientation sessions to become familiar with the scale qualities (color, flavor, overall acceptability) of meat using a hedonic scale prior to sample evaluation. Sensory scores were 1=Dislike extremely, 2= Dislike very much, 3=Dislike moderately, 4=Dislike slightly, 5=Neither like nor dislike, 6=Like slightly, 7=Like moderately, 8=Like very much, 9=Like extremely. Sensory evaluation was conducted at day 0 and then again on day 5, 10, and 15.

Physicochemical and biochemical properties

pH measurement

HANNA HACCP Quality pH meter was used to determine the pH. The pH meter was calibrated before use by placing it in a buffer with a pH value of 7, and the meter was left undisturbed for approximately 1-2 min. Following that, the electrode was placed on the meat samples, allowing 1-2 min for the measurement of the pH levels in the meat samples.

Color value estimation

Konica Minolta Chroma Meter (CIE L*a*b* specified) was used to measure the change of color in meat. The color measurement was performed by directly placing the Chroma meter in contact with the outer surface of the meat. The color assessment involved measuring the following parameters: CIE L* for lightness, CIE a* for redness, and CIE b* for yellowness.

Cooking loss

To assess the cooking loss, a mass of 20 g was measured for each sample. Then it was enclosed in heat-resistant foil paper, and immersed into a water bath maintained at a temperature of 70°C for a duration of 30 min. Subsequently, the meat was weighed once more after removing the drip that originated from the cooked meat. This measurement was practiced on day 0, 5, 10, and 15.

Water Holding Capacity

It was determined by using a centrifugal machine, 1 g of meat sample was taken in a tube and centrifuged at 10000 rpm for 10 min.

Oxidative Stability

Method described by Witte et al. (1970) was followed to determine the Thiobarbituric Acid Reactive Substances (TBARS) value. In this method, 5 g of the meat sample was blended with 25 mL of a 20% trichloroacetic acid solution, which contained 200 g/L of trichloroacetic acid in a 135 mL/L phosphoric acid solution. Then it was mixed thoroughly by using a vortex mixer for 30 s. The resulting content was then filtered using Whatman filter paper number 4. To measure the TBARS value, 2 mL of the filtrate was mixed with 2 mL of a 0.02 M aqueous TBA (Thiobarbituric Acid) solution, which was prepared at a concentration of 3 g/L. The solution was incubated for 30 min. Then, a UV-VIS spectrophotometer was used to measure the absorbance value of the solution at a wavelength of 532 nm. The TBARS value, indicating the level of malondialdehyde in the meat sample, was expressed as mg of malondialdehyde (MDA)/kg of meat sample.

Microbial assessment

The microbial assessment includes total viable count (TVC), total coliform count (TCC), and total yeast-mold count (TYMC). The procedure suggested by the International Organization for Standardization (ISO, 1995) was followed to conduct this test. At first, 10 g of chicken meat from each treatment was taken aseptically. Then it was transferred into a blender containing 90 mL of 0.1% (w/v) peptone water. It was blended to produce a homogenized suspension of 1:10 dilution. Finally, different dilutions ranging from 10^{-2} to 10^{-6} were prepared and each dilution was mixed thoroughly by using a vortex mixer. Then it was proceeded to perform the TVC, TCC, and TYMC tests.

Statistical analysis

SAS Statistical Discovery software, NC, USA, was used to statistically analyze the data. The significance of variations between treatment means was assessed using the DMRT test.

Results and Discussion

Sensory Evaluation

Colors, flavor, tenderness, juiciness, and overall acceptability values of cooked meat were from 6.75 to 7.75, 6.25 to 7.75, 6.25 to 7.00, 6.00 to 7.00, and 6.75 to 7.25 respectively, and during post mortem stress period the values for the color, flavor, tenderness, juiciness, and overall acceptability were 5.25 to 9.00, 4.75 to 9.00, 4.75 to 9.00, 4.25 to 9.00, 5.50 to 9.00, respectively (Table 1). In the case of color, the same superscript was observed from the four treatments indicating that there were no significant ($p>0.05$) differences among the four treatments. The most preferable color was observed in the T_3 treatment, while the least preferable color was observed in the T_2 treatment which aligns with a prior study by Mukhtar et al. (2018). The most preferable color was observed at the beginning of the storage period (0 d), whereas the least preferable color was observed at 15 d, also reported by Singh et al. (2011). When it came to flavor, there were significant differences between all treatments, indicated by different superscripts. The T3 treatment had the most preferable flavor because of the antioxidant and antibacterial components like the natural antioxidant preventing deterioration of flavor (Horbanczuk et al., 2019), while the T2 treatment had the least preferable flavor. Furthermore, there were significant changes in flavor values across all treatments during the observation period, suggesting deterioration in flavor with increased storage time**.** Regarding tenderness, T_3 and T_4 treatments were found to have the most preferable tenderness, while the T_2 treatment had the least preferable tenderness. The most preferable tenderness was observed at the beginning of the storage period (0 d), and the least preferable tenderness was observed at the 15 d. In terms of juiciness, the T_3 treatment scored the highest for juiciness, while the T_2 treatment scored the lowest. Similar to tenderness and color, the most preferable juiciness was observed at the beginning of the storage period (0 d), and the least preferable juiciness was observed at 15 d. The findings aligned with those of Krishnan et al. (2014) and Chidanandaiah et al. (2009), who similarly found a decrease in the tenderness and juiciness scores of several meat products during refrigeration. The overall acceptability of the meat was highest in the T_3 treatment and lowest in the T_2 treatment. Similarly, the most preferable overall acceptability was observed at the beginning of the storage period (0 d), and the least preferable overall acceptability was observed at 15 d. The lowest test scores for both juiciness and overall acceptability decreased to 4.25 and 5.50, respectively, in all treatments at 15 d of storage. The decline in overall acceptability was attributed to the decrease in sensory scores for other parameters such as appearance, flavor, and taste. These findings align with a previous study by Yadav et al. (2018), which also reported a significant decrease in overall acceptability during the storage period.

Table 1. Effect of different packaging and extra virgin olive oil on sensory parameters (Mean ± SE) on cooked broiler meat stored at 4°C

Parameters	Treatment	Mean	PMSP (Days)	Mean	Level of Significance		
					Treatment	PMSP	T*PMSP
Color	T_1	7.25^{a}	0	9.00^{a}	<0.0001	<0.0001	<0.0001
	T_2	6.75^{a}	5	8.00^{b}			
	T_3	7.75^{a}	10	6.75^{c}			
	T_4	7.25^{a}	15	5.25^{d}			
Flavor	T_1	7.25^{a}	0	9.00^{a}	<0.0001	<0.0001	<0.0001
	T_2	6.25^{a}	5	7.75^{b}			
	T_3	7.75^{a}	10	5.75^{c}			
	T_4	6.75^{a}	15	4.75^{d}			
Tenderness	T_1	6.75^{a}	0	9.00^{a}	<0.0001	<0.0001	<0.0001
	T_2	6.25^{a}	5	7.75^{b}			
	T_3	7.00^{a}	10	5.75^{c}			
	T_4	7.00^{a}	15	4.75^{d}			
Juiciness	T_1	6.50^{a}	0	9.00^{a}	<0.0001	<0.0001	<0.0001
	T_2	6.00^{a}	5	7.25^{b}			
	T_3	7.00^{a}	10	5.75^{c}			
	T_4	6.75^{a}	15	4.25^{d}			
Overall Acceptability	T_1	7.00^{a}	0	9.00^{a}	<0.0001	<0.0001	<0.0001
	T_2	6.75^{a}	5	7.50^{b}			
	T_3	7.50^{a}	10	6.50^{c}			
	T_4	7.25^{a}	15	5.50^{d}			

Sensory scores were 1=Dislike extremely, 2= Dislike very much, 3=Dislike moderately, 4=Dislike slightly, 5=Neither like or dislike, 6=Like slightly, 7=Like moderately, 8=Like very much, 9=Like extremely. Mean in each row having different superscript varies significantly at values $p < 0.05$. Again, mean values having same superscript in each row did not differ significantly at $p > 0.05$. T_1 = Aerial packaging of EVOO treated meat, T_2 = Aerial packaging of raw meat, T_3 = Vacuum packaging of EVOO treated meat, T_4 = Vacuum packaging of raw meat, PMSP = Post mortem stress period, Treat = Treatment, T*PMSP = Interaction of Treatment and Post mortem stress period.

Physicochemical properties

Physicochemical properties such as raw pH, CIE L*a*b* color, cooking loss, and water holding capacity (WHC) value were determined and presented in Tables 2 & 3. The range for instrumental color, for CIE L*a*b* at different treatments, were 44.76 to 53.55, 3.93 to 5.14, and 5.77 to 6.81 respectively (Table 2). The most preferable CIE L* was observed in the T_2 group, the most preferable CIE a* was observed in the T_4 group, most preferable CIE b* was observed in the T_4 group. The results of meat color analysis, particularly for breast meat samples, align with previous research that indicates CIE L* values increase as the meat ages. Several published reports, such as those by Santé et al. (1996), Le Bihan-Duval et al. (1999), Mallia et al. (2000),

Owens and Sams (2000), Owens et al. (2000), and Qiao et al. (2001), support these findings. The range of raw pH values across treatments was found to be between 6.40 and 6.49. Similarly, the range for cooking loss was 25.51% to 29.16%, and for WHC it was 86.32% to 87.05%. Over the observation period, range values for raw pH were 6.27 to 6.73, for cooking loss were 25.39% to 29.50%, and for WHC were 84.80% to 89.33%. The T_2 treatment exhibited the most preferable raw pH. The raw pH was observed to be most preferable at the beginning of the storage period (0 d), and less preferable on the 10 d of observation. This decrease in pH over time potentially due to the reduction of bacteria and mold, which release pH-lowering components. Similar findings have been reported in a study by Singh et al. (2014). However, there was a significant increase in pH on 15 d, possibly due to bacterial consumption of acids produced during protein breakdown, as the stored glucose gets depleted. Another potential cause of the pH increase could be the release of ammonia molecules from endo protease or proteolytic microbial flora in the raw meat, as suggested by Mokhtar et al. (2012). The T_3 treatment showed the most preferable cooking loss. A reduction in the weight of meat during the cooking process is referred to as cooking loss. Thawing, dripping, and evaporation are major contributors to cooking losses (Jama et al., 2008). The lower cooking loss observed in the T_3 treatment suggests that it is more preferable to consumers compared to the other treatments. Thawing loss, which occurs due to freezing and subsequent thawing, is a significant component of cooking losses (Jama et al., 2008; Muchenje et al., 2009). The T_3 treatment exhibited the most preferable WHC, with the most preferable values observed on the 10 d and less preferable values on the 5 d of observation. The rate and extent of pH decline, proteolysis, and protein oxidation in the early post mortem period can influence the ability of meat to retain moisture, as reported by Huff-Lonergan (2005). Therefore, the interaction between treatment and post mortem stress period for raw pH, cooking loss, and water holding capacity was significant (Table 3).

Table 2. Effect of different packaging and extra virgin olive oil on instrumental color (Mean ± SE) on broiler meat stored at 4°C

Parameters	CIE Value	Treatment	Mean	PMSP (Days)	Mean	Level of Significance		
						Treatment	PMSP	T*PMSP
Color	**L***	T_1	52.15^{a}±3.73	0	48.80^{a}±2.42	0.0350	0.2405	0.9177
		T_2	53.55^{a}±2.47	5	53.90^{a}±3.00			
		T_3	51.86^{a}±5.25	10	51.53^{a}±4.02			
		T_4	44.76^{b}±3.36	15	48.09^{a}±5.37			
	a*	T_1	4.73^{a}±1.03	0	3.60^{a}±0.16	0.3489	0.1115	0.5945
		T_2	3.96^{a}±0.72	5	5.19^{a}±1.60			
		T_3	3.93^{a}±0.60	10	3.88^{a}±0.90			
		T_4	5.14^{a}±0.91	15	5.10^{a}±0.60			
	b*	T_1	5.92^{a}±0.96	0	4.37^{c}±0.29	0.3733	<0.0001	0.0334
		T_2	5.77^{a}±0.85	5	6.59^{a}±1.06			
		T_3	6.22^{a}±0.70	10	6.00^{b}±0.65			
		T_4	6.81^{a}±0.56	15	7.76^{a}±1.25			

Mean in each row having different superscript varies significantly at values $p < 0.05$. Again, mean values having same superscript in each row did not differ significantly at $p > 0.05$. T_1 = Aerial packaging of EVOO treated meat, T_2 = Aerial packaging of raw meat, T_3 = Vacuum packaging of EVOO treated meat, T_4 = Vacuum packaging of raw meat, PMSP = Post mortem stress period, Treat = Treatment, T*PMSP = Interaction of Treatment and Post mortem stress period.

Table 3. Effect of different packaging and extra virgin olive oil on physiochemical parameters (Mean ± SE) on broiler meat stored at 4°C

Parameters	Treatment	Mean	PMSP (Days)	Mean	Level of Significance		
					Treatment	PMSP	T*PMSP
RAW p^H	T_1	6.42^{a}±0.03	0	6.73^{a}±0.05	0.0664	<0.0001	0.0015
	T_2	6.49^{a}±0.05	5	6.35^{b}±0.13			
	T_3	6.43^{a}±0.01	10	6.27^{c}±0.01			
	T_4	6.40^{b}±0.02	15	6.38^{b}±0.05			
Cooking loss (%)	T_1	29.16^{a}±0.97	0	25.39^{c}±0.72	<0.0001	<0.0001	<0.0001
	T_2	27.89^{b}±0.57	5	27.09^{b}±0.73			
	T_3	25.51^{c}±0.66	10	29.50^{a}±0.73			
	T_4	26.77^{d}±0.72	15	27.36^{b}±0.73			
Water Holding capacity (%)	T_1	86.32^{a}±1.54	0	85.70^{b}±1.48	0.9247	0.0018	0.9177
	T_2	86.71^{a}±1.66	5	84.80^{b}±1.13			
	T_3	87.05^{a}±0.96	10	89.33^{a}±1.20			
	T_4	86.90^{a}±1.53	15	87.16^{a}±1.87			

Mean in each row having different superscript varies significantly at values $p < 0.05$. Again, mean values having same superscript in each row did not differ significantly at $p > 0.05$. T_1 = Aerial packaging of EVOO treated meat, T_2 = Aerial packaging of raw meat, T_3 = Vacuum packaging of EVOO treated meat, T_4 = Vacuum packaging of raw meat, T_4 = Vacuum packaging of raw meat, PMSP = Post mortem stress period, Treat = Treatment, T*PMSP = Interaction of Treatment and Post mortem stress period.

Oxidative stability

Thiobarbituric acid reactive substances (TBARS) Value

TBARS serves as an indicator for lipid oxidation and is utilized to evaluate the progression of secondary lipid oxidation, as highlighted by Jeon et al. (2002). The range of TBARS values observed across the different treatments was between 0.09 and 0.11. Notably, the TBARS value in the T_3 treatment was significantly lower ($p<0.05$) compared to the other treatment groups after 15 d of storage. During the post mortem stress period, the range of overall observed TBARS values was between 0.10 and 0.12. A lower TBARS value indicates a more preferable product for consumer health. In this case, the T_3 treatment showed a

more preferable TBARS value (Table 4). It was observed that the TBARS values of all samples increased significantly as the storage period extended, which aligns with a previous study by Biswas et al. (2012).

Table 4. Effect of different packaging and extra virgin olive oil on Thiobarbituric acid reactive substances (TBARS) value (Mean ± SE) on broiler meat stored at 4°C

Parameters	Treatment	Mean	PMSP (Days)	Mean	Level of Significance		
					Treatment	PMSP	T*PMSP
TBARS (Mg MDA/KG)	T1	0.10^{b}±0.00	0	0.10^{b}±0.00	<0.0001	<0.0001	<0.0001
	T2	0.11^{b}±0.01	5	0.10^{a}±0.08			
	T3	0.09^{a}±0.08	10	0.11^{b}±0.01			
	T4	0.11^{b}±0.01	15	0.12^{b}±0.00			

Mean in each row having different superscript varies significantly at values $p < 0.05$. Again, mean values having same superscript in each row did not differ significantly at $p > 0.05$. T_1 = Aerial packaging of EVOO treated meat, T_2 = Aerial packaging of raw meat, T_3 = Vacuum packaging of EVOO treated meat, T_4 = Vacuum packaging of raw meat, PMSP = Post mortem stress period, Treat = Treatment, T*PMSP = Interaction of Treatment and Post mortem stress period.

Microbiological assessments

The ranges for TVC, TCC, and TYMC at different treatments were 5.55–5.69, 3.60–3.75, and 3.68 to 3.72 log CFU/g, respectively, and during the postmortem stress period TVC, TCC and, TYMC were 5.28 to 5.89, 3.44 to 3.84, and 3.59 to 3.89 log CFU/g, respectively (Table 5). T_3 displayed the lowest TVC value at the end of storage. This suggests that EVOO and vacuum packaging are efficient in inhibiting microbial growth during storage. As the storage period increased, the TVC showed an upward trend, indicating an increase in the amount of microbial growth. In intermediate moisture foods the major spoilage microorganisms were inhibited by mixtures of clove (*Syzygium aromaticum*) and cinnamon (*Cinnamomum verum*) (Matan et al., 2006). Comparable finds have been found by Kim et al. (2013) on beef patties, Singh et al. (2015) on chevon cutlets and Bhat et al. (2015) on chicken nuggets which, with regard to tomato powder, Aloe vera, and clove oil, have also noticed a similar downside in the TVC. The TCC was significantly higher in T_2 than in the samples treated with natural antioxidants. During storage, TCC value was increased. The different superscript was observed in 0, 5, 10 and, 15 d of observation indicating that there were significant ($p<0.05$) differences among these four days of observation. The yeast and mold counts in the T_4 sample was significantly higher than the other samples. As storage days increased, TYMC was gradually raised during various treatments. The antifungal properties of EVOO may be responsible for the treated meat sample's lower TYMC. Veronica sirocchi et al. (2017) found that in vacuum-packed conditions, the growth of microorganisms can be slowed. Essential spice oil also increased the lifetime of minced beef to six days when kept at a temperature of 4±1°C. Similar findings were also observed by Javaherzadeh et al. (2020) in chicken fillet treated with essential oil at refrigerated temperature, Majdinasab et al. (2020) in refrigerated chicken fillet treated with summer savory essential oil emulsions, and Mulla et al. (2017) in chicken meat treated with clove essential oil.

Table 5. Effect of different packaging and extra virgin olive oil on Microbial assessment (Mean ± SE) of raw broiler meat stored at 4°C temperature.

Parameters	Treatment	Mean	PMSP (Days)	Mean	Level of Significance		
					Treatment	PMSP	T*PMSP
TVC (log CFU/)	T_1	5.69^{a}±0.01	0	5.28^{d}±0.05	0.301	<0.0001	0.072
	T_2	5.58^{a}±0.02	5	5.42^{c}±0.01			
	T_3	5.55^{a}±0.03	10	5.70^{b}±0.02			
	T_4	5.56^{a}±0.03	15	5.89^{a}±0.01			
TCC (log CFU/)	T_1	3.70^{a}±0.01	0	3.44^{c}±0.05	0.0003	<0.0001	0.0007
	T_2	3.75^{a}±0.01	5	3.65^{b}±0.01			
	T_3	3.69^{a}±0.01	10	3.81^{a}±0.01			
	T_4	3.60^{b}±0.04	15	3.84^{a}±0.00			
TYMC (log CFU/)	T_1	3.71^{a}±0.02	0	3.59^{d}±0.01	0.0105	<0.0001	0.433
	T_2	3.72^{a}±0.01	5	3.64^{c}±0.02			
	T_3	3.68^{b}±0.01	10	3.71^{b}±0.01			
	T_4	3.72^{a}±0.02	15	3.89^{a}±0.02			

Mean in each row having different superscript varies significantly at values $p < 0.05$. Again, mean values having same superscript in each row did not differ significantly at $p > 0.05$. T_1 = Aerial packaging of EVOO treated meat, T_2 = Aerial packaging of raw meat, T_3 = Vacuum packaging of EVOO treated meat, T_4 = Vacuum packaging of raw meat, PMSP = Post mortem stress period, Treat = Treatment, T*PMSP = Interaction of Treatment and Post mortem stress period.

Conclusions

Vacuum packaging and EVOO-treated meat was better regarding sensory, physicochemical, anti-oxidative, and microbial properties. Hence, to increase the shelf life and prevent lipid oxidation of stored meat and meat products, vacuum packaging and EVOO may be used in the future as alternatives to synthetic antioxidants for meat preservation.

Conflicts of Interest

The authors declare no potential conflicts of interest.

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