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Effect of Ultrasound and Oil Palm (*Elaeis guineensis* Jacq.) Fronds Extract on Quality Characteristics of Marinated Goat Meat

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ABSTRACT

The present study was conducted to evaluate the effect of ultrasound and aqueous extract of oil palm fronds (OPF) powder on the quality attributes of ultrasonic-assisted marinated (UAM) goat meat. The OPF extraction was carried out at powder to solvent (filtered water) of 1:7.5 w/v ratio and ultrasound application (37-kHz frequency, 150 W power at 40°C temperature for 20 min). The goat meat marination was done by applying ultrasonic treatment (280 W power, 37 kHz frequency, 30 min below 10°C) and adding 1.0% OPF extract viz., Control (marinade without extract and no ultrasonication), T1 (marinade with 1.0% OPF extract, no ultrasonication), T2 (marinade with ultrasonication), and T3 (marinade with 1.0% OPF extract and ultrasonication). The samples were analysed on day 0 (immediately after 30 min) and were stored under refrigeration and evaluated for various quality parameters on 1 and 3 days. The ultrasonic and extract incorporation resulted in a significant ($p<0.05$) increase in marinade pick-up and a significant ($p<0.05$) decrease in shear force value. Ultrasonic application (T2 and T3 samples) resulted in a higher cooking loss as compared to control and T1 on day 0 but the cooking loss of all treated samples was comparable on day 3 of refrigerated storage. The ultrasound and extract incorporation improved the appearance, flavour, and tenderness of the goat meat. Thus, the ultrasonic application for 30 min with 1.0% OPF extract in the marinade improved the quality attributes of marinated goat meat.

HIGHLIGHTS

- Aqueous extract of oil palm fronds exhibited potent antioxidant potential.
- Ultrasonic application improved marinade pick-up, appearance, flavour,and tenderness of the goat meat.
- A 30 minutes ultrasonic application and 1% aqueous extract of oil palm fronds improved goat meat quality attributes.

Keywords: Oil palm fronds, extraction, ultrasound, marination, goat meat, quality evaluation

Goat meat is a very popular meat and its consumption is devoid of any social, religious, or cultural taboos. It has lower calorific content, saturated fatty acids, and cholesterol content and is higher in potassium, iron, and high-quality protein (Kumar *et al*., 2023; Rathour *et al*.,

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2017b). However, goat meat is less tender and juicier than other red and poultry meat, although having an acceptable colour (Webb *et al*., 2005). The presence of a high amount of connective tissue in goat meat leads to higher toughness/ poor tenderness and stringiness. Other factors affecting the quality of goat meat are the use of culled/ spent animals, improper pre-slaughter handling, poor managemental practices, and undernutrition (Kumar *et al*., 2023; Umaraw *et al*., 2017). Hence, there is an urgent need to apply suitable technological interventions to improve the quality and acceptance of goat meat.

Among the various technological interventions available, marinating meat with suitable marinade is a common method used for improving tenderness, quality, and consumer acceptance. Immersion marination could lead to high salt pick-up, irregular marinade distribution, over-tenderised meat with poororganoleptic attributes. To overcome this ultrasonic application could be applied to accelerate the marination process of meat (González-González *et al*., 2017). The application of ultrasound radiation creates acoustic cavitation, shock waves (due to the collapse of tiny vapour-filled bubbles), and increases local temperature, thereby improving mass transfer, tenderisation, and functional quality of products without compromising other attributes (Mehta *et al*., 2022a; b). For improving the tenderness of the meat, low-frequency ultrasonic (20-100 kHz) radiations are used to vibrate the meat and create high-pressure areas (compressions) and low-pressure areas (rarefactions) (Wen *et al*., 2019).

Plant extracts are incorporated into meat and meat products as natural preservatives by inhibiting lipid oxidation and the growth of pathogenic and spoilage microorganisms (Kumar *et al*., 2013, 2020; Awad *et al*., 2021; 2022). However, there is still a lack of studies that utilise an agricultural by-product such as oil palm (*Elaeis guineensis* Jacq.) fronds in meat marination. The oil palm frond (OPF) extract contains potent antioxidant properties due to the presence of flavonoids and phenolics compounds (Tow *et al*., 2021). The antioxidants and antimicrobials such as flavonoids and phenolics contained in plant leaves were observed to significantly affect the quality characteristic of marinated beef during refrigerated storage (Istrati *et al*., 2013). The quality characteristics of goat meat during storage can be improved with antioxidants and antimicrobial compounds consisting of aqueous oil palm frond (OPF) extract.

The ultrasonic-assisted aqueous extraction (UAE) promises to be an effective, cost-saving, simple to run, and versatile technique. The UAE approach was observed to improve the antioxidant activity of the final extract by increasing the production of phenolic compounds relative to other methods (Arteaga-Crespo *et al*., 2020). The extraction by using water as a solvent is preferred due to its cost-effectiveness, food safety, and readily availability (Awad *et al*., 2021; 2022). The aqueous medium is also considered environmental-friendly as the aqueous solution is non-toxic than the organic solvents (Rathour *et al*., 2017). Thus, the application of ultrasound-assisted aqueous extraction of OPF could be beneficial in the development of novel meat products with improved quality characteristics. The present study was designed to utilises the ultrasonic-assisted aqueous extract of OPF and to evaluate the effect of marinades with this OPF extract at 1.0% level on storage stability and quality characteristics of goat meat stored under refrigeration temperature.

MATERIALS AND METHODS

Oil palm fronds powder and its characterization

Fresh *E. guineensis* fronds were collected at the small animal holding facility at the Institute of Tropical Agriculture and Food Security (ITAFoS) located in Universiti Putra Malaysia (UPM). The *E. guineensis* fronds were collected with a sharp knife from 2.0 years old oil palm trees,rinsed with clean water, and drained before drying. The drained fronds were dried at 60°C in a hot air oven for 17 h and ground into powder form. The powder was strained through a 100-mesh sieve and stored at room temperature in hermetically sealed polythene bags. The OPF powder was assessed for various quality attributes viz., pH as per Hayat *et al*. (2021), moisture percent and ash content as per (Association of Official Analytical Chemists, 2019) and colour profile (CIE L^*, a^*, b^*) by using ColorFlex® system (Illuminant D65, aperture size 5 cm, 10° standard observer).

Extract preparation and its DPPH value (% inhibition)

Based on preliminary trials and available literature, the OPF powder to solvent (filtered water) (1:7.5 w/v ratio) was mixed with pre-weighted solvent in a 500 mL flat bottom flask. During extraction, an ultrasonic bath cleaner (Elmasonic S 30) (frequency-37kHz, power-150W for 20 min) was used. The ultrasonic-assisted extraction was performed at 40±2°C, with the temperature continually monitored by a thermocouple and ice cubes to prevent temperature rise. The solution was centrifuged at 1500 rpm for 5 minutes after ultrasonic treatment and the precipitate was filtered through Whatman filter paper. The filtrate was concentrated further in a rotatory evaporator (RE300 Yamato Rotary Evaporator, Japan) at 40-45°C temperature, 70-75 rpm, 100 bar pressure, and 3°C chiller temperature. The semi-liquid extract was collected and refrigerated in amber-coloured vials until further usage. The overall procedure of extraction is shown in Fig. 1.

The free radical scavenging ability (scavenge 2, 2 diphenyl-1-picrylhydrazyl (DPPH)) of the aqueous extract was next assessed as per (Brand-Williams *et al*., 1995).

Goat meat

Goat meat was obtained by Halal slaughtering of goats (10 intact male, crossbred Boer, 6-9 months age, 20-25 kg live weight) at the research slaughterhouse, Department of Animal Science, Faculty of Agriculture, Universiti Putra Malaysia as per the standard protocols outlined in the MS 1500:2009 (Department of Standards Malaysia, 2009). The carcasses were kept for conditioning for 24 h in a cold room at 4±2°C. The aged carcass was manually deboned and trimmed off of any visible fat, fascia, and connective tissues. In the present study, the semimembranosus muscle was used for marination. The deboned meat (ultimate pH 5.5) was cut into small chunks (2.5 cm × 2.0 cm × 2.0 cm) and submerged in the prepared marinade.

Marination liquid (ML) preparation

Based on preliminary trials marinade liquid was prepared by using water, vinegar, salt, honey, black pepper, curry powder, and thyme. A marinade solution was made by combining filtered water (75%) and cider vinegar (25%). Salt (1.0%), honey (2.0%), thyme (0.2%), black pepper powder (0.2%), and curry powder (0.2%) were added to this solution and well mixed. The marinade was kept in clean water bottles and refrigerated until it was used.

Marination of goat meat

The goat meat was subsequently separated into four groups: C-control marinated without extract and ultrasound, T1-marinated with 1.0% aqueous OPF extract, T2-marinated and sonicated for 30 min; T3-marinated with 1.0% aqueous OPF extract and sonicated for 30 min. The ultrasonic

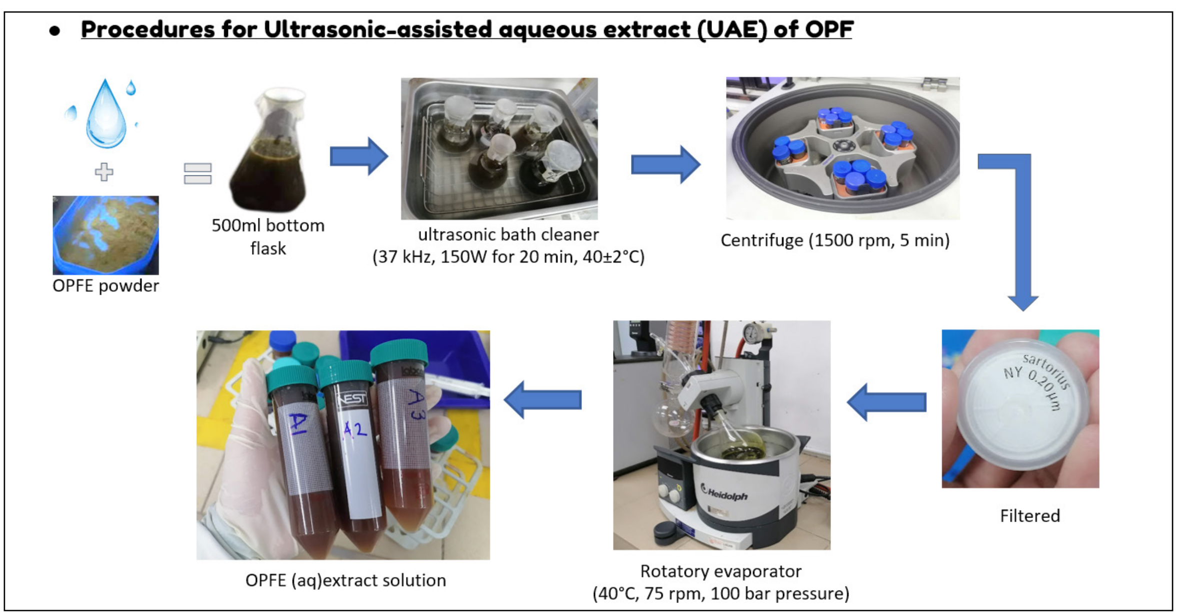

Fig. 1: Procedure for extraction of bioactive compounds from oil palm fronds

radiation (280 W power, 37 kHz frequency, 30 min below 10°C) was applied to the T2 and T3. All of the treatments were then sealed in low-density polyethylene (LDPE) bags (100 gauge) and stored in a refrigerator at 4±1°C. The samples were assessed for pH, marinade pick-up, surface colour, shear force, sensory analysis, cooking loss, and water holding capacity (WHC) at day 0 (immediately after 30 min of marination), day 1, and day 3.

Meat analysis techniques

To measure the cooking loss, meat sample was immersed in an 80°C water bath after being put in a polyethylene bag until the interior temperature reached 78°C. The samples were then left to cook for another 10 minutes. The bags containing the samples were then cooled for 30 minutes under running tap water before being dried by dabbing paper towels without squeezing and the weight was measured again. The cooking loss % was calculated using the following equation:

$$\text{Cooking loss (\%)} = \frac{wt \text{ before cook } (g) - wt \text{ after cook } (g)}{wt \text{ before cook } (g)} \times 100$$

The cooking yield was calculated by subtracting the cooking loss value from 100 by using the following formula:

$$\textit{Cooking yield} \text{ (\%)} = 100 - \textit{cooking loss}$$

The pH of marinated chevon was determined indirectly using a portable pH meter (Mettler Toledo, AG 8603, Switzerland). The pH was calibrated at pH 4.0 and pH 7.0 before application. To stop further glycolysis, a 0.5 g sample of crushed muscle was homogenised (Wiggen Hauser® D-500, Germany) in 10 ml of ice-cold double-distilled water (ddH_2O) for 20 seconds with 5 mM of sodium iodoacetate (Merck Schuchardt OHG, Germany). The pH of the resulting homogenates was determined using a portable glass electrode connected to a pH meter as per method described by Hayat *et al*. (2021).

The marinade pick-up technique was performed within 24 hours of marination to determine how much marinade solution was taken by the chevon muscle during 24 hours of marination. Each meat sample from C, T1, T2, and T3 was weighed before being combined with their respective treatments. After 24 hours, the weight of the meat in each sample was recorded. The percentage of marinade pick-up was estimated using the following formula:

$$\text{Marinade pickup (\%)} = \frac{wt \text{ after marination } (g) - wt \text{ prior marination } (g)}{wt \text{ prior marination } (g)} \times 100$$

The ColorFlex® system with an illuminant D65 as the light source and a 10-standard observer was used to assess the meat colour characteristics (L^*: lightness, a^*: redness, and b^*: yellowness) (aperture size of 5 cm). The equipment was calibrated against white and black tiles prior to use. The L^*, a^*, and b^* colour coordinate values were measured on the sliced surface of the muscle after 30 minutes of bloom time.

Forshear force analysis, the samples of the marinated goat meat from each of the treatment bags were cut into three replicates in a parallel direction to the muscle fibres. After being placed on the base plate of a TA-HD plus texture analyser (Stable Micro System, Surrey, UK), using a Volodkevich bite jaw (stainless-steel probe shaped like an incisor), and each block was then sheared perpendicularly in the longitudinal direction of the fibres (Hayat *et al*., 2021).

A total number of 7 in-housed trained panellists analysed the hot water bath cooked marinated meat samples for various sensory attributes viz. appearance, flavour, and tenderness on a 5-point descriptive scale for assessment (1-not acceptable; 2- moderately acceptable 3- good; 4- very good; 5- excellent) as per Lytou *et al*. (2017).

STATISTICAL ANALYSIS

The mean value and standard error of replicates (N=6) were analysed on SPSS-20.0 software packages, IBM Corporation, USA. The significant difference between means was compared by using analysis of variance (ANOVA) by using Duncan's Multiple Range Test (DMRT). The statistical significance was tested at a 5% level ($p \leq 0.05$).

RESULTS AND DISCUSSION

Characterisation of oil palm frond (OPF) powder

The results for the characterisation of OPF powder are summarised in Table 1. The pH value of the OPF powder was 5.33±0.05, thus falling under the category of slightly acidic food materials. The moisture content of OPF powder was recorded at 5.93±0.09 which is considered in the range of low range of moisture content (Hamdan *et al*., 2012). According to Ebrahimi *et al*. (2022), moisture content in oil palm leaves powder represents the water molecules that are trapped inside the matrix cell of the plant; it can appear as a free mass that resides outside the cell wall and an inherent type (water resides inside the cell wall) (Sulaiman *et al*., 2016). The ash content (%) of the OPF obtained was recorded 8.52±0.02. This finding is supported by Saka *et al*. (2008), who reported the presence of a higher amount of inorganic compounds in the oil palm, especially in their fronds and kernel cake containing potassium, calcium, and phosphorus. The colour of the OPF powder appears as dark greenish-yellowish in colour with colour attributes as $L*$ (44.18±1.04), $a*$ (2.09±0.62), and $b*$ (26.84±1.01). This might be due to the green pigmentation (chlorophyll) of the oil palm leaves (Zungu *et al*., 2020). The OPF powder was green-dark yellowish in colour as the yellowish colouration might also be due to the carotenoid substance present in oil palm fronds.

Table 1: Characterisation of oil palm fronds leaves powder

Parameter	Value
pH	5.33±0.05
Moisture (%)	5.93±0.09
Ash (%)	8.52±0.02
Lightness (*L**)	44.18±1.04
Redness (*a**)	2.09±0.62
Yellowness (*b**)	26.84±1.01
dE	51.73±1.31
Chroma	26.09±0.98
Hue	85.54±1.08

The DPPH (% inhibition) of ultrasound-assisted aqueous extract was recorded as 76.64±1.92. Similarly, Ibraheem *et al*. (2014) reported a very high concentration of polyphenols (52.4 mg GAE/ g) with catechin (0.55%) and ferulic acid (0.63%) as the main polyphenols in the purified extract of OPF. Further, the methanolic extract of OPF had total phenolic content slightly higher than TPC of green tea extract (24.3±1.7 vs 22.5±1.7 mg GAE/g extract) (Irine *et al*., 2003).

Marinade pick-up and shear force of marinated goat meat

The application of the ultrasound waves during marination was observed to increase the marinade pick-up significantly (Table 2). In the present study, the treatment with UAM (T2 and T3 samples) significantly ($p \leq 0.05$) increased the marinade pick-up as compared to T1 and C groups. Moreover, the marinades pick-up value increased further ($p \leq 0.05$) in T3, with the presence of OPF extract solution showing the highest weight gain among all treatments. This could be due to the increased absorption of marinade by the meat (Roslan *et al*., 2019) via ultrasonication treatment which ruptures the connective tissue and muscle tissue, thus improving the absorption of marinade by increasing its mass transfer. Other than that, the presence of OPF extract could also help to break down the meat muscle fibre, thus, the meat marinated with the OPF extract could be more receptive towards the marination solution hence improving the marinade pick-up.

The shear force value indicates the tenderness of the meat as the higher the shear force value obtained, the tougher the meat (Haraf *et al*., 2023). In this study, UAM, along with OPF extract, is applied to improve the tenderness of the marinated goat meat. The treatment with the presence of UAM together with OPF extract was observed to significantly ($p \leq 0.05$) decrease the shear force value (T2 and T3) as compared to T1 and control groups (Table 2). The decreasing value of shear force could be due to the rupture of myofibrils along the Z lines leading to muscle swelling during the application of UAM (Zou *et al*., 2018; Mehta *et al*., 2022a). This decrease in the shear force might be due to the rupturing of the myofibrillar component. Other than UAM, proteolytic enzymes such as calpain activity might cause the rupture of the myofibrillar component, as the calpain system is the major contributor to meat tenderness during post-mortem storage (Kaur *et al*., 2020). Singh *et a*l. (2018) observed that calpains present in muscles could be activated by calcium ions and thiol compounds. Therefore, the improvement of the tenderness of the T3 treatment could be affected by the higher calcium content found in OPF extract. Thus, this study has shown that the UAM application with the presence of OPF extract significantly ($p<0.05$) reduce the hardness of the goat meat as compared to the T1 and C groups.

Table 2: Effect of ultrasonic and aqueous extract of oil palm fronds on marinade pick-up and shear force of marinated goat meat (Mean±SE)*

Parameters	C	T1	T2	T3
Marinade pick-up (%)	1.70 ± 0.04^{a}	1.84 ± 0.06^{a}	2.57 ± 0.17^{b}	3.72 ± 0.19^{c}
Shear force (g)	1955.03 ± 48.02^{c}	1781.51 ± 20.65^{b}	1215.33 ± 40.13^{a}	1139.33 ± 29.23^{a}

*Means bearing different superscripts with small letters a, b, c, d-- within a row and capital letter A, B C– along column differ significantly at $p \leq 0.05$. C-control marinated without extract and ultrasonic, T1- marinated with extract, T2-marinated and sonicated for 30 min; T3-marinated with extract and sonicated for 30 min

pH, cooking yield, and cooking loss of marinated goat meat

The ultrasound and OPF extract incorporation was observed to affect pH, cooking loss and cooking yield of marinated goat meat (Table 3). The pH values of marinated goat meat were recorded as significant ($p \leq 0.05$) different among treatment samples on day-0 of marination. A significantly higher ($p \leq 0.05$) pH value was recorded on the treatment with the presence of the OPF extract and UAM (T3), 5.28±0.02 followed by the treatment with UAM and without OPF extract (T2) 5.12±0.01, treatment without UAM and without OPF (T1) 5.19±0.01 and the control (C) which there was no UAM and OPF treatment at pH of 5.07±0.02. However, upon increasing storage day, the pH value of marinated goat meat was significantly ($p\leq 0.05$) decreased.

On day 1 of marination, the pH value of the marinated meat of T3 (5.21±0.03) recorded significant ($p \leq 0.05$) higher as compared to T1 (5.14±0.02). The OPF extract with an aid of UAM treatment resulted in a significant ($p \leq 0.05$) effect on the pH-value as shown on T3 which was the highest value. While the lowered pH-value of T1 and C on day 1 marination process was due to the increase in storage duration of marinades as compared to the pH-value records (T1 and C) on day 0. The trend of the pH value recorded on the marinated goat meat during days of storage could be due to the presence of the OPF extract and ultrasound effect. Other than that, the antimicrobial properties that are present in the OPF extract could also contribute to the pH maintenance of the marinated.

The presence of OPF extract along with storage duration had a significant effect on the cooking yield and cooking loss of marinated goat meat (Table 3). The cooking loss of all treatments was significantly ($p\leq 0.05$) increased and cooking yield showed a decreased trend ($p\leq 0.05$) with increasing storage duration of the marinated goat meat. On day 3 of marination storage, the T3 and T2 recorded significantly ($p\leq 0.05$) higher cooking loss as compared to control samples, but a non-significant difference when compared to the T1 treatment. This increase in cooking loss of T2 and T3 could be due to the rupturing of the myofibrillar components within the muscle tissue of marinated goat meat. This destruction of muscle fibres could also facilitate easy movement of water between muscles resulting in more water loss recorded during the cooking process (Mehta *et al*., 2022a). The increasing cooking loss of meat at ultrasound application for more than 20 min was also reported by Li *et al*. (2015) in chicken breast batter.

Colour profile of marinated goat meat

Colour of meat products is the primary factor affecting consumer acceptance of meat. It is affected by meat protein structure, the status of myoglobin, and meat lipid oxidation (Nair *et al*., 2017). The marination storage and OPF extract incorporation with UAM treatment had a significant effect on the various colour attributes of goat meat (Table 4).

On day 0 of marination, the lightness (L^*) 43.94±0.21 and hue values 71.52±0.43 of the T3 were significantly ($p<0.05$) low as compared to the other treatment but the redness (a^*), yellowness (b^*) and chroma values were recorded high towards the T3 treatment as compared to others. A decrease in lightness (L^*) value and higher yellowness (b*) were also recorded by Bao *et al*. (2022) in dry-cured yak meat upon sonication for 30 min. The colour value changes during the day 0 of marination could be due to the antioxidant properties of the OPF together with the low temperature (4°) could slow down the oxidation process within the meat tissue, thus it could observe that the meat would appear slightly bright red in

Table 3: Effects of ultrasonic and aqueous extract of oil palm fronds on pH, cooking yield, and cooking loss of marinated goat meat (Mean±SE)*

Storage day	C	T1	T2	T3
pH				
0	5.07±0.02^{Ba}	5.19±0.01^{Bb}	5.12±0.01^{Bc}	5.28±0.02^{Bd}
1	5.04±0.02^{Ba}	5.14±0.02^{Bb}	5.06±0.02^{Aa}	5.21±0.03^{Ac}
3	4.91±0.01^{Aa}	4.92±0.04^{Aa}	5.03±0.02^{Ab}	5.17±0.01^{Ac}
Cooking loss (%)				
0	37.56±0.50^{Aa}	37.46±0.53^{Aa}	40.62±0.40^{Ab}	40.83±0.28^{Ab}
1	38.07±0.48^{Aa}	39.82±0.24^{Bb}	41.21±0.66^{ABb}	41.29±0.60^{ABb}
3	41.41±0.43^{Ba}	41.19±0.36^{Cab}	42.55±0.45^{Bb}	42.45±0.27^{Bb}
Cooking yield (%)				
0	62.44±0.50^{Bb}	62.54±0.53^{Cb}	59.38±0.40^{Ba}	59.17±0.28^{Ba}
1	61.93±0.48^{Bb}	60.18±0.24^{Ba}	58.79±0.66^{ABa}	58.71±0.60^{ABa}
3	58.59±0.43^{Aab}	58.81±0.36^{Ab}	57.45±0.45^{Aa}	57.55±0.27^{Aa}

*Means bearing different superscripts with small letters a, b, c, d-- within a row and capital letter A, B C– within a column differ significantly at $p \leq 0.05$. C-control marinated without extract and ultrasonic, T1- marinated with extract, T2-marinated and sonicated for 30 min; T3-marinated with extract and sonicated for 30 min.

Table 4: Effect of ultrasonic and aqueous extract of oil palm fronds on colour profile of raw marinated goat meat (Mean±SE)*

Storage day	C	T1	T2	T3
L* (Lightness)				
0	45.40±0.10^{Ab}	49.52±0.12^{c}	53.39±0.37^{Cd}	43.94±0.21^{Ca}
1	47.97±0.08^{Bbc}	48.78±1.43^{c}	44.83±0.05^{Ba}	46.27±0.37^{Bab}
3	45.23±0.23^{Ac}	51.04±0.21^{d}	41.78±1.39^{Ab}	37.98±0.05^{Aa}
a* (Redness)				
0	4.68±0.04^{Cc}	3.40±0.03^{Bb}	2.35±0.03^{Ba}	3.50±0.08^{Cb}
1	4.22±0.07^{Bc}	2.51±0.38^{Ab}	4.30±0.03^{Cc}	1.89±0.02^{Aa}
3	3.42±0.01^{Ab}	4.40±0.10^{Cc}	1.94±0.28^{Aa}	3.26±0.02^{Bb}
b* (Yellowness)				
0	16.57±0.05^{Ac}	22.81±0.16^{Bd}	14.34±0.06^{Bb}	10.49±0.07^{Ba}
1	17.47±0.12^{Bb}	23.39±0.23^{Cd}	21.80±0.21^{Ac}	9.82±0.07^{Aa}
3	22.45±0.12^{Cd}	15.87±0.10^{Ac}	14.07±0.27^{Ab}	12.73±0.09^{Ca}
Chroma				
0	17.22±0.06^{Ac}	23.06±0.15^{Bd}	14.53±0.06^{Ab}	11.06±0.07^{Ba}
1	17.97±0.13^{Bb}	23.54±0.22^{Bd}	22.22±0.20^{Bc}	10.00±0.06^{Aa}
3	22.71±0.12^{Cd}	16.47±0.08^{Ac}	14.22±0.24^{Ab}	13.15±0.08^{Ca}
Hue				
0	74.23±0.10^{Ab}	81.52±0.12^{Bd}	80.67±0.17^{ABc}	71.52±0.43^{Aa}
1	76.42±0.17^{Ba}	83.86±0.94^{Cc}	78.84±0.16^{Ab}	79.08±0.20^{Cb}
3	81.35±0.02^{Cb}	74.50±0.37^{Aa}	82.06±1.23^{Bb}	75.62±0.19^{Ba}

*Means bearing different superscripts with small letters a, b, c, d-- within a row and capital letter A, B C– within a column differ significantly at $p \leq 0.05$. C-control marinated without extract and ultrasonic, T1- marinated with extract, T2-marinated and sonicated for 30 min; T3-marinated with extract and sonicated for 30 min.

colour during the day 0 of marination. However, during the final day (day 3) of marination, it was observed that L^* and hue values were further decreased. This could be observed due to the extended marination period of three days which promoted metmyoglobin formation during the storage day.

Throughout this study, the lightness (L^*), redness (a^*), yellowness (b^*), chroma, and hue value was significantly ($p<0.05$) decreased in all treatment as recorded on C, T1, T2, and T3 with the increasing of storage duration and due to the cooking process (Table 5). The cooked marinated goat meat appeared dark-brownish in colour. The brownish colouration on the cooked meat could be attributed to the Maillard reaction. Under heating conditions, reducing sugars and free amino compounds react to form a series of Maillard reaction, hence change the meat colouration (Sun *et al*., 2022). Fencioglu *et al*. (2022) also reported decreased colour value upon cooking of marinated beef sticks.

Sensory attributes of marinated goat meat

Sensory attributes play a major role in consumer acceptance and marketing of meat. The general appearance, flavour, and tenderness of marinated products are crucial for the popularisation and marketing of marinated products. In the present study, the T3 showed the highest appearance (4.61±0.07), flavour (4.73±0.01), and tenderness (4.79±0.01) scores as compared to the other treatment (Table 6). The improved flavour score could be due to the Maillard reaction of cooked marinated meat (Liu *et al*., 2022). Other than that, the variety of substances that were present in the marination liquid (ML) such as several spice and honey could improve the flavour of this cooked marinated meat. The improved tenderness of the cooked marinated meat could be due to the disintegration of myofibrils integrity and structural proteins of the marinated meat (Shi *et al*., 2022).

Table 5: Effect of ultrasonic and aqueous extract of oil palm fronds on colour profile of cooked marinated goat meat (Mean±SE)*

Storage day	C	T1	T2	T3
L* (Lightness)				
0	41.12 ± 0.18^{Cc}	39.75 ± 0.11^{Cb}	36.07 ± 0.16^{Ba}	41.28 ± 0.27^{Bc}
1	40.25 ± 0.26^{Bb}	38.81 ± 0.24^{Ba}	41.61 ± 0.21^{Cc}	45.71 ± 0.17^{Cd}
3	33.76 ± 0.24^{Ab}	32.48 ± 0.21^{Aa}	35.00 ± 0.19^{Ac}	38.80 ± 0.16^{Ad}
a* (Redness)				
0	3.83 ± 0.04^{Bb}	3.69 ± 0.07^{Cb}	2.72 ± 0.11^{Ca}	2.65 ± 0.06^{Aa}
1	3.79 ± 0.07^{Bd}	2.89 ± 0.01^{Bb}	1.75 ± 0.05^{Ba}	3.33 ± 0.05^{Cc}
3	2.77 ± 0.05^{Ad}	2.07 ± 0.01^{Ab}	1.28 ± 0.03^{Aa}	2.54 ± 0.03^{Ac}
b* (Yellowness)				
0	13.50 ± 0.04^{Ca}	13.96 ± 0.11^{Ba}	15.45 ± 0.47^{Bb}	16.64 ± 0.22^{Bc}
1	13.34 ± 0.05^{Ba}	16.11 ± 0.07^{Cb}	16.73 ± 0.08^{Cc}	18.35 ± 0.21^{Cd}
3	8.07 ± 0.05^{Aa}	9.30 ± 0.03^{Ab}	9.92 ± 0.06^{Ac}	11.21 ± 0.12^{Ad}
Chroma				
0	14.03 ± 0.03^{Ca}	14.44 ± 0.10^{Ba}	15.69 ± 0.48^{Bb}	16.85 ± 0.22^{Bc}
1	13.87 ± 0.06^{Ba}	16.37 ± 0.06^{Cb}	16.82 ± 0.08^{Cd}	18.65 ± 0.22^{Cc}
3	8.54 ± 0.06^{Aa}	9.53 ± 0.03^{Ab}	10.00 ± 0.06^{Ac}	11.50 ± 0.12^{Ad}
Hue				
0	74.16 ± 0.19^{Ba}	75.18 ± 0.29^{Ab}	80.03 ± 0.10^{Ac}	80.96 ± 0.08^{Cd}
1	74.13 ± 0.23^{Ba}	79.84 ± 0.07^{Cb}	84.04 ± 0.17^{Cc}	79.70 ± 0.10^{Bb}
3	71.07 ± 0.26^{Aa}	77.45 ± 0.08^{Bb}	82.65 ± 0.20^{Bb}	77.22 ± 0.12^{Ac}

*Means bearing different superscripts with small letters a, b, c, d-- within a row and capital letter A, B C– within a column differ significantly at $p \leq 0.05$. C-control marinated without extract and ultrasonic, T1- marinated with extract, T2-marinated and sonicated for 30 min; T3-marinated with extract and sonicated for 30 min.

Table 6: Effect of ultrasonic and aqueous extract of oil palm fronds on the sensory attributes of marinated goat meat (Mean±SE)*

Storage day	C	T1	T2	T3
Appearance				
0	4.58±0.04^{b}	4.50±0.06^{a}	4.51±0.7^{a}	4.59±0.02^{b}
1	4.58±0.02^{ab}	4.55±0.02^{a}	4.55±0.02^{a}	4.65±0.03^{b}
3	4.49±0.05^{a}	4.51±0.03^{a}	4.52±0.03^{a}	4.61±0.07^{b}
Flavour				
0	4.40±0.02^{a}	4.55±0.03^{b}	4.61±0.04^{Abc}	4.71±0.09^{c}
1	4.51±0.01^{a}	4.56±0.04^{b}	4.75±0.05^{Bb}	4.77±0.02^{b}
3	4.49±0.01^{a}	4.52±0.06^{ab}	4.63±0.03^{Ab}	4.73±0.01^{c}
Tenderness				
0	4.21±0.02^{Aa}	4.35±0.04^{Ab}	4.68±0.02^{c}	4.71±0.05^{c}
1	4.52±0.03^{Ba}	4.63±0.01^{Bb}	4.75±0.05^{c}	4.77±0.03^{c}
3	4.58±0.08^{Ba}	4.66±0.01^{Bab}	4.73±0.08^{bc}	4.79±0.01^{c}

*Means bearing different superscripts with small letters a, b, c, d-- within a row and capital letter A, B C– within a column differ significantly at $p \leq 0.05$. C-control marinated without extract and ultrasonic, T1- marinated with extract, T2-marinated and sonicated for 30 min; T3-marinated with extract and sonicated for 30 min.

Tenderness values recorded in the present study is in accordance with the shear force value and higher (p>0.05) shear force with incorporation of UAM and OPF might be due to the structural changes, formation of disulphide cross-links, protein oxidation with prolong marination duration and enzymatic inactivation (Barroug *et al*., 2021). The pH of marinated meat also has impact on the textural properties of meat and a stable pH value recorded during marination period can increases the textural changes of the meat. Zhou *et al*. (2022) observed improved sensory attributes viz., overall taste intensities, richness, and umami with decreased bitterness in dry cured ham as compared to control. Overall, the T3 sample was recorded as having good sensory attributes and higher consumer acceptance based on the 5-point hedonic scale.

CONCLUSION

The ultrasonic application and oil palm fronds extract incorporation were observed to improve marinade pick-up, appearance, flavour, and tenderness of the goat meat. These findings suggest that ultrasonic application (30 minutes) together with OPF extract (1%) offers great potential to improve the goat meat quality attributes through the marination process during three days of refrigerated storage. Further studies with an extended marination process could provide the food industry with a broadening view towards the adoption of the oil palm fronds (OPF) extract in the application towards the meat processing industry.

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