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Research Article

The effect of aerobic and modified atmospheric packaging on the color chemistry of refrigerated chicken leg meat

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Abstract

The demand for chicken meat is continuously increasing in the consumer market. Increasing the shelf life of chicken meat with modern packaging technology in the supply chain is necessary. Hence, research was undertaken to study the effect of aerobic packaging (AP) and modified atmospheric packaging (MAP) on the quality and shelf-life of chicken meat. The chicken leg meat (CLM) was stored under refrigerated storage (4±1°C) with aerobic and modified atmospheric packaging (MAP20 = 20% O_2 + 30% CO_2 + 50% N_2, MAP10 = 10% O_2 + 40% CO_2 + 50% N_2, MAP0 = 0% O_2 + 20% CO_2 + 80% N_2) conditions and evaluated for quality attributes. The results indicated that MAP has significantly increased the color of the chicken leg meat compared to AP. The changes in myoglobin forms, meat pigment, haeme iron, hunter lab color units (L*, a*, b*) were insignificant under aerobic as well as modified atmospheric packaging. It is concluded that under refrigerated storage conditions, MAP extends the desirable color of chicken leg meat upto 15 days compared to only 6 days for aerobic packaging.

Key words: Aerobic packaging, Chicken leg meat, Modified atmospheric packaging, Quality, Shelf-life

Highlights

- Modified atmospheric packaging (MAP) significantly ($p<0.05$) stabilizes the color of chicken leg meat.
- Aerobic packaging (AP) significantly ($p<0.05$) decreases the total meat pigment and haeme iron in chicken leg meat.
- A low oxygen high carbon dioxide MAP (0-20% O2+20-40% CO2+50-80% N2) can increase the shelf-life by 150% in chicken meat under refrigeration storage.

INTRODUCTION

Modified atmospheric packaging is generally employed in the food industry to preserve the quality and prolong the shelf life of meat and meat products. McMillin (2008) stated that modified atmospheric packaging is the replacement and/or removal of the atmospheric gases surrounding the food product before sealing the package with vapor-barrier packaging materials. The key principle of MAP is the exclusion of oxygen (which limits the shelf-life of meat by causing lipid oxidation and/or by increasing the growth of spoilage microorganisms) by using a barrier film or by altering the gaseous environment surrounding the meat. The use of any preservation method intended to improve the shelf-life of foods has to consider the dynamics of the total system. In the case of MAP of meat, the chief concerns as a result of dynamic changes are enzymatic ageing, microbial deterioration, oxidative rancidity, and differences in the oxidative forms of the myoglobin pigment (Narasimha Rao and Sachindra, 2002).

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Three gases are mainly used in MAP namely carbon dioxide, oxygen, and nitrogen. Oxygen preserves the bright red color of meat but causes oxidative rancidity, growth of aerobic spoilage organisms, premature browning during cooking. Carbon dioxide has antimicrobial effects but it causes pack collapse and a minor decrease in pH. The efficiency of the MAP in improving the shelf-life of meat relies on the antibacterial property of carbon dioxide existing inside the package. Nitrogen is used as filler gas as well as to prevent pack collapse caused by carbon dioxide. Nitrogen has no antimicrobial properties and does not affect the meat color (Narasimha Rao and Sachindra, 2002). Nitorgen gas packaging did not significanlty affect the growth of microbial populations but delayed the degradation of food product appearance (Koseki and Itoh, 2002).

Some of the researchers have established that modified atmosphere packaging improves the quality and shelf life in chicken meat. Chmiel *et al.* (2018) indicated that chicken breast meat packaged in MAP with 75% O_2+25% CO_2 maintained the quality and shelf life till 9 days in cooling display case compared to 8 days in packing with normal air. Abdullah *et al.* (2017) reported that 70% N_2+30% CO_2 is preferable for modified atmosphere packaging of organic chicken meat in polyolefin films under chiller storage. Patsias *et al.* (2008) found that MAP reduced the Pseudomonads 2-4 log cfu/g and inhibits the growth of yeast and molds in chicken fillets stored under freeze chilling. Kahraman *et al.* (2015) showed that rosemary essential oil in combination with MAP reduced the lipid oxidation in poultry fillets. Meredith *et al.* (2014) illustrated that MAP (40% CO_2+30% O_2+30% N_2) of chicken fillets reduced *Campylobacter* and increased the shelf-life beyond 14 days in chiller storage.

There is still a big challenge to the meat researchers and processors to arrive at definite gas mixtures using MAP for a specific meat to enhance the shelf life at a specific storage condition by maintaining the required quality and safety of meat. Besides, there is lack of research with regards to MAP and comparisons of different gaseous compositions for leg meat of chicken and the effects of aerobic packaging versus MAP on meat quality. Therefore, this research was undertaken to study the comparative effects of MAP and aerobic packaging on the quality attributes of chicken meat.

MATERIALS AND METHODS

Meat sample: The broiler chicken meat (Cobb strain) was obtained from the local retail chicken meat shop in Chengicherla, Hyderabad. The chicken breast meat sample of approximately 200 g was weighed and placed in a clean tray (Tray-EVOH; Overwrap-PET/PP). The packaging trays were sterilized under the UV chamber for 30 minutes to avoid any cross-contamination. For modified atmospheric packaging, the gas mixture (O_2, CO_2, N_2) was blended in a Gas mixing machine (Elixir technologies, GAS MIXER - E2M316, Bangalore) attached to oxygen, carbon dioxide, nitrogen cylinders. Then the gases were flushed into the trays containing meat and sealed in a Tray sealing machine (Elixir technologies, Tray sealer - ETS 300 GS, Bangalore). The concentrations used in modified atmospheric packaging were MAP-20 (20% O_2+30% CO_2+50% N_2), MAP-10 (10% O_2+40% CO_2+50% N_2), and MAP-0 (0% O_2+20% CO_2+80% N_2). In aerobic packaging, the trays were sealed using a Tray sealing machine without flushing any gas. The packaged meat was then stored under refrigeration storage at 4±1ºC. The aerobically packaged meats were analyzed on 0, 3, 6, and 9 days of storage. Modified atmosphere packaged samples were studied at 0, 3, 6, 9, 12, 15, 18, and 21 days of storage.

Physico-chemical parameters: The moisture content was estimated by hot air oven, protein using automatic digestion and distillation unit, and the fat was estimated by ether extraction following AOAC (1995).

To extract the myoglobin from the chicken meat sample Krzywicki (1982) and Shang *et al*. (2020) method was used. Five gram of chicken meat sample was weighed and then 50 mL of phosphate buffer (40 mmol/L, pH 6.8, 4ºC) was added to it. Using an Ultrasonic probe sonicator (PCI Analytics, PKS-750F, Mumbai, India) samples were homogenized and kept in the ice bath for 60 min. Then samples were taken in 50 mL centrifuge tubes and frozen centrifuged at 5000 rpm (4ºC) for 30 min. The supernatant was filtered through filter paper Grade no: 1 (Hi-Media Laboratories Pvt Ltd., Mumbai). Krzywicki's equations were modified using wavelength maxima at 503 nm, 557 nm, 582 nm for metmyoglobin (Mmb), deoxymyoglobin (Dmb), oxymyoglobin (Omb) respectively. The absorbance was recorded with the help of a UV-VIS Spectrophotometer (UV-1700 PharmaSpec, Shimadzu, Japan), at 525 nm, 503 nm, 557 nm, 582 nm. The proportions of the three forms of myoglobin were calculated as follows:

$$Dmb\% = -0.543R_1 + 1.594R_2 + 0.552R_3 - 1.329$$
$$Omb\% = 0.722R_1 - 1.432R_2 - 1.659R_3 + 2.599$$
$$Mmb\% = -0.159R_1 - 0.085R_2 + 1.262R_3 - 0.520$$

Where $R_1 = A_{582}/A_{525,}\ R_2 = A_{557}/A_{525,}\ R_3 = A_{503}/A_{525.}$

Solvent extraction technique modified from Hornsey (1956) was used to determine the total meat pigments of chicken meat. Using the Ultrasonic probe sonicator (PCI Analytics, PKS-750F, Mumbai, India) 10 g of minced chicken meat sample was homogenized with 23 mL of a mixture containing 40 mL of acetone + 2 mL of distilled water and 1 mL of concentrated HCl. The remaining solution was added and kept for 1 hour with intermittent mixing. This solution was then filtered which gave a solution of acid haematin in 80% acetone. The filtrate was composed of haematin derived from any uncombined meat pigments present, together with that resulting from the oxidized pigments. At 640 nm, the optical density of the filtrate is measured. Distilled water was used as blank. The obtained absorbance was then multiplied by a factor of 680 which gave the concentration of total pigments present in meat as ppm of haematin. Haeme iron content was calculated as follows by using the haematin concentration.

Haematin (ppm) (a) : Abs (640 nm) × 680

Haeme iron : (a × 8.82) / 100

The instrumental color was measured using Hunter Lab Apparatus (Lovibond-RT-500 series, serial number: 35177, WO-A26424, Dortmund, Germany). The chicken meat sample was placed below the disc of Hunter Lab Apparatus. The lightness (L*), redness (a*), and yellowness (b*) color units were recorded by comparing the meat sample with that of standard.

Sensory analysis: The sensory quality of the chicken meat samples was judged based on appearance, color, odor, and sliminess characteristics. The samples were subjected to sensory evaluation by a panel consisting of a minimum of seven members. A minimum of seven values was collected for each sample and the sensory evaluation was repeated thrice.

Statistical analysis: The experiment has been repeated a minimum of three times in duplicate and the data obtained for different meat quality parameters were compiled and analyzed using SPSS (version 16.0 for Windows, SPSS, Chicago, USA). The data were subjected to analysis of variance, (one-way ANOVA) for different groups and storage days. The least significant difference and Duncan's multiple range tests were applied for comparing the means to find the difference between groups and storage days. The smallest difference (D5%) for the two means was reported as significantly different ($p<0.05$).

RESULTS

Proximate composition: The mean values of the moisture, protein, and fat content of leg meat were 74.01, 18.64, and 4.65% respectively.

Deoxymyoglobin/Oxymyoglobin/ Metmyoglobin content: The deoxymyoglobin content of all the groups was significantly

($p<0.05$) increasing, with storage time (Table 1). The metmyoglobin content of the AP-CLM and MAP-CLM10 significantly ($p<0.05$) increased with storage time (Table 1). There was no significant difference ($p>0.05$) in MAP-CLM20 and MAP-CLM0 groups with the storage period. The metmyoglobin content of the AP-CLM group was significantly ($p<0.05$) lower compared to MAP-CLM groups on days 0 and 3 of the refrigerated storage period. The Mmb content of MAP-CLM20 was significantly ($p<0.05$) lower on days 18 and 21 and significantly ($p<0.05$) higher on days 6. The oxymyoglobin content of all the groups was found to be significantly ($p<0.05$) decreasing with storage time (Table 1), which may be due to a decrease in oxygen % with storage time. There was no significant difference ($p>0.05$)

Table 1. Myoglobin form changes in aerobic and modified atmospheric packaged chicken leg meat during refrigeration storage (4±1ºC)

Parameters/ Groups	Days of storage							
	0	3	6	9	12	15	18	21
Deoxymyoglobin (%)								
AP-CLM	26.45^{aAB} ±0.73	25.69^{aB} ±0.58	25.40^{aB} ±0.26	27.25^{aA} ±0.31	ND	ND	ND	ND
MAP-CLM20	22.02^{bB} ±1.44	23.44^{bAB} ±0.54	23.74^{aAB} ±1.08	25.14^{AB} ±0.71	24.54^{aAB} ±1.37	24.44^{aAB} ±1.00	25.50^{aA} ±0.48	26.00^{aA} ±1.26
MAP-CLM10	22.19^{bC} ±0.29	24.47^{abBC} ±0.64	23.77^{aBC} ±0.89	24.82^{BC} ±0.54	24.40^{BC} ±0.52	25.20^{aBC} ±0.33	26.72^{aAB} ±1.58	28.75^{aA} ±2.35
MAP-CLM0	21.19^{bC} ±1.68	23.50^{bBC} ±0.69	24.27^{aBC} ±0.46	24.04^{bBC} ±0.76	23.67^{aBC} ±1.11	25.07^{aAB} ±0.42	25.67^{aAB} ±0.82	28.32^{aA} ±1.98
Metmyoglobin (%)								
AP-CLM	55.99^{bB} ±1.33	56.60^{bB} ±0.52	59.97^{aA} ±0.24	59.77^{aA} ±0.11	ND	ND	ND	ND
MAP-CLM20	58.67^{abA} ±1.20	60.65^{aA} ±1.27	59.89^{aA} ±2.26	60.17^{aA} ±0.41	59.70^{aA} ±0.66	60.51^{aA} ±0.79	60.51^{bA} ±1.97	59.27^{bA} ±1.59
MAP-CLM10	59.62^{aC} ±0.36	58.90^{abC} ±0.83	60.77^{aBC} ±0.65	60.80^{aBC} ±1.24	61.48^{aBC} ±1.35	62.30^{aABC} ±0.71	64.30^{aAB} ±0.51	65.70^{aA} ±2.51
MAP-CLM0	59.79^{aA} ±1.18	60.02^{bA} ±0.97	60.19^{aA} ±0.67	60.90^{aA} ±0.62	62.17^{aA} ±1.05	61.71^{aA} ±1.10	62.04^{abA} ±0.89	62.50^{abA} ±0.64
Oxymyoglobin (%)								
AP-CLM	17.79^{aA} ±0.99	16.40^{abB} ±0.75	14.79^{aC} ±0.41	14.54^{aC} ±0.33	ND	ND	ND	ND
MAP-CLM20	19.55^{aA} ±2.00	17.75^{aAB} ±0.72	16.64 ±2.00^{aABC}	14.75^{aBC} ±0.82	14.18^{aBC} ±0.23	14.87^{aBC} ±0.67	13.64^{aBC} ±1.40	13.47^{aC} ±1.28
MAP-CLM10	17.72^{aA} ±1.86	15.09^{bAB} ±0.77	14.43^{aAB} ±0.64	14.65^{aAB} ±0.92	14.37^{aAB} ±1.49	14.47^{abAB} ±2.10	10.67^{aBC} ±0.46	6.50^{abC} ±4.25
MAP-CLM0	18.87^{aA} ±0.72	16.67^{abAB} ±0.63	16.84 ±1.53^{aAB}	14.43^{aBC} ±0.61	12.60^{aCD} ±0.75	11.37^{bCD} ±0.36	11.77^{aCD} ±1.91	10.94^{aD} ±1.06

n=6; Means with different superscripts in the same column (small letters) and same row (capital letters) differ significantly ($p<0.05$); AP-CLM= Aerobic packaged chicken leg meat; MAP-CLM20 = Modified atmosphere packaged chicken leg meat (20% O_2+30% CO_2+50% N_2); MAP-CLM10 = MAP leg meat (10% O_2+ 40% CO_2+50% N_2); MAP-CLM0 = MAP leg meat (0% O_2 + 20% CO_2+80% N_2) packaged at 4±1ºC in Omb between the AP-CLM group and MAP-CLM groups during the whole storage time. The Omb content of the MAP-CLM20 was significantly ($p<0.05$) higher compared to other MAP groups.

Total meat pigments (TMP): The total meat pigments concentration and haeme iron content of all the groups were significantly ($p<0.05$) decreasing, with storage time (Table 2). The TMP concentration and haeme iron content of the AP-CLM group were significantly ($p<0.05$) higher compared to MAP-CLM groups on days 3 and 6 of the refrigerated storage period. The TMP concentration & haeme iron content of MAP-CLM20 was significantly ($p<0.05$) lower on days 3, 6, and 9 and significantly ($p<0.05$) higher on days 18 and 21 compared to other MAP groups.

Hunter lab color value: The lightness (L*) value was significantly ($p<0.05$) increasing in the AP-CLM group with storage time (Table 3). No significant differences ($p>0.05$) in L* values were noticed between the AP-CLM and MAP-CLM groups with the storage time. The redness (a*) value was significantly ($p<0.05$) increasing in the MAP-CLM20 group with storage time (Table 3), which may be due to more oxygen concentration. The redness (a*) values of the AP-CLM group was significantly ($p<0.05$) higher than MAP-CLM groups on days 0 and 9 of the refrigerated storage period. The redness (a*) value was significantly ($p<0.05$) lower in MAP-CLM10 on day 15 of the refrigerated storage period. No significant difference ($p>0.05$) in yellowness (b*) values was noticed in AP-CLM and MAP-CLM groups with storage time (Table 3). The yellowness (b*) value was

Table 2. Total meat pigments and haeme iron changes in aerobic and modified atmospheric packaged chicken leg meat during refrigeration storage (4±1ºC)

Parameters/ Groups	Days of storage							
	0	3	6	9	12	15	18	21
Total meat pigments (ppm)								
AP-CLM	7.41^{aA} ±0.30	6.97^{aA} ±0.15	5.60^{aB} ±0.23	4.01^{abC} ±0.31	ND	ND	ND	ND
MAP-CLM20	6.04^{aA} ±1.26	3.78^{bB} ±0.25	3.60^{bB} ±0.14	3.44^{bB} ±0.12	3.88^{aB} ±0.24	4.15^{aB} ±0.39	4.82^{aAB} ±0.43	4.94^{aAB} ±0.55
MAP-CLM10	6.51^{aA} ±0.25	6.34^{aA} ±1.16	5.92^{aA} ±0.41	4.29^{aB} ±0.37	4.01^{aB} ±0.29	3.89^{aB} ±0.39	3.66^{bB} ±0.33	3.70^{bB} ±0.29
MAP-CLM0	6.85^{aA} ±1.39	5.76^{aAB} ±0.19	5.28^{aABC} ±0.09	4.74^{aBCD} ±0.19	4.06^{aBCD} ±0.33	4.12^{aBCD} ±0.44	3.84^{bCD} ±0.36	3.44^{bD} ±0.24
Haeme iron (mg/kg)								
AP-CLM	6.53^{aA} ±0.27	6.15^{aA} ±0.13	4.93^{aB} ±0.20	3.61^{abC} ±0.27	ND	ND	ND	ND
MAP-CLM20	5.32^{aA} ±1.11	3.33^{bB} ±0.22	3.17^{bB} ±0.12	3.02^{bB} ±0.10	3.41^{aB} ±0.22	3.63^{aB} ±0.34	4.25^{aAB} ±0.38	4.35^{aAB} ±0.48
MAP-CLM10	5.73^{aA} ±0.22	5.58^{aA} ±1.02	5.21^{aA} ±0.36	3.77^{aB} ±0.33	3.53^{aB} ±0.26	3.42^{aB} ±0.35	3.22^{bB} ±0.29	3.26^{bB} ±0.26
MAP-CLM0	6.03^{aA} ±1.23	5.07^{aAB} ±0.17	4.99^{aAB} ±0.15	4.17^{aBC} ±0.17	3.57^{aBC} ±0.30	3.65^{aBC} ±0.39	3.38^{bC} ±0.32	3.03^{bC} ±0.22

n=6; Means with different superscripts in the same column (small letters) and same row (capital letters) differ significantly ($p<0.05$); AP-CLM = Aerobic packaged chicken leg meat; MAP-CLM20 = Modified atmosphere packaged chicken leg meat (20% O_2+30% CO_2+50% N_2); MAP-CLM10 = MAP leg meat (10% O_2+ 40% CO_2+50% N_2); MAP-CLM0 = MAP leg meat (0% O_2 + 20% CO_2+80% N_2) packaged at 4±1ºC

Table 3. Color value changes in aerobic and modified atmospheric packaged chicken leg meat during refrigeration storage (4±1ºC)

Parameters/ Groups	Days of storage							
	0	3	6	9	12	15	18	21
L* value								
AP-CLM	63.67^{aB} ±4.19	65.17^{aB} ±3.44	67.67^{aAB} ±3.26	73.34^{aA} ±3.11	ND	ND	ND	ND
MAP-CLM20	68.50^{aA} ±3.34	70.84^{aA} ±3.42	76.34^{aA} ±5.08	75.34^{aA} ±0.67	72.00^{aA} ±2.53	69.17^{aA} ±4.17	63.67^{aA} ±3.91	72.00^{aA} ±6.67
MAP-CLM10	67.34^{aA} ±3.47	71.00^{aA} ±1.57	71.84^{aA} ±1.82	71.67^{aA} ±3.41	71.00^{aA} ±2.52	69.67^{aA} ±8.35	64.00^{aA} ±6.56	70.50^{aA} ±6.56
MAP-CLM0	69.17^{aA} ±1.85	68.50^{aA} ±4.94	66.67^{aA} ±7.17	74.00^{aA} ±0.45	67.00^{aA} ±4.78	65.34^{aA} ±4.75	70.17^{aA} ±4.60	72.17^{aA} ±3.68
a* value								
AP-CLM	23.84^{aA} ±3.82	20.17^{aA} ±2.94	22.84^{aA} ±2.80	19.17^{aA} ±2.10	ND	ND	ND	ND
MAP-CLM20	13.00^{bC} ±2.58	13.17^{aC} ±0.91	15.17^{aBC} ±1.22	15.83^{abBC} ±2.96	16.67^{aBC} ±1.23	20.17^{abABC} ±2.09	21.83^{aAB} ±3.47	26.5^{aA} ±4.12
MAP-CLM10	22.34^{abA} ±3.95	19.50^{aA} ±2.66	19.50^{aA} ±2.60	14.00^{abA} ±1.90	15.84^{aA} ±0.91	14.00^{bA} ±2.78	22.67^{aA} ±4.77	19.67^{aA} ±2.88
MAP-CLM0	22.50^{abA} ±1.41	20.50^{aA} ±3.49	20.67^{aA} ±5.34	12.00^{bA} ±0..77	16.34^{aA} ±1.48	23.67^{aA} ±4.64	24.17^{aA} ±5.28	20.84^{aA} ±4.21
b* value								
AP-CLM	29.17^{aA} ±5.70	32.84^{aA} ±4.23	32.50^{aA} ±4.10	31.50^{aA} ±2.80	ND	ND	ND	ND
MAP-CLM20	38.34^{aA} ±2.59	24.34^{aA} ±4.51	28.00^{aA} ±3.96	26.83^{aA} ±5.28	37.00^{aA} ±3.70	26.00^{bA} ±3.91	36.00^{aA} ±8.56	29.84^{aA} ±5.67
MAP-CLM10	27.17^{aA} ±4.77	27.00^{aA} ±2.78	29.50^{aA} ±5.52	32.34^{aA} ±4.39	28.00^{aA} ±4.62	25.67^{bA} ±4.01	35.34^{aA} ±5.59	23.50^{aA} ±4.01
MAP-CLM0	32.00^{aA} ±1.63	30.17^{aA} ±5.09	29.84^{aA} ±5.18	30.50^{aA} ±2.87	31.67^{aA} ±5.89	39.19^{aA} ±4.52	34.67^{aA} ±6.14	34.17^{aA} ±6.26
Color (sensory)								
AP-CLM	5.00 ±0.01	5.00^{a} ±0.01	4.00^{b} ±0.01	2.00^{c} ±0.01	ND	ND	ND	ND
MAP-CLM20	5.00^{A} ±0.01	5.00^{aA} ±0.01	4.67^{aAB} ±0.21	4.00^{aBC} ±0.01	3.97^{aC} ±0.42	3.67^{aC} ±0.42	1.67^{aD} ±0.21	1.34^{aD} ±0.21
MAP-CLM10	5.00^{A} ±0.01	4.17^{bB} ±0.11	4.67^{aAB} ±0.21	4.00^{aBC} ±0.01	3.34^{aCD} ±0.56	3.00^{aD} ±0.37	1.34^{abE} ±0.21	1.33^{aE} ±0.21
MAP-CLM0	5.00^{A} ±0.01	4.50^{abAB} ±0.32	3.84^{bBC} ±0.31	3.67^{bBC} ±0.21	3.34^{aC} ±0.56	3.34^{aC} ±0.21	1.34^{abD} ±0.21	1.34^{aD} ±0.21

n=6; Means with different superscripts in the same column (small letters) and same row (capital letters) differ significantly ($p<0.05$); AP-CLM = Aerobic packaged chicken leg meat; MAP-CLM20 = Modified atmosphere packaged chicken leg meat (20% O_2+30% CO_2+50% N_2); MAP-CLM10 = MAP leg meat (10% O_2+ 40% CO_2+50% N_2); MAP-CLM0 = MAP leg meat (0% O_2 + 20% CO_2+80% N_2) packaged at 4±1ºC significantly ($p<0.05$) higher in MAP-CLM0 on day 15 of the refrigerated storage period.

Sensory color value: The color score of all the modified atmosphere groups was significantly ($p<0.05$) decreasing, with storage time. The color score of the AP-CLM group was significantly ($p<0.05$) lower than MAP-CLM groups on days 6 and 9 of the refrigerated storage period (Table 3). MAP-CLM10 had a significantly ($p<0.05$) lower color score within MAP-CLM groups on day 3. The color was moderately acceptable up to day 6 in aerobic packages and MAP-CLM groups for up to 15 days.

DISCUSSION

Proximate composition: More amount of fat content may be due to the slaughter of older birds or birds fed on the high-fat content diet, which denotes the intensively reared broiler chicken used in the study. The differences in the proximate composition may be attributed to the fact that changes in the seasonal and nutrition states of birds, age of slaughter, and food composition. Clark *et al.* (1997) noticed that the moisture content of cooked chicken dark meat and light meat were 66% and 65% respectively. The moisture content of raw chicken breast and drumsticks were 76.5% and 75.5% respectively (Kongkachuichai *et al.*, 2002). Cortez-Vega *et al.* (2012) indicated a mean value of moisture, protein, and crude fat percentage in the raw chicken breast at 5ºC as 75.82, 20.65, and 2.8 respectively. On day 1 of storage, the percentage of the proximate composition of turkey meatballs was as follows: moisture - 77.03%; fat - 1.98%; protein - 19.03%; ash - 1.61% and connective tissue - 1.46% (Gantner *et al.*, 2017). The mean values of the moisture, protein and fat content of raw longissimus dorsi of 6 months old lamb meat were found to be 73.60%, 63.40%, and 33.51% respectively (Pourkhalili *et al.*, 2013). The total protein content of the chicken breast muscles was found to be 23.22% and 23.24% for outdoor and indoor rearing systems respectively (Michalczuk *et al.*, 2014). The results of moisture and protein % were similar to mean values of the moisture, protein, and ether extract fat content of Cobb strain chicken breast showing 75.57%, 22.49% and 0.75% respectively. Similarly, the mean values for thigh meat of Cobb strain for moisture, protein, and ether extract content were 76.14%, 19.86%, and 2.88% respectively (Souza *et al.*, 2011).

Deoxymyoglobin/Oxymyoglobin/ Metmyoglobin content: Muscles contain metmyoglobin reducing enzymes, which catalyze the reduction of Mmb to Dmb which then reacts with oxygen to form Omb (Leygonie *et al.*, 2012). The metmyoglobin content of normal pH beef steak increased from 4.31% to 31.6% as storage time extended, with distinguishable differences between normal pH and dark cutting groups after 4 days of storage. Steaks in 20% O_2- MAP showed the highest metmyoglobin content after day 7, explained by the relatively low O_2 partial pressure on the meat surface, enhancing metmyoglobin formation (Lu *et al.*, 2020). Results were similar to Teuteberg *et al.* (2021) who found that on day 1, pork samples frozen for 12 weeks (-18ºC and 80ºC) showed, independent of the storage temperature, significantly lower deoxy-myoglobin and metmyoglobin and high oxymyoglobin % in comparison to samples, frozen for 24 weeks (-18ºC and 80ºC). Teuteberg *et al.* (2021) explained that the increased Mmb % and decreased Omb % in the pork samples, previously frozen stored for 24 weeks (-18ºC and 80ºC) was due to decrease or loss of myoglobin reducing activity during freezing.

Total meat pigments (TMP): The total meat pigments concentration gradually decreased in the meat up to day 11 of storage, by 36.23% for goose meat packed in MA (80% O_2+20% CO_2) and 23.77% for meat packed in vacuum. After 24 h concentration of TP reached 2.65 mg/g; however, on d 11 of storage, it reached 1.69 mg/g for MA and 2.02 mg/g for vacuum packaged meat (Orkusz *et al.*, 2017). The decrease in total meat pigment under MAP might be attributed to the oxidation of myoglobin during prolonged storage condtions and the amount of extractable pigment becomes less over the storage period. Cooked patties composed of ground chuck only (pH 6.0) exhibited a more intense stable pink color than the same patties with a pH of 5.7 (Mendenhall, 1989). Clark *et al.* (1997) expressed that the haeme iron values of cooked chicken dark meat and light meat were 5.6 μg/g and 2.3 μg/g. Valenzuela *et al.* (2009) noticed that the mean values of haeme iron in loin and brisket of beef were 0.9 mg/100g and 0.8 mg/100g respectively. Pourkhalili *et al.* (2013) noticed that the mean value of haeme iron content on a dry weight basis in raw lamb meat at -18ºC was 44.62 μg/g.

Hunter lab color value: An increase in the lightness value may be due to structural variations such as protein oxidation or cross-linking, most likely under highly oxidized conditions (Lu *et al.*, 2020). There was no significance between the redness (a*) values of the roast chicken meat in different treatments (N: 100% N_2, M2: 20% CO_2+80% N_2, M3: 30% CO_2+70% N_2 and M4: 40% CO_2+60% N_2) and storage time. The initial L* value of samples was 37.78 and the L* (lightness) values increased significantly only at day 4, and then remained to be stable. No significant differences ($p>0.05$) in L* values were noticed between the AP-CLM and MAP-CLM groups with the storage time. The color of muscle is affected by numerous factors the most important of which are sex, age, intramuscular fat, moisture percentage, pre-slaughtering conditions, processing methods, presence of muscle pigments (Mothershaw *et al.*, 2009). According to Li *et al.* (2020), the older chicken muscles exhibited darker, redder, and less yellow color than the chicken muscles with younger age. Decreased a* values are usually related to the gradual formation of metmyoglobin which causes meat discoloration (Insausti *et al.*, 2001). Orkusz *et al.* (2017) found that goose meat packed in MA (80% O_2+20% CO_2) for 7 d showed an increase in yellowness at 4ºC. The change of the b* value, for MA packed samples, resulted from the significant decrease in total pigments and relative concentration of oxymyoglobin %, as well as an increase in the relative concentration of metmyogloibin %.

Sensory color value: The decrease in color may be due to the oxidation of myoglobin to metmyoglobin. Lee *et al.* (2018) noticed that the taste and odor of wrap-packaged dry-aged beef stored at 4ºC for 7 days were significantly deteriorated at day 5, while the overall acceptance significantly decreased at day 3 when compared to day 0.

The desirable color of chicken leg meat analyzed inaerobic packaging under refrigerated conditions (4±1°C) was 6 days. Modified atmospheric packaging of chicken leg meat had a desirable color of 15 days irrespective of different gaseous concentrations. Modified atmosphere packaging allows the extension of the desirable color of chicken meat in comparison to aerobic packaging by at least 9 days for leg meat under refrigeration storage. For chicken leg meat, oxygen at the rate of 0-20% and carbon dioxide at the rate of 20-40% along with nitrogen gas at the rate of 50-80% are recommended in MAP for improving the desirable color in refrigerated storage.

Conflict of interest: Authors have no conflict of interest in this study.

Author's contribution: GK: Conceptualized the idea, supervised the research, analyzed the data, written and corrected the manuscript; TA: Executed the research work, tabulated the data, and written the manuscript; MS: Helped in guidance of the research scholar; YB & KM: Helped in writing and editing of the manuscript.

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