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EFFECT OF *MORINGA OLEIFERA* LEAVES AQUEOUS EXTRACT ON THE PHYSICOCHEMICAL, COLOR, SHEAR FORCE, AND LIPID OXIDATION OF VARIOUS GOAT MUSCLES

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ABSTRACT

The present study evaluated the effect of aqueous extract of *Moringa oleifera* leaves (MOLE) on various physicochemical characteristics color, shear force, and lipid oxidation of various goat muscles. Longissimus dorsi m., infraspinatus m., biceps femoris m., and semimembranous m., were marinated with MOLE (0.10, 0.50, and 1.0% w/v) along with positive control containing 0.1% BHT (butylated hydroxytoluene) and negative control (without extract and BHT). The samples were marinated under refrigeration in low-density polyethylene bags for 7 days and assessed for various quality attributes on 1, 3, and 7 days. The water-holding capacity and moisture content of goat muscles were observed to follow a decreasing trend with increasing storage days, and a higher ($p<0.05$) value was recorded for samples on day 1 of storage as compared to day 7 of storage. Lipid oxidation recorded a significant ($p<0.05$) increase with the advancement of storage days, and samples with 1.0% MOLE were observed to show comparable ($p>0.05$) thiobarbituric acid reactive substances (TBRAS) to that of BHT-added samples. Thus, the inclusion of MOLE at a 1.0% concentration demonstrated significant improvement in the physico-chemical quality, and color stability while also inhibiting lipid oxidation similar to that achieved with 0.10% BHT.

1.Introduction

Goat meat is very popular and universally preferred by consumers across various cultures, religions, and societies due to the absence of religious issues. Goat meat is recommended for health-conscious consumers due to its desirable lipid profile, lower calorific value, and lower sodium content (Chaosap *et al.*, 2021; Watkins *et al.*, 2021). Goat meat has low glycolytic potential, thus making it crucial to preserve muscle glycogen levels by mitigating preslaughter stress for a desirable ultimate pH. In addition, the small and lean carcass of the goat is more prone to shortening during aging

(Pophiwa *et al.*, 2020). Further, the higher toughness/stringiness of goat meat due to its production from culled/spent animals, lack of sufficient nutrition, inappropriate pre-slaughter handling, and post-slaughter processing remain significant issues in goat meat production (Kumar *et al.*, 2022) and warrant the immediate attention of meat scientists. Various technological interventions are applied to improve the tenderness of goat meat, such as marination and ultrasound applications (Kumar *et al.*, 2023; Sobri *et al.*, 2023).

Like other meat, goat meat is prone to quality deterioration due to oxidative and microbial changes during storage (Kumar *et al.*, 2013). Various preservatives are used in the meat industry to control the quality deterioration. These preservatives can be categorized into two groups: synthetic preservatives (butylated hydroxytoluene, butylated hydroxyanisole, propyl gallate, etc.) and natural preservatives (plant extracts, essential oils, and bioactive compounds). With the increasing awareness and consumer shifts towards minimally processed food and the potential adverse effects of synthetic preservation on consumer health, the meat industry is increasingly using natural preservatives as replacement of synthetic preservatives (Awad *et al.*, 2021, 2022). Various plant extracts prepared by extracting the bioactive compounds from the plant matrix are increasingly used to develop functional meat products with extended shelf life (Mehta *et al*., 2022).

Moringa oleifera/ drumstick has a high amount of polyphenolic and bioactive molecules such as rhamnetin, anthraquinones, kaempferol, saponins, alkaloids, kaempferitrin, isoquercitrin, terpenoids, triterpenoids, and tannins (Singh *et al.*, 2015). Leaves and flowers of *Moringa* are commonly used as food additives, lactagogues, mineral supplements, immune modulators, antimicrobials, antidiabetic and cardioprotective roles (Gopalakrishnan *et al.*, 2016). *Moringa oleifera* leaves are incorporated in powdered or extract form to improve nutritional and technological qualities, oxidative stability, sensory attributes, and shelf-life extension in food products. *Moringa oleifera* leaves extract (MOLE) incorporation in meat products was reported to improve the organoleptic attributes and inhibit lipid oxidation, such as at 0.3% level in goat meat nuggets (Rahman *et al.*, 2020), 2.0 % extract in buffalo meat (Kenawi and El-Hameed, 2018), and at 0.25% extract in mortadella (Francelin *et al.*, 2022).

Several studies reported the application of MOLE in improving oxidative stability, organoleptic attributes, and shelf life of goat meat products, but there is a lack of studies on the application of MOLE on the various quality attributes of various goat muscles. In addition, a comparative analysis regarding the effect of MOLE on individual muscle groups is lacking. Thus, the present study was undertaken to evaluate the effect of the incorporation of MOLE on the quality attributes of various goat muscles.

2. Materials and methods

2.1. Extract preparation

Moringa plants were cultivated at Ladang 15, Faculty of Agriculture, Universiti Putra Malaysia, and produced organically. Fresh *M. oleifera* leaves were harvested approximately after 60 days of plantation The harvested leaves were cleaned, freeze-dried, and ground to fine powder form. The aqueous extract of *Moringa oleifera* leaves was prepared by taking 1: 10 powder: solvent (double distilled water) ratio in a conical flask at ambient temperature (25 ± 2°C) and stirred at 200 rpm for 2 h followed by centrifugation (Anke DL-6000 B; China) at 2500 g for 30 min at 4°C. The supernatant was stored under refrigeration for use in the study.

2.2. Meat sampling and marination

Goat skeletal muscles were obtained by the slaughter of 5 male goats (Boer cross, live weight 18-21 kg, age 5-6 months) by following Halal slaughter as per the standard protocols outlined in the MS 1500:2009 by the Department of Standards Malaysia. After the ventral neck cut and proper removal of blood, goats were hoisted on rails and skinned and dressed manually. The carcasses were kept in the chiller (4±1°C) for 24 h for aging. Four major muscles viz., longissimus

dorsi (LD), biceps femoris (BF), infraspinatus (IS), and semi-membranous (SM), were carefully cut with a clean and sharp knife under hygienic conditions.

Immediately after collecting muscles from the carcass, the muscles were marinated by preparing marinades viz., negative control (clean potable water without MOLE and BHT) and positive control (water added with 0.1% BHA), T1 (0.1% MOLE), T2 (0.5% MOLE), and T3 (1.0% MOLE), thereby resulted in the preparation of a total of 20 samples for the present study (Table 1).

Table 1. Sampling protocol of the experiment

Muscle type	NC	C	T1	T2	T3
LD	LD-	LD+	LDT1	LDT2	LDT3
IS	IS-	IS+	IST1	IST2	IST3
BF	BF-	BF+	BFT1	BFT2	BFT3
SM	SM-	SM+	SMT1	SMT2	SMT3

(NC- negative control without BHT and MOLE, C- control with 0.10% BHT, LD-Longissimus dorsi m.; IS-Infraspinatus m.; SM- semimembranosus m.; BF-Biceps femoris m., BHT-Butylated hydroxytoluene, MOLE-*Moringa oleifera* leaves aqueous extract)

2.3. Physicochemical parameters

The WHC of goat muscle was assessed by per Whiting & Jenkins (1981). About 30 g of mixed meat of each individual type of goat muscle was taken and placed in between two filter papers. The sample was placed on a rigid glass plate, and 40 psi pressure (equivalent to 2.81 kg) was applied for 5 min. After the pressure application, the meat sample was removed, and the weight of the dry meat flake was noted.

$$\text{WHC (\%)} = [(\text{Pre-press weight of flake} - \text{Post-press weight of meat flake}) / (\text{Pre-press weight of flake})] \times 100 \quad (1)$$

The pH of various goat muscle samples was assessed by using a portable pH meter (Mettler Toledo, AG 8603, Switzerland) calibrated at pH 4.0 and pH 7.0. The 0.5 g of pulverized sample was homogenized (Wiggen Hauser® D-500, Germany) along with 5 mM sodium iodoacetate for 30 s in 10 mL of ice-cold distilled water in order to stop further glycolysis.

Moisture levels in various goat muscles were measured by calculating the reduction in weight before and after heating the samples in the hot air oven at (105°C) for 3 h in a moisture cup and transferred to a desiccator to cool.

$$\text{Moisture \%} = (W1-W2) \times 100 \quad (2)$$

where :
W1= weight g before drying
W2=weight g after drying

2.4. Thiobarbituric acid-reacting substances (TBARS)

The lipid oxidation of various goat muscles was assessed by estimation of TBARS (Wang *et al.*, 2002). Five grams of muscle tissue was homogenized for 30 s in a homogenizer with 25 mL of 20% trichloroacetic acid solution and filtered through the Whatman filter paper number. A 2 mL of 0.02 M thiobarbituric acid aqueous solution (3 g/L) was added to the muscle filtrate in a test tube and heated to 100°C for 30 minutes. The sample was cooled under running water followed by measuring absorbance at 532 nm by using UV-VIS spectrophotometer (UV-1200, Shimadzu, Japan). The TBARS value was assessed with help from the standard curve and presented as mg malonaldehyde/kg of sample.

2.5. Shear force analysis

The water-bath cooked goat muscle samples (10 min at 78°C internal temperature) were cut parallel to the direction of the muscle fibers in three replicate samples of uniform size of 1 × 1× 2 cm. Each block was set on the base plate of a TA-HD plus texture analyzer (Stable Micro System, Surrey, UK) and sheared perpendicularly in the longitudinal direction of the fibers with the help of attached Volodkevitch biting jaw to the texture analyzer.

2.6. Color profile

The CIE color value (*L**: +lightness/- dark, *a**: +redness/- green, and *b**: yellowness/- blue) of water bath cooked (10 minutes at 78°C internal temperature) goat muscle samples were measured by using ColorFlex® system (5cm aperture size, 10° standard observer, D65 illuminant). Before usage, the instrument was calibrated using white and black reference tiles supplied with the equipment, and the *L**, *a**, and *b** color coordinates were recorded on the muscle's sliced surface.

2.7. Statistical analysis

The mean value and standard error of replicates (N=6) were analyzed on SPSS-20.0 software packages, IBM Corporation, USA. The significant difference between means within a muscle type affected by MOLE concentration and storage was compared by using a two-way analysis of variance (ANOVA) by using Duncan's Multiple Range Test (DMRT). For texture profiles and color analysis on day 3 of storage, one-way ANOVA was used to compare these attributes among muscle samples. The statistical significance was tested at a 5% level ($p<0.05$).

3.Results and discussions

The marination of goat muscle with various concentrations of MOLE (0.1%, 0.5%, 1.0%) significantly affected the physico-chemical and quality characteristics.

3.1. Water holding capacity

The WHC of goat muscles was affected by the MOLE concentration in marinates and storage days (Table 2). With the advancement of storage days, WHC of all muscle samples exhibited a decreasing trend, with all four muscle samples, viz., LD, IS, SM, and BF samples, exhibiting significantly ($p<0.05$) lower values on day 7 as compared to WHC value of their respective samples on day 1 of storage.

Among LD muscle, increasing MOLE concentration was recorded with higher WHC value with LD-02 sample was recorded significantly ($p<0.05$) higher value than LDT-01 and LD+ and comparable to LD-. On the last day of refrigerated storage, LD-01 and LD-03 samples had comparative WHC and a significant ($p<0.05$) lower value than other LD muscle samples. The mean WHC values of IS+ muscle and IS-01 were recorded as comparable and significantly ($p<0.05$) higher than IS-02. IS-03 sample on day 1 of storage. The WHC of the IS-03 sample exhibited comparable values on day 1 and day 3 and on day 7 of storage, the WHC of IS-03 samples was significantly ($p<0.05$) reduced as compared to those on day 1 and day 7.

On day 1, the mean WHC value of SM-03 was significantly ($p<0.05$) higher than all other SM groups, viz., SM-01, SM-02, SM+, and SM-. There was a significant ($p<0.05$) decrease in WHC value for the SM-02 sample upon storage to 3 days, and the WHC values of SM-02 on day 3 and day 5 were comparable ($p>0.05$). Among SM samples on day 7, the highest value was recorded for SM-01, which was comparable ($p>0.05$) to SM-03 and SM-. The mean WHC of SM-03 was recorded as comparable to all other samples on day 3 and day 7. The mean value of WHC among BF groups, BF-03, had recorded the highest value among all other BF muscle samples throughout the storage.

The WHC of goat muscles has shown a decreasing trend with increasing days of storage. This result could possibly be explained by denaturation and proteolysis of muscle protein during refrigeration storage, leading to decreased water binding by the myofibrillar proteins. A similar decrease in the WHC upon increasing storage was observed in ground meat (Ahmed *et al.*, 2015; Das *et al.*, 2011). The higher WHC of goat muscles with MOLE samples could be due to the potential preservative effect of the MOLE.

3.2. pH values

In general, the mean pH value of goat muscle samples showed an increasing trend with the increasing storage days (Table 3). The mean pH value of all muscle samples on day 7 was significantly ($p<0.05$) higher than their corresponding value at the beginning of the study, i.e., day 1. Among various treatments of LD muscle, the incorporation of MOLE and BHT resulted in increasing pH, on day 1, LD-

samples had significantly ($p<0.05$) lower pH values to LD-01 and lower but non-significant ($p>0.05$) difference than other samples viz., LD-02, LD-03, and LD+. On day 7 of storage, LD-02 and LD-03 samples had comparable values, which in turn resulted in significantly ($p<0.05$) lower pH value than the pH value of LD+ and LD- samples.

Table 2. Water holding capacity (WHC) of goat muscles marinated with *Moringa oleifera* leave extract (Mean ±SE)

Treatment	Day 1	Day 3	Day 7
LD			
LD-01	91.63 ± 0.54^{bA}	90.87 ± 0.44^{bA}	80.36 ± 0.05^{aA}
LD-02	98.64 ± 0.11^{cC}	91.85 ± 0.06^{bA}	84.77 ± 2.90^{aB}
LD-03	95.98 ± 2.31^{cB}	89.48 ± 0.22^{bA}	81.55 ± 0.43^{aA}
LD+	95.91 ± 1.32^{bB}	92.55 ± 1.30^{aB}	86.30 ± 3.33^{aB}
LD-	97.38 ± 0.78^{bC}	90.56 ± 1.93^{aA}	90.04 ± 2.43^{aC}
IS			
IS-01	97.92 ± 0.98^{bB}	91.50 ± 0.43^{aA}	92.65 ± 1.54^{aC}
IS-02	94.21 ± 0.32^{bA}	93.96 ± 0.43^{abAB}	91.76 ± 1.43^{aBC}
IS-03	96.29 ± 0.33^{bAB}	94.19 ± 1.26^{bB}	80.66 ± 0.31^{aA}
IS+	99.09 ± 0.88^{cB}	92.95 ± 0.21^{bA}	88.54 ± 1.02^{aB}
IS-	95.94 ± 0.21^{bAB}	92.16 ± 0.98^{aA}	92.85 ± 1.54^{aC}
SM			
SM-01	94.00 ± 1.32^{bA}	93.26 ± 1.43^{bB}	90.08 ± 0.43^{aB}
SM-02	95.92 ± 0.97^{bA}	88.55 ± 3.22^{aA}	85.42 ± 0.44^{aA}
SM-03	97.68 ± 1.43^{cB}	91.25 ± 0.67^{bAB}	87.88 ± 3.90^{aAB}
SM+	94.86 ± 0.54^{cA}	91.09 ± 0.33^{bAB}	84.78 ± 3.06^{aA}
SM-	93.95 ± 1.43^{bA}	93.70 ± 1.88^{bB}	89.54 ± 2.54^{aB}
BF			
BF-01	94.34 ± 1.20^{bAB}	91.01 ± 0.20^{aA}	90.89 ± 1.09^{aA}
BF-02	96.68 ± 0.11^{bC}	95.68 ± 0.65^{bB}	88.12 ± 3.44^{aA}
BF-03	97.93 ± 0.23^{bC}	94.94 ± 0.43^{aB}	93.54 ± 1.31^{aB}
BF+	95.26 ± 1.03^{bB}	94.09 ± 0.67^{bC}	92.35 ± 0.65^{aAB}
BF-	92.66 ± 0.44^{aA}	92 ± 0.99^{aA}	91.87 ± 1.21^{aAB}

N=6, Mean with different superscripts in A, B, C---and a, b, c differed significantly ($P < 0.05$) within a column-wise and row-wise, respectively; LD: longissimus dorsi m.; IS: infraspinatus m.; SM: semimembranous m.; BF: bicep femoris m., Muscle-1: muscle with 0.10% MOLE, Muscle-2: muscle with 0.50% MOLE, Muscle-03: muscle with 1.0% MOLE, Muscle-: muscle without BHT and MOLE, Muscle+: muscle with 0.10% BHT

Table 3. pH values of goat muscles marinated with *Moringa oleifera* leave extract (Mean ±SE)

Treatment	Day 1	Day 3	Day 7
LD			
LD-01	5.99 ± 0.02^{bB}	5.89 ± 0.02^{aAB}	6.03 ± 0.02^{bAB}
LD-02	5.86 ± 0.02^{aAB}	5.91 ± 0.08^{bAB}	5.95 ± 0.04^{bA}
LD-03	5.86 ± 0.02^{aAB}	6.08 ± 0.04^{cB}	5.93 ± 0.03^{bA}
LD+	5.88 ± 0.04^{aAB}	5.84 ± 0.06^{aA}	6.31 ± 0.02^{bC}
LD-	5.78 ± 0.01^{aA}	5.91 ± 0.04^{bAB}	6.11 ± 0.03^{cB}
IS			
IS-01	5.98 ± 0.02^{aC}	6.15 ± 0.08^{bC}	6.19 ± 0.04^{bC}
IS-02	5.85 ± 0.03^{aB}	5.90 ± 0.07^{bA}	5.94 ± 0.08^{bA}
IS-03	5.99 ± 0.04^{aC}	6.03 ± 0.04^{aAB}	6.05 ± 0.02^{aAB}
IS+	6.03 ± 0.04^{aCD}	6.07 ± 0.05^{abB}	6.14 ± 0.03^{bBC}
IS-	5.61 ± 0.06^{aA}	6.08 ± 0.09^{bB}	6.10 ± 0.07^{bB}
SM			
SM-01	6.03 ± 0.04^{a}	6.15 ± 0.09^{bB}	6.28 ± 0.04^{c}
SM-02	6.00 ± 0.07^{a}	5.90 ± 0.09^{aA}	6.30 ± 0.08^{b}
Sm-03	5.99 ± 0.02^{a}	6.16 ± 0.06^{bB}	6.32 ± 0.06^{c}
SM+	$6.05\pm.03^{a}$	$6.06\pm.08^{aA}$	6.33 ± 0.07^{b}
SM-	6.05 ± 0.04^{a}	6.19 ± 0.03^{bB}	6.31 ± 0.04^{c}
BF			
BF-01	5.98 ± 0.07^{bB}	5.85 ± 0.08^{aA}	6.03 ± 0.06^{bA}
BF-02	5.99 ± 0.02^{bB}	5.91 ± 0.05^{aAB}	6.13 ± 0.08^{cB}
BF-03	5.97 ± 0.06^{aB}	5.88 ± 0.07^{aA}	6.28 ± 0.07^{bC}
BF+	6.06 ± 0.01^{bC}	5.87 ± 0.04^{aA}	6.22 ± 0.04^{cC}
BF-	5.84 ± 0.07^{aA}	6.07 ± 0.03^{bB}	6.09 ± 0.06^{bAB}

N=6, Mean with different superscripts in A, B, C---and a, b, c differed significantly ($P < 0.05$) within a column-wise and row-wise, respectively; LD: longissimus dorsi m.; IS: infraspinatus m.; SM: semimembranous m.; BF: bicep femoris m., Muscle-1: muscle with 0.10% MOLE, Muscle-2: muscle with 0.50% MOLE, Muscle-03: muscle with 1.0% MOLE, Muscle-: muscle without BHT and MOLE, Muscle+: muscle with 0.10% BHT

Similar trends of the lowest mean pH value for the IS- sample were recorded at the beginning of the experiment and thereafter exhibited increasing value with the advancement of storage duration. Further, the pH value for IS samples on day 7 was significantly ($p<0.05$) higher than the pH value on day 1 of their respective IS samples, except for IS-03 samples. In SM samples, the mean pH value of all SM samples was recorded non-significantly ($p>0.05$) different on day 1 and day 7 of storage. The pH value of BF- showed an increasing trend with the advancement of storage days, with pH values of days 3 and 7 comparable and were significantly ($p<0.05$) higher than the pH value on day 1. All other samples of BF muscles exhibited a slight decrease in pH on day 3 compared to day 1 except for BF- samples, and again, increased pH values for all samples were recorded on day 7.

The incorporation of MOLE had an impact on the pH value of goat muscles. The pH showed an increasing trend with the advancement of storage days. The lowest pH among all muscle samples was recorded at the end of the storage period. This process increases proteolysis, forming primary amines (Rusman *et al.*, 2023; Yousof *et al.*, 2024). The higher pH of MOLE extract could also contribute to this value (Widiantara *et al.*, 2023).

3.3. Moisture content

The moisture content of all four-goat muscles under study, viz., longissimus dorsi, infraspinatus, semimembranous, and bicep femoris, exhibited decreasing trends with increasing storage days (Table 4). The muscle samples with the highest MOLE concentration (1.0%) had a higher moisture content than all other respective muscle samples except for IS muscle samples.

The moisture content of all treatments of all four muscle types under studies exhibited significantly ($p<0.05$) lower moisture content on day 7 of storage as compared to the moisture content of their respective treatment at the start of the storage experiment, i.e., day 1 of study. Among LD groups on the day 7 storage, moisture content for LD-03 samples was recorded significantly ($p<0.05$) higher than LD-01 and LD-02 and LD- samples, whereas LD-03 and LD+ have non-significant ($p>0.05$) moisture differences. The moisture content of IS-01 sample was recorded highest and significantly ($p<0.05$) different than all other IS samples on day 1 and day 3 of storage. Among SM muscle on day 7 storage, moisture content of SM-03, SM+, and SM-02 was recorded as comparable and significantly ($p<0.05$) higher than SM-01 and SM- samples

Table 4. Moisture content (%) of goat muscles marinated with *Moringa oleifera* leave extract (Mean ±SE)

Treatment	Day 1	Day 3	Day 7
LD			
LD-01	69.48 ± 1.32^{aA}	67.82 ± 3.65^{aA}	67.22 ± 2.40^{aA}
LD-02	68.26 ± 4.76^{aA}	68.04 ± 2.40^{aA}	68.54 ± 2.44^{aA}
LD-03	73.22 ± 3.43^{aB}	70.87 ± 3.21^{aB}	72.65 ± 1.01^{aB}
LD+	72.42 ± 3.21^{bB}	70.90 ± 2.32^{aA}	70.01 ± 0.32^{aAB}
LD-	73.10 ± 3.27^{bB}	71.50 ± 3.55^{bB}	67.47 ± 2.54^{aA}
IS			
IS-01	74.25 ± 2.95^{bC}	73.18 ± 2.49^{bC}	67.62 ± 2.43^{aB}
IF-02	72.91 ± 2.55^{bB}	70.89 ± 1.43^{bB}	69.92 ± 1.43^{aBC}
IS-03	69.73 ± 1.02^{bA}	65.86 ± 1.43^{abA}	63.81 ± 3.21^{aA}
IS+	72.07 ± 3.21^{bAB}	70.75 ± 0.54^{bB}	62.96 ± 3.72^{aA}
IS-	72.03 ± 2.43^{bAB}	71.45 ± 0.87^{aB}	69.77 ± 1.09^{aC}
SM			
SM-01	69.32 ± 0.55^{bA}	66.78 ± 2.54^{bA}	60.17 ± 1.43^{aA}
SM-02	72.64 ± 1.22^{bB}	70.26 ± 0.96^{bB}	70.06 ± 0.65^{aB}
SM-03	71.51 ± 2.54^{bC}	70.85 ± 2.54^{bB}	71.55 ± 0.54^{aB}
SM+	72.16 ± 1.54^{bA}	72.30 ± 0.76^{bB}	70.03 ± 1.40^{aB}
SM-	68.48 ± 2.32^{bB}	68.15 ± 2.44^{bB}	65.79 ± 1.54^{aA}
BF			
BF-01	71.23 ± 2.43^{bAB}	70.18 ± 0.43^{aAB}	69.08 ± 2.43^{aB}
BF-02	69.89 ± 1.55^{bA}	65.53 ± 1.29^{aA}	65.52 ± 1.98^{aA}
BF-03	72.09 ± 3.21^{bB}	71.72 ± 0.32^{aB}	70.48 ± 1.90^{aB}
BF+	72.42 ± 3.21^{bB}	70.80 ± 1.54^{bB}	67.49 ± 1.54^{aAB}
BF-	70.69 ± 3.25^{bAB}	68.28 ± 3.42^{bAB}	67.74 ± 0.32^{aAB}

N=6, Mean with different superscripts in A, B, C---and a, b, c differed significantly ($P < 0.05$) within a column-wise and row-wise, respectively; LD: longissimus dorsi m.; IS: infraspinatus m.; SM: semimembranous m.; BF: bicep femoris m., Muscle-1: muscle with 0.10% MOLE, Muscle-2: muscle with 0.50% MOLE, Muscle-03: muscle with 1.0% MOLE, Muscle-: muscle without BHT and MOLE, Muscle+: muscle with 0.10% BHT

The average moisture of the muscles under various treatments does not vary significantly ($p>0.05$) based on the type of the muscle and the age. The average moisture was recorded at about 70%, which is about the expected percentage of 75% (Babiker *et al.*, 1990). This could be due to proteolytic enzymes and minerals (calcium ions) present in *Moringa oleifera* leaves. The increasing calcium content has also been known to exert a tenderizing effect by increasing the activity of calpains (Khorchid and Ikura, 2002). The comparatively higher value of water holding capacity for 0.5% and 1.0% MOLE marinades and 0.1% BHA could be due to lower proteolysis in these samples due to better storage stability and antioxidant potential

Table 5. TBARS values (mg malondialdehyde/kg) of goat muscles marinated with *Moringa oleifera* leave extract (Mean ±SE)

Treatment	Day 1	Day 3	Day 7
LD			
LD-01	0.139 ± 0.01^{a}	0.431 ± 0.11^{bA}	0.845 ± 0.01^{cB}
LD-02	0.140 ± 0.05^{a}	0.385 ± 0.32^{bA}	0.749 ± 0.43^{cAB}
LD-03	0.138 ± 0.10^{a}	0.322 ± 1.30^{bA}	0.666 ± 1.55^{cA}
LD+	0.143 ± 0.20^{a}	0.321 ± 0.22^{bA}	0.675 ± 1.40^{cA}
LD-	0.143 ± 1.30^{a}	0.6275 ± 0.43^{bB}	1.238 ± 0.79^{cC}
IS			
IS-01	0.138 ± 1.11^{a}	0.428 ± 1.45^{bB}	0.829 ± 0.66^{cB}
IF-02	0.141 ± 1.65^{a}	0.406 ± 1.76^{bB}	0.763 ± 0.34^{cAB}
IS-03	0.138 ± 1.32^{a}	0.327 ± 1.87^{bA}	0.652 ± 1.54^{cA}
IS+	0.139 ± 0.32^{a}	0.322 ± 0.45^{bA}	0.676 ± 1.76^{cA}
IS-	0.144 ± 0.86^{a}	0.631 ± 0.32^{bC}	1.316 ± 0.98^{cC}
SM			
SM-01	0.14 ± 0.65^{a}	0.427 ± 0.44^{bB}	0.814 ± 0.65^{cC}
SM-02	0.139 ± 0.72^{a}	0.386 ± 0.74^{bAB}	0.732 ± 0.88^{cB}
Sm-03	0.139 ± 0.33^{a}	0.318 ± 0.77^{bA}	0.644 ± 0.32^{cA}
SM+	0.143 ± 1.43^{a}	0.351 ± 0.43^{bA}	0.683 ± 0.15^{cA}
SM-	0.143 ± 0.21^{a}	0.611 ± 0.24^{bC}	1.294 ± 0.98^{cD}
BF			
BF-01	0.141 ± 0.3^{a}	0.433 ± 0.41^{bB}	0.819 ± 0.32^{cC}
BF-02	0.1415 ± 0.2^{a}	0.398 ± 0.17^{bAB}	0.754 ± 1.76^{cB}
BF-03	0.1385 ± 1.54^{a}	0.318 ± 0.43^{bA}	0.644 ± 1.90^{cA}
BF+	0.1385 ± 1.22^{a}	0.388 ± 0.16^{bAB}	0.714 ± 0.76^{cAB}
BF-	0.144 ± 0.28^{a}	0.604 ± 0.55^{bC}	1.281 ± 1.87^{cD}

N=6, Mean with different superscripts in A, B, C---and a, b, c differed significantly ($P < 0.05$) within a column-wise and row-wise, respectively; LD: longissimus dorsi m.; IS: infraspinatus m.; SM: semimembranous m.; BF: bicep femoris m., Muscle-1: muscle with 0.10% MOLE, Muscle-2: muscle with 0.50% MOLE, Muscle-03: muscle with 1.0% MOLE, Muscle-: muscle without BHT and MOLE, Muscle+: muscle with 0.10% BHT

3.4. Thiobarbituric acid reacting substances

The mean TBARS value of all treatments of goat muscles under study was recorded to have a significant ($p<0.05$) increase with the advancement of storage days (Table 5). Among the treatments of muscles, the negative control sample showed the highest TBARS value throughout all sampling days, whereas muscle with 1% MOLE and 0.1% BHA exhibited the lowest and comparable TBARS value. At the end of storage days (day 7), the TBARS value of negative control samples (muscle marinated with potable water) had a TBARS value of more than 1.0 in all muscle samples.

On day 7 of storage, LD-03 and LD+ had comparable ($p>0.05$) TBARS values. The TBARS value of LD muscles at the end of storage exhibited the following trends viz., LD-03<LD+<LD-02<LD-01<LD-. Among groups, all treatments of a muscle (5 treatments per muscle viz., Muscle-01, Muscle-02, Muscle-03, Muscle+, and Muscle -) had non-significant ($p>0.05$) differences in TBARS values at day 1 of storage.

The lower TBARS value of positive control samples (0.1% BHA) and samples marinated in a higher MOLE solution could be due to polyphenolic compounds present in MOLE exerting antioxidant activity (Awad *et al.*, 2022; El-Sayed *et al.*, 2017; Shah *et al.*, 2015; Yadav *et al.*, 2022). The higher antioxidant potential of *Moringa oleifera* leaves and its extract was reported in pork patties (Muthukumar *et al.*, 2014), buffalo meat products (Kenawi and El-Hameed, 2018), cooked meat patties (Das *et al.*, 2012) and goat meat nuggets (Rahman *et al.*, 2020).

3.5. Shear force values

Various goat muscle samples were water-bath cooked samples were measured on day 3 of storage. Marination with MOLE had a significant ($p<0.05$) effect on the mean shear force value of LD muscle (Table 6). The mean shear force value of the LD-03 sample was recorded as the lowest and comparable to other MOLE-incorporated samples of LD muscle. The highest shear force value was recorded for the LD- sample.

Table 6. Shear force values (kg) of goat muscles marinated with *Moringa oleifera* leave extract over 3 days of refrigerated storage (Mean ±SE)

Shear force	Day 3
LD	
LD-01	3.558 ± 0.43^{A}
LD-02	3.508 ± 0.01^{A}
LD-03	3.572 ± 0.15^{A}
LD+	3.787 ± 0.76^{B}
LD-	5.201 ± 1.30^{C}
IS	
IS-01	3.107 ± 0.87^{B}
IS-02	2.814 ± 0.22^{A}
IS-03	2.956 ± 0.88^{A}
IS+	4.807 ± 0.52^{C}
IS-	5.508 ± 1.34^{D}
SM	
SM-01	2.786 ± 0.01^{A}
SM-02	2.657 ± 0.32^{A}
SM-03	$2.606\pm.21^{A}$
SM+	2.707 ± 1.5^{A}
SM-	3.979 ± 1.83^{B}
BF	
BF-01	3.978 ± 0.33^{C}
BF-02	3.219 ± 1.40^{B}
BF-03	2.681 ± 0.43^{A}
BF+	5.452 ± 0.09^{D}
BF-	5.597 ± 1.43^{D}

N=6, Mean with different superscripts in A, B, C differed significantly ($P < 0.05$) within a column-wise for a muscle type; LD: longissimus dorsi m.; IS: infraspinatus m.; SM: semimembranous m.; BF: bicep femoris m., Muscle-1: muscle with 0.10% MOLE, Muscle-2: muscle with 0.50% MOLE, Muscle-03: muscle with 1.0% MOLE, Muscle-: muscle without BHT and MOLE, Muscle+: muscle with 0.10% BHT

Among IS muscle samples, the mean value for IS+ was recorded highest and significantly ($p<0.05$) higher shear force value than all other treatment groups of the same muscle. IS-02 and IS-03 samples had comparable ($p>0.05$) shear force values and were significantly ($p<0.05$) lower than the IS-01 sample. There was a non-significant ($p>0.05$) variation in mean shear

force value recorded for SM muscle samples except SM- which exhibited a significantly ($p<0.05$) higher value. The mean shear force value for BF-03 and BF- muscle was recorded as non-significant ($p<0.05$), but significantly ($p<0.05$) higher than all remaining samples of BF muscle.

The tenderness of the meat was measured by shear force value. The goat muscle samples treated with MOLE extract had lower shear force value as compared to positive and negative control samples. The lowest shear force and thus highest tenderness of goat muscle sample with the highest level of MOLE (1.0%) was recorded for all muscle samples as compared to their other respective samples viz., control, positive control, muscle-01, and muscle-02. This could be due to the proteolytic enzymes present in MOLE extract as well as the higher amount of calcium content in *Moringa oleifera* powder (Dania *et al.*, 2014; Singh *et al.*, 2015). A higher calcium content increases the calpain enzyme actions thus improving the tenderness of the meat (Gerelt *et al.*, 2002).

3.6. Colour profile

The color profile of the various water bath-cooked goat muscle samples was assessed on day 3 of storage (Table 7). The lightness (*L**) of all muscle samples having MOLE concentration was recorded at lower values as compared to the positive and negative control samples. The redness (*a**) and yellowness (*b**) values of LD muscle with MOLE extract were reported higher as compared to positive and negative control samples.

Incorporating higher MOLE levels resulted in better retention of color attributes due to the antioxidant activity of MOLE extract owing to polyphenolic substances. The increasing MOLE concentration in the marinades causes an increase in the yellowness value of muscle samples. This result could be due to pigments in the MOLE. Further, the yellowness and redness were also affected by the grinding and drying methods (Ali *et al.*, 2017). The incorporation of MOLE was reported to improve color stability in raw chilled beef (Shah *et al.*, 2015) and in cooked buffalo meat (Hazra *et al.*, 2012).

Table 7: Color values of goat muscles marinated with *Moringa oleifera* leave extract (Mean ±SE)

Treatment	*L** (lightness)	*a**(redness)	*b** (yellowness)
LD			
LD-01	53.92 ± 0.07^{BC}	9.50 ± 0.10^{C}	16.56 ± 0.02^{B}
LD-02	50.86 ± 1.85^{A}	9.21 ± 0.61^{C}	16.78 ± 0.14^{B}
LD-03	52.49 ± 0.34^{AB}	8.22 ± 0.38^{B}	18.96 ± 0.29^{C}
LD+	55.77 ± 0.16^{C}	6.50 ± 0.32^{AB}	14.52 ± 0.10^{A}
LD-	55.69 ± 1.05^{C}	5.79 ± 0.15^{A}	14.87 ± 0.17^{A}
IS			
IS-01	49.52 ± 0.25^{A}	10.50 ± 0.18^{C}	16.12 ± 0.40^{B}
IF-02	54.79 ± 0.15^{C}	7.17 ± 0.13^{A}	18.20 ± 0.29^{C}
IS-03	51.68 ± 0.09^{B}	11.11 ± 0.60^{C}	18.65 ± 0.12^{C}
IS+	55.41 ± 0.20^{C}	6.97 ± 0.05^{A}	15.08 ± 0.28^{AB}
IS-	55.64 ± 0.34^{C}	8.07 ± 0.14^{B}	13.99 ± 0.03^{A}
SM			
SM-01	49.21 ± 1.39^{C}	8.66 ± 0.50^{AB}	13.34 ± 0.54^{AB}
SM-02	44.57 ± 1.24^{B}	12.01 ± 0.15^{D}	16.39 ± 0.73^{C}
SM-03	40.64 ± 0.50^{A}	11.62 ± 0.67^{CD}	15.71 ± 0.39^{C}
SM+	49.39 ± 1.75^{C}	10.00 ± 0.80^{B}	12.58 ± 0.26^{A}
SM-	51.38 ± 0.40^{D}	7.63 ± 0.21^{A}	13.90 ± 0.43^{B}
BF			
BF-01	46.45 ± 0.24^{A}	8.53 ± 0.20^{C}	13.57 ± 0.08^{D}
BF-02	48.31 ± 0.38^{B}	6.08 ± 0.61^{B}	13.73 ± 0.50^{D}
BF-03	56.15 ± 0.92^{C}	9.41 ± 0.27^{C}	12.91 ± 0.09^{CD}
BF+	57.49 ± 0.22^{D}	5.82 ± 0.27^{AB}	11.39 ± 0.24^{B}
BF-	56.29 ± 0.63^{C}	5.26 ± 0.12^{A}	8.17 ± 1.20^{A}

N=6, Mean with different superscripts in A, B, C differed significantly ($P < 0.05$) within a column-wise for a muscle type; LD: longissimus dorsi m.; IS: infraspinatus m.; SM: semimembranous m.; BF: bicep femoris m., Muscle-1: muscle with 0.10% MOLE, Muscle-2: muscle with 0.50% MOLE, Muscle-03: muscle with 1.0% MOLE, Muscle-: muscle without BHT and MOLE, Muscle+: muscle with 0.10% BHT

4. Conclusions

Thus, it can be concluded that goat muscles marinated in a solution having higher levels of aqueous extract of *Moringa oleifera* leaves (1.0%) retained better quality characteristics such as color, decreased shear force, and lower thiobarbituric acid reacting substances during 7 days of storage under refrigeration conditions. *Moringa oleifera* leaves extract, due to its polyphenolic content, could be used as a natural

preservative in improving the oxidative stability of goat meat. The incorporation of aqueous extract 1.0 % Moringa oleifera leaves extract had a comparable preservative effect similar to the synthetic preservative used in the present study (0.1% BHA).

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