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RESEARCH

Quality and Shelf Life of Boiled and Unboiled Palmyrah (*Borassus flabellifer*) Shoot Flour Incorporated Chicken Meatballs During Refrigerated (4±1 °C) Storage

Varthani Susruthan[1,3]* and S.M.C. Himali[2,3]

[1]Department of Biosystems Technology, Faculty of Technology, University of Jaffna, Sri Lanka
[2]Department of Animal Science, Faculty of Agriculture, University of Peradeniya, Sri Lanka
[3]Postgraduate Institute of Agriculture, University of Peradeniya, Sri Lanka

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Susruthan, V.
https://orcid.org/0000-0001-6178-7482

*Corresponding author- vsusruthan@gmail.com

ABSTRACT

Plant-based non-meat ingredients have been studied for decades and recently gained more attraction in the food industry and research communities. The current study was conducted to produce chicken meatballs incorporating boiled-dried (*Plukodiyal*) and dried Palmyrah (*Odiyal*) flour with a focus on reducing manufacturing costs. Chicken meatballs were prepared with two flours as binders at the levels of 5% and 10% (w/w). Different treatment samples were stored at 4±1 °C for five days until further analysis. Sensory properties, proximate composition, physical properties such as processing yield, diameter changes, cooking loss, colour, and microbial properties such as total viable plate count, total yeasts and mould count and total coliform count of meatballs were determined. Five formulations (Control, T1- 5% *Odiyal*, T2 -10% *Odiyal*, T3- 5% *Plukodiyal*, 10% *Plukodiyal*) were produced and subjected to sensory evaluation to obtain the optimum product in terms of aroma, taste, texture, juiciness, and overall acceptability. From the sensory evaluation, the treatments T2 (10% of Palmyrah unboiled flour) and T4 (10% of Palmyrah boiled flour) were found to be significantly ($P< 0.05$) superior in terms of taste and overall acceptability. From the physicochemical analysis, T2 was found to be significantly superior ($P< 0.05$) in terms of taste, colour, fat content (3.96±0.03%), crude fibre content (2.16±0.06%), diameter reduction (3.27±0.03%), and cost of production for ingredients based (LKR.109.36). The results of the present study suggest that Palmyrah has excellent prospects for the formulation of chicken meatballs as a viable alternative to wheat flour. Incorporating Palmyrah flours was positively associated with processing yield, moisture retention, diameter reduction, sensory properties, and nutrients such as high crude protein and low fat. Under aerobic refrigerated (4±1 °C) storage, Palmyrah flour incorporated meatballs retained their microbiological quality for up to three days. Thus, Palmyrah flour, a valuable ingredient often ignored, can be recommended as a viable binding agent for chicken meatballs.

INTRODUCTION

Meat is a significant source of high-biological-value protein and micronutrients, including iron, zinc, selenium, vitamin B12, and vitamin D (Babji and Yusof, 1995). Additionally, consumers value the sensory qualities (Islam et al., 2018). The desire for healthy meat products is rising quickly nowadays. Such consumers need the development of meat products with various kinds of healthy bioactive substances. In this regard, many plants and components of plant origin are employed in formulating meat products. These substances enhance product binding, add therapeutic ingredients such as phytochemicals, and lower formulation costs (Alirezalu et al., 2020). Plant-origin proteins are employed as non-meat additives to include bioactive components in meat products (Jiménez-Colmenero, 2007).

Recently, much research has been done on the applications of various plant-based ingredients in meat products. The range of functional products obtained from poultry meat is relatively limited (Stangierski and Lesnierowski, 2015). Poultry meat and its products are frequently and highly considered health-promoting and nutritious food items, and may exhibit functional food properties. Although many varieties of meat products are available in the food industry, there is a desire for improved and cost-effective meat-based products. Chicken meatballs are the most popular and often consumed worldwide. There is an increase in the consumption of chicken meat and meat products (Mielnik et al., 2002).

Meatball is made from minced meat combined with other non-meat ingredients to increase its nutritional and functional value. Binders are frequently used non-meat ingredients in the meat industry to significantly enhance the product's organoleptic qualities (Mongi and Gomezulu, 2022). Binders have a macromolecular structure that enables them to create structures that can capture vast quantities of water produced during heat processing to prevent exudation and retain nutrients and flavour. They bind water and fat to maintain meat emulsion, particularly in ground meat products like meatballs (Ianiţchi et al., 2023). Many chemicals, such as carrageenan and transglutaminase binders, are employed, which is not ideal for health reasons (Tobacman, 2001; Lerner and Benzvi, 2021). Therefore, researchers and industries are interested in finding the best plant-based binder.

Palmyrah, *Borassus flabellifer* L., is a gift from nature to humankind, which is under the family Arecaceae. It is a plant which offers the community several ecological, medical, economic, and sociological advantages (Isam and Farajalla, 2019; Krishnaveni et al., 2020). Many plant components, including the root, shoot, leaves, fruit, and seeds, have historically been used as food. Palmyrah fruit generally has three seeds. During germination, edible fleshy scale leaves develop, called the palmyrah tuber. Palmyrah flour is a ground raw, dried tuber and a boiled, dried tuber. The sun-dried tuber flour is called "*Odiyal*", and boiled and dried tuber flour is called "*Plukodiyal*". The two main types of carbohydrates in shoot flour are starch and fibre (Jansz, Wickremasekara and Sumuduni, 2002; Thivya and Durgadevi, 2023). Shoot flour's high fibre content reduces the glycemic impact (Behera, 2022; Thivya and Durgadevi, 2023). Regarding energy value and major nutrients, Odiyal flour is comparable to common flours like rice and wheat flour. Additionally, it has lower sugar content and low-fat content compared to cereals and tubers (Jansz, Wickremasekara and Sumuduni, 2002). The high gelatinisation temperature and thermal stability of palmyrah starch are potentially useful characteristics in products that have undergone high-temperature processing, like canned foods and sauces; however, the low extent of retrogradation character is suitable for use as a thickener in frozen foods. The high resistant starch content may have techno-functional benefits and physiological and/or health benefits (Naguleswaran et al., 2010).

The flour may be used to make a variety of meals popular in traditional cuisine. The *Odiyal* is often eaten as a steaming dish called *Pittu* and a porridge known as *Khool*. *Plukodiyal* is typically processed into oil cakes and a biscuit-like product called Palmyrah *cunchy* (Jansz, Wickremasekara and

Sumuduni, 2002; Mahilrajan et al., 2015; Thuraisingam, Sangeetha and Sithara, 2023). However, Palmyrah flour is an underutilised source readily available in the Northern Province of Sri Lanka, and very little information is available on its use as a binder. Therefore, this study aimed to elucidate the impact of incorporating Palmyrah as a natural binding agent/ filler in meat products on proximate composition, sensory properties and microbial properties over refrigerated storage.

METHODOLOGY

Raw material and product development

Fresh chicken meat (breast and leg) was purchased from the local market, Kilinochchi, Sri Lanka. Chicken flesh was divided into several components and trimmed, and lean meat with little connective tissue was used. The cleaned, processed, and good-quality *Odiyal* (unboiled-dried) and *Plukodiyal* (boiled-dried) flour were brought from the local market, Jaffna, Sri Lanka. The *Odiyal* flour was soaked in water and drained before being incorporated into the meatball mix. All wheat and *Plukodiyal* flours were sieved and cleaned. Other essential ingredients were purchased from the local market in Jaffna, Sri Lanka.

The composition of the ingredients used for the production of meatballs is given in table 1 along with the five groups of meatballs, including the control and the treatments (Control- 15% of Wheat flour, T1- 5% of Palmyrah unboiled flour + 10% of Wheat flour, T2 - 10% of Palmyrah unboiled flour + 5% of Wheat flour, T3- 5% of Palmyrah boiled-dried flour+ 10% Wheat flour, and T4- 10% of Palmyrah boiled-dried flour + 5% of Wheat flour). The levels of Palmyrah flour to be incorporated were decided through preliminary trials of meatball preparation. The design enabled us to evaluate the effect of varying substitution levels of two different types of palmyrah flour on the physicochemical and sensory properties of meatballs.

Meat from freshly slaughtered chicken was minced using a meat mincer, and seasonings and other ingredients (except flour) were added. The resultant mixture was kneaded by hand for 15 minutes, and flours were added to each batch, followed by an additional 15 minutes of kneading to achieve a homogeneous dough. Three batches of meatballs were prepared from the control and the treatments.

Each dough was shaped into 2 cm diameter meatballs weighing 15–20 g. Finally, the prepared meatballs were hygienically packaged (Low-density polythene; aerobic packaging method) and stored at 4±1 °C. After the sensory evaluation of cooked (steamed and fried) meatballs, the selected treatments were stored and used for analysis. The meatballs were cooked (at above 80 ± 5 °C) before analysing the cooking loss, diameter changes, moisture retention, processing yield, and pH. Uncooked meatballs were used for the microbiological analysis. All the analyses were replicated three times.

Table 1: The composition of meatball preparations

Ingredients ((%), w/w)	Control	T1	T2	T3	T4
Meat	65	65	65	65	65
Pepper	2.1	2.1	2.1	2.1	2.1
Onion	3	3	3	3	3
Cumin	0.4	0.4	0.4	0.4	0.4
Garlic	0.5	0.5	0.5	0.5	0.5
Ice flakes	12	12	12	12	12
Salt	2	2	2	2	2
Wheat Flour	15	10	5	10	**5**
Unboiled and dried Palmyrah flour (*Odiyal*)	-	5	10	-	-
Boiled and dried Palmyrah flour (*Plukodiyal*)	-	-	-	5	10

Control- 15% of Wheat flour, T1- 5% of Palmyrah unboiled flour + 10% of Wheat flour, T2 - 10% of Palmyrah unboiled flour + 5% of Wheat flour, T3- 5% of Palmyrah boiled-dried flour+ 10% Wheat flour, and T4- 10% of Palmyrah boiled-dried flour + 5% of Wheat flour.

Sensory evaluation

In the sensory evaluation test, the cooked meatball samples were presented (at room temperature around 32 °C) in a random order to 30 panellists (age 24-35 years old, Male: Female 1:1); they had been semi-trained in sensory evaluation at the University of Jaffna, Sri Lanka. Panellists were requested to evaluate the meatballs regarding their aroma, taste, juiciness, texture, and overall acceptability with a five-point hedonic scale (1: did not like at all, 5: liked very much) (Mörlein, 2019; Augustyńska-Prejsnar et al., 2022. Samples were named by different codes (control= 369; T1= 781; T2= 513; T3= 247; T4= 635) and served warmly. Between each sample, the panellists were asked to consume non-salted crackers and water to neutralise the taste. Sensory attributes and the scaling system were discussed with the panellists before starting the session.

Proximate composition analysis

Standard methods of the Association of Official Analytical Chemists were used to determine the nutritional composition of selected samples. Moisture content (%) was calculated by weight difference before and after the hot air oven (BIOBASE, BOV-V12F, China) (AOAC International, 2002) at 105 °C until the constant weight was reached. Around 2.0g of each fresh sample was dried to a constant weight in a crucible placed in an oven. Crude protein (CP) content (%) was determined by the Kjeldahl method (AOAC International, 2005) using the Kjeldahl apparatus (Velp UDK159, Italy). The crude fat content (%) was determined by the Soxhlet Extraction method (AOAC International, 2012) by the Soxhlet apparatus, using 5.0g of each sample (EMEA 60250/CE, England). The crude fibre content (%) was determined by the Weende method using the ANKOM System (ANKOM200, USA) (AOAC 978.10 protocol), using 2.0g of each sample (Augustyńska-Prejsnar et al., 2022).

Determination of pH

The pH of uncooked and cooked meatballs was measured using a pH meter (Peak S-610, USA). Two grams of minced meatball samples were homogenised using a homogeniser in 18 ml of distilled water, and the homogenised solution was filtered using a muslin cloth. The pH of the resultant filtrate was measured at room temperature (at 29-32 °C) according to the method described by AOAC International (2002).

Determination of cooking loss

The cooking loss of samples was calculated by using equation 1 described by Golge in 2018 (Golge, Kılınççeker and Koluman, 2018). Meatballs were steamed and fried. The formula used to determine cooking loss was as follows:

Equation: 01

$$Cooking\ loss\ (\%) = \frac{(Uncooked\ meatball\ weight - Cooked\ meatball\ weight) \times 100}{Uncooked\ meatball\ weight}$$

Determination of diameter changes

The dimension change of the meatballs due to cooking was calculated by comparing the diameter (width) of the uncooked and cooked meatballs, measured with a calliper (Range: 0-200 mm) (Golge, Kılınççeker and Koluman, 2018; Mansour and Khalil, 1997). The formula used to determine diameter reduction was as follows:

Equation: 02

$$Diameter\ reduction\ (\%) = \frac{(Uncooked\ meatball\ diameter - Cooked\ meatball\ diameter) \times 100}{Uncooked\ meatball\ diameter}$$

Determination of processing yield

The weights of meatballs before and after cooking were measured to determine the processing yield (%) of meatballs. The processing yield was estimated as the weight ratio of cooked meatballs to the weight of uncooked meatballs, and it was expressed as a percentage (Golge, Kılınççeker and Koluman, 2018; Verma et al., 2015). The formula used to determine frying yield was as follows:

Equation: 03

$$Processing\ yield\ (\%) = (Cooked\ meatball\ weight \times 100)/(Uncooked\ meatball\ weight\ )$$

Determination of moisture retention percentage

The moisture retention value in the cooked product per 100 g was calculated using the equation by El-Magoli, Laroia, and Hansen (1996) and Verma et al. (2015). The formula used to determine moisture retention was as follows:

Equation: 04

$$Moisture\ retention\ (\%) = ((Cooking\ yield\ \%) \times (Moisture\ content\ of\ cooked\ meatball))/100$$

Determination of colour

The colour of uncooked meatball (cross-section) samples was measured using a Precision Colourimeter (NR20XE, China) at four different spots on their surface. Based on the CIE colour system, the L* value represents the brightness of the samples, the a* value represents the red-green colour value, and the b* value represents the yellow-blue colour value. The colour device was calibrated by using its white and black ceramic plates before use. The device was fixed on the table to avoid different sampling heights, and the samples were scanned at various points to get average readings (Machete et al., 2016; Radikara et al., 2016).

Microbial analysis

One gram of meatball sample was aseptically mixed with 9 mL of sterile saline solution and homogenised in a stomacher (BagMixer 400P, France). Serial tenfold dilutions of meatball samples were prepared with sterilised 0.1% peptone water from 10^{-1} to 10^{-5} (Keler et al., 2010). The total viable bacterial count, yeast count, and coliform count were determined using plate count agar, potato dextrose agar, and MacConkey agar media, respectively. All Media were prepared according to the manufacturer's instructions and sterilised by autoclaving at 121°C for 15 minutes. Each sterilised medium was poured after cooling down to 40-50 °C into Petri dishes with inoculum and allowed to set. The inoculation was carried out using the pour plate method for all media. The inoculated Petri dishes were then incubated at a specified temperature and duration (Table 2). After incubation, colonies were counted and recorded using a colony counter (Galaxy330, Taiwan).

Data processing

The research used two types of Palmyrah flour (*Odiyal* and *Plukodiyal*) in two different percentages (5 and 10%) and wheat flour. The meatballs that contained only wheat flour (15%) were used as a control. The meatball production was done in three replicates, and the analyses of the samples were held in parallel. The Friedman test was performed for sensory evaluation. The analysis of variance (ANOVA) was conducted to determine the variation between control and Palmyrah-added meatballs in terms of sensory analysis, nutritive composition, properties, and microbial analysis. The mean separation was carried out using the Duncan Multiple Range Test (DMRT). All statistical analyses were done using SAS® 9.4 (SAS Institute Inc., USA, 2012). A confidence interval of 5% was used to compare least square means. The values were given as mean ± standard error of difference (SED). The total cost of the formulated meatballs (Ingredients-based) (100 g) was calculated.

Table 2: Microbiological quality test of meatballs

Test	Medium	Incubation condition	References
Total viable bacterial count	Plate count agar	37 °C for 1-2 days	(Kivaria, Noordhuizen and Kapaga, 2006)
Total yeast and mould count	Potato dextrose agar	25 °C for 3-5 days	(Tournas et al., 2020)
Total coliform plate count	MacConkey agar	35 °C for 1-2 days	(Feng et al., 2020)

RESULTS AND DISCUSSION

Sensory attributes

The quantity of other substances was maintained throughout the process of creating the samples, except for the proportion of wheat flour, *Odiyal,* and *Plukodiyal*. All prepared meatball samples underwent three sensory evaluations for overall acceptability, aroma, taste, texture, and juiciness. The results are presented in Figure 1 as a web diagram. According to Figure 1, formulations were coded for sensory analysis.

According to the results, the addition of different flour in two percentages has significantly ($P<0.05$) improved the overall acceptability and taste of chicken meatballs. However, the aroma, juiciness, and texture were not significantly different ($P>0.05$) among treatments.

The raw Palmyrah flour is bitter because of flabelliferin compounds (Davis and Johnson, 1987; Thivya and Durgadevi, 2023). However, the bitterness does not affect the taste of the end products because the used flours were well processed (*Odiyal*-dried and milled; *Plukodiyal*-wet boiled, dried, and milled). Reported literature reveals that thermal treatments like drying, wet boiling, and milling can reduce bitterness and toxicity (Thivya and Durgadevi, 2023).

Moreover, the meatballs incorporated with boiled-dried Palmyrah flour (*Plukodiyal*) had a slightly sweet taste, which is not much preferred by the panellists in terms of taste. As a result, the meatballs incorporated with unboiled flour (*Odiyal*) had a higher score for taste. On the other hand, the *Odiyal* flour-incorporated meatballs had a slightly brown colour, and *Plukodiyal* flour-incorporated meatballs had a pleasing colour compared to other meatballs, due to which the overall acceptability was higher for the meatballs incorporated with boiled-dried flour (*Plukodiyal* flour). Treatment 1 (5% of *Odiyal*) was removed from the study because it did not show a significant ($p>0.05$) in terms of sensory attributes compared to the control, T1 and T2. T3 (5% of *Plukodiyal*) was removed from further test due to the low score for all attributes, and the overall acceptability score was lower (2.97±1.25) compared with the control and other treatments.

The texture parameters commonly depend on the type and amount of the ingredients used and their interactions. The present study showed that formulated chicken meatballs had poorer brittleness and were not significantly ($p>0.05$) different compared to the control group, which is in agreement with the Augustyńska-Prejsnar (2022) study, where the meatballs, incorporated with seeds of linseed, amaranth, and hemp, had poorer brittleness. From the sensory results, the T2 (10% of *Odiyal*) and T4 (10% of *Plukodiyal*) were selected for the subsequent studies.

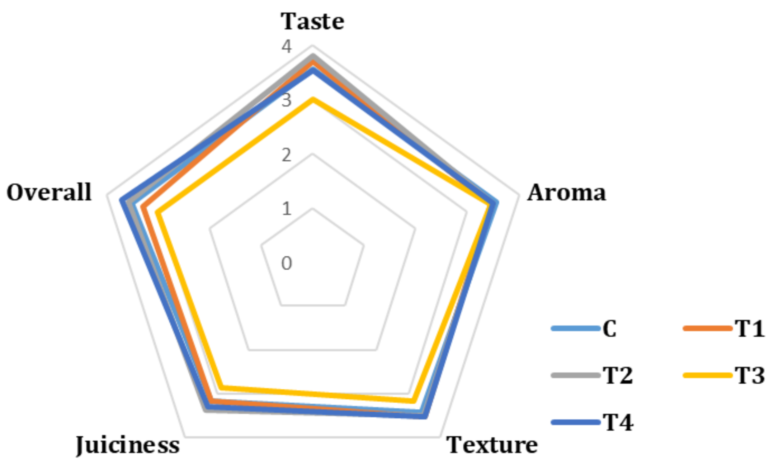

Figure 1: Sensory properties of fried meatballs

Control- 15% of Wheat flour, T1- 5% of Palmyrah unboiled flour + 10% of Wheat flour, T2 - 10% of Palmyrah unboiled flour + 5% of Wheat flour, T3- 5% of Palmyrah boiled-dried flour + 10% Wheat flour, and T4- 10% of Palmyrah boiled-dried flour + 5% of Wheat flour.

Proximate, pH and physical properties analysis of chicken meatballs incorporated with different Palmyrah flour

Table 3 illustrates the proximate composition and pH of the cooked and uncooked control and selected treatment meatballs after sensory evaluation. Also, the physical attributes of the meatball are presented in table 3.

The incorporation of different flours did not significantly (p>0.05) affect the moisture contents of the cooked and uncooked meatball samples, and the moisture content of uncooked meatball samples ranged from 48.64±3.92% to 50.21±51.93%. The control meatballs showed the highest moisture content. The moisture contents of cooked meatball samples ranged from 42 to 46% (Table 3). Generally, the frying process causes water evaporation from the meatballs (Turhan et al., 2014; Kılınççeker and Kurt, 2018), and due to that, the moisture content has been reduced in cooked samples compared with uncooked samples. In a different study, the results showed that the moisture content of uncooked meatball samples was changed by the addition of cowpea flour (P>0.05), and a gradual drop was noticed as the amount of cowpea flour was increased. The uncooked samples' moisture content ranged from 50.63% to 44.03% (Kahraman, Dağlioğlu and Yilmaz, 2023). According to a study done by Dinçer in 2018, the incorporation of wheat and oats bran into meatballs at percentages of 5, 10, 15, and 20 caused a steady drop in the moisture and fat contents of the meatballs due to the dilution effect because the moisture concentration in the flour was lower than in the meat (Dinçer et al., 2018). In 2021, a study by Niamke revealed that the moisture content of wheat flour bread was higher (11.22%) than that of the Palmyra-incorporated bread (3.89%). However, the potential moisture reduction can help to reduce microbial activity and enhance the shelf-life (Gosai, 2021).

Table 3: Proximate composition and physical properties of uncooked and cooked meatballs formulated with different Palmyrah flour

		Treatments		
		Control	T2	T4
Proximate composition				
Moisture (%)	Uncooked	50.21±1.93^{a}	48.64±3.92^{a}	49.17±5.58^{a}
Fibre (%)		0.62±0.03^{a}	2.16±0.06^{b}	1.17±0.18^{c}
Crude protein (%)		43.35±1.26^{b}	36.69±3.69^{a}	42.25±0.69^{b}
Fat (%)		6.12±0.03^{a}	3.96±0.02^{b}	5.51±0.02^{c}
pH		5.86±0.00^{a}	5.93±0.01^{b}	5.95±0.00^{c}
Moisture (%)	Cooked	42.02±2.19^{a}	43.41±2.88^{a}	45.95±3.25^{a}
pH		6.12±0.00^{a}	6.06±0.00^{b}	5.92±0.00^{c}
Physical properties				
Cooking loss (%)	Cooked	10.67±0.78^{a}	10.16±1.99^{a}	9.22±1.24^{a}
Processing yield (w/w %)		89.33±0.78^{a}	89.84±1.98^{a}	90.78±3.60^{a}
Dimension reduction (%)		5.83±0.13^{b}	3.27±0.26^{a}	3.30±0.24^{a}
Moisture retention (%)		37.53±1.85^{a}	38.96±1.74^{a}	41.70±2.18^{a}
Colour properties				
Lightness (L*)	Uncooked	13.27±0.83^{a}	24.39±1.96^{b}	28.24±0.76^{c}
Redness (a*)		7.75±1.05^{a}	5.82±0.47^{b}	5.27±0.26^{c}
Yellowness (b*)		8.98±1.23^{a}	14.73±2.43^{b}	10.08±0.42^{c}

Data are mean ± SED. Mean values in the same row that are followed by different alphabetical letters are significantly different (P <0.05). Control- 15% Wheat flour, T2 - 10% of Palmyrah unboiled flour + 5% of Wheat flour, T4- 10% of Palmyrah boiled-dried flour + 5% of Wheat flour.

In the current study, the addition of different flours significantly affected the crude fibre content (% w/w) of the uncooked meatball samples (Table 3). The study result revealed that the mean fibre contents of the three treatments differ. In contrast, T2 (10% of *Odiyal*) had the highest fibre portion (2.17±0.06% w/w), and the control accounted for the lowest percentage (0.62±0.03% w/w). T4 had 1.17±0.18% of fibre (dry basis), which was higher than the control. A study done by Gosai in 2021 revealed that the fibre content of 5% Yangben (Wild edible lichen) incorporated meatball was 1.7% (dry basis). The addition of plant-based additives can increase the total fibre content in chicken meatballs. The dietary fibre has numerous health benefits for humans (Niamke et al., 2021; Augustyńska-Prejsnar et al., 2022). In 2022, Montoya revealed that adding dietary fibre as a fat replacer in pork and chicken meatballs has many health benefits without affecting the sensory properties (Montoya et al., 2022). In this study, fibre has an inverse relationship with fat, showing that dried Palmyrah shoot flour can be used as a fat replacer in meat-based products.

The incorporation of different flours significantly affected the crude protein content of the uncooked meatball samples. The differences between the protein contents of the meatballs were significant ($P<0.05$). The protein content was ranged from 36.69±3.69% to 43.35±1.26%. The control had the highest protein content (43.35±1.26%), whereas the T2 had the lowest protein content (36.69±3.69%). The amount of crude protein in the meatball was reduced by the inclusion of *Odiyal* and *Plukodiyal* flour compared with wheat flour (Table 3). While the protein content of *Odiyal* ranges from 3.1% to 6.4% (Jansz, Wickremasekara and Sumuduni, 2002), that of wheat ranges from 10% to 18% of the total dry matter (Irge, 2017). *Odiyal* has a greater protein level than tubers but a lower protein content than cereal grains (Jansz, Wickremasekara and Sumuduni, 2002). As reported by Kahraman, Dağlioğlu and Yilmaz (2023), the protein content of cooked cowpea-added beef meatballs was higher than uncooked, varying from 17.70 to 21.89% and 19.92 to 23.45%, respectively. The wheat-added chicken meatballs had a CP content of 20.70% (Isam and Farajalla, 2019), and retrograded flour to produce beef meatballs (Dinçer et al., 2018) showed a lower CP%. Around 20% tapioca flour incorporated meatballs had the lowest protein content (11.77%), and crude protein in the meatballs was reduced when additional tapioca flour was added. So, the protein supply was lowered due to the inclusion of tapioca, which decreases the amount of chicken flesh (Yudiastari et al., 2021).

In the current study, the fat content of the uncooked meatball samples (control and treatments) significantly differed (Table 3). The control sample had the highest fat level, 6.12±0.025%. The fat content was low in both T2 and T4 compared to the control. It is shown that the incorporation of Palmyrah flour could reduce the fat content. However, a significant reduction was obtained at 10% *Odiyal* flour level**.** In a previous study, it was reported that the *Odiyal* has a lower fat content than grains and tubers (Jansz, Wickremasekara and Sumuduni, 2002). The addition of *Odiyal* and *Plukodiyal* flours reduced the fat content of the chicken meatballs, and they met the national standard, which is below 20% (Ministry of Health, Sri Lanka, 2019). A study done by Okuskhanova in 2017 revealed that the incorporation of sea cabbage into beef meatballs increased the fat content (Okuskhanova et al., 2017). However, the current study showed a reduction of fat content due to the incorporation of Palmyrah flour and increased crude fibre in T2 and T4 samples compared to the control sample. This is in agreement with the study done by Montoya in 2022. The meatballs produced with 10% of the different additional retrograded flour sources were found to have significantly differing fat contents. Because the fat content and properties of each type of flour differed, and a higher percentage was observed in 5% of retrograded flour-incorporated meatballs (Dinçer et al., 2018).

The variation in pH of meatballs before and after cooking is illustrated in Table 3. Because pH directly influences the water holding capacity, cooking yield, colour, and shelf life of meat and meat products, measuring pH is a crucial parameter (Kahraman, Dağlioğlu and

Yilmaz, 2023). The added different flours significantly ($P<0.05$) impacted the uncooked and cooked meatballs' pH. It has been noted that meatballs containing dietary fibre may react differently depending on the pH of the fibre source that has been added (Dinçer *et al*., 2018). The highest pH value (5.95±0.00) was observed in the T4 (10% *Plukodiyal*) added chicken meatball, and the lowest (5.86±0.003) was observed in the control sample. Additionally, it has been shown that cooking (frying) causes the pH value of meat to increase. The pH values of control and T2 were increased after cooking to 6.12±0.00 and 6.06±0.00, respectively. However, the T4 pH declined from 5.95±0.00 to 5.91±0.00. Nuray and Oz relate the release of bonds containing imidazole, sulfhydryl, and hydroxyl groups as the cause of the elevation in the pH value of cooked meat (Nuray and Oz, 2019). Kahraman, Dağlioğlu and Yilmaz (2023) reported similar findings (pH 5.83–6.08) in meatloaf formulated with the whole cowpea flour. In 2003, Yılmaz and Dağlıoğlu also noted that the pH range was similar for oat bran-incorporated meatballs. The pH of the chicken meatballs in the research ranged from 6.21 to 6.25, and the addition of a combination of seeds in either of the tested groups had no effect ($P> 0.05$) (Augustyńska-Prejsnar et al., 2022).

Physical properties of formulated meatballs

The results for cooking loss (%), processing yield (%), dimension reduction (%) and moisture retention (%) of the meatballs are given in Table 3. The cooking loss (%), processing yield (%), and moisture retention (%) values of the meatballs were not significantly affected by adding 10% Palmyrah flour to the meatballs. However, the dimension reduction (%) was affected significantly by the *Palmyrah* flour source. Cooking or processing yield is the most important product behaviour in the meat industry (Serdaroğlu et al., 2006). Compared to the control samples, the processing yields of the meatballs produced using both *Palmyrah* flours were not significantly different ($p>0.05$). The processing yields of chicken meatballs varied from 89.33±0.78 to 90.78±3.60%.

The cooking loss of meatballs produced using *Odiyal* and *Plukodiyal* flours was similar to that of control meatballs ($P>0.05$). The addition of fibres to the formulation reduces this cooking loss by adhering to the water released (Galanakis, Tornberg and Gekas, 2010). Proteins shrink and become denatured during cooking, which causes water to be released from the protein. During cooking, the starch gelatinised, absorbing the released water (Dinçer et al., 2018). Because of these reactions, the cooking loss of all samples was less than 11%. It has been reported that in comparison to the meatballs incorporated with wheat roll, meatballs with the combination of seeds like linseeds, amaranth, and hemp showed lesser losses following thermal processing. Which was likely because enriched wheat rolls, enriched with plant additives, retain moisture better than wheat rolls (Augustyńska-Prejsnar et al., 2022). The meatballs, which contained a combination of seeds in equal quantities (8%), were distinguished by fewer cooking losses, which could be of technological significance. However, the current study revealed a lower cooking loss than the recorded values of the study done by Augustyńska-Prejsnar *et al.* in 2022. The addition of retrograded flour ranging from 5% to 20% significantly reduced cooking loss (from 21.95% to 6.19%) compared to the control (26.23%) (Dinçer *et al*., 2018). Hughes (1997) stated that the amount of fat and moisture affects cooking loss in Frankfurters. The incorporation of cowpea flour caused a slight decrease in the meatballs' cooking loss values; however, the differences were not significant (Kahraman, Dağlioğlu and Yilmaz, 2023). This study agrees with the current research.

The denaturing of the meat proteins and the loss of water and fat during cooking result in changes in the meatballs' dimensions. Additionally, compared to the other meatballs, the modified meatball's diameter decreased less while cooking ($P<0.05$). This may be because fibres may create extremely viscous solutions; as a result, they are utilised as thickeners in meatball mixtures (Dinçer et al., 2018). The control sample showed the highest dimension reduction (5.83±0.13%), while the *Odiyal* and *Plukodiyal* treatments exhibited similar changes with dimension reduction percentages of 3.27±0.26% and 3.30±0.24%, respectively. Similar outcomes were shown with low-fat hamburger patties produced with varied combinations of wheat fibres (Mansour and Khalil, 1997).

No significant differences were recorded in moisture retention values, which ranged between 38.15±1.18 per cent and 41.04±2.85%. The current study agrees with the study done in 2015 by Verma. The addition of an Inulin-like fibre to minced meat improved emulsion stability by retaining more fat and water (Öztürk et al., 2015).

Colour of meatballs

The product colour is a significant visual aspect that affects how consumers choose and decide whether to buy or consume it and how they judge its quality. In addition to raw meat, additives and their inclusion levels in the recipe significantly impact the final product colour (Augustyńska-Prejsnar et al., 2022). The L*, a* and b* values of meatballs can be seen in Table 3, where the values were significantly different. The L* values were highest in T4, which indicates that the use of *Plukodiyal* flour made the final product lighter in colour than the control and T2, and the lowest was in the control group ($P<0.05$). While a* and b* were highest in T2, and b* was lowest in the control group. Meatball redness was reduced with the addition of Palmyrah flour because values for a* (redness) were varied ($P<0.05$) for various Palmyrah flour inclusion levels. The control group had the highest a* value (7.75±1.05). Both treatment groups had higher overall b* (yellowness) values than the controls. Compared to the control samples, the addition of Palmyrah flour to meatballs seems to boost the product's yellowness. The Palmyrah fruit pulp is rich in carotenoid (3.2mg/100g) compounds (Jansz, Wickremasekara and Sumuduni, 2002). The fresh Palmyrah shoot has carotenoid compounds, which are responsible for the colour parameters L*, a* and b* of fresh Palmyrah shoot flour were 55.04 ± 1.37, -2.94 ± 0.32 and 25.16 ± 1.91 (Korese, Achaglinkame and Chikpah, 2021). The pigments in Palmyrah shoots flour may be accountable for this, and the colour compounds can be removed due to thermal processing (Korese, Achaglinkame and Chikpah, 2021; Thivya and Durgadevi, 2023). Therefore, it could be concluded that samples T4 tend to decrease redness and yellowness. The quantity of raw meat in each group was the same. The type of plant additions utilised caused the colour differences in the chicken meatballs. Augustyńska-Prejsnar (2022) mentioned that the additives used in the blend of linseed, amaranth, and hemp seeds had a significant ($P<0.05$) impact on the colour of the cross-section of completed products. Regardless of the quantity of substances used, meatballs supplemented with seeds exhibited a more brightly coloured appearance. According to the kind of meat product and processing methods, Ozturk (2015) noted that the influence on colour might change.

Microbiological analysis

The value of the total viable plate count (TVPC) and total yeast and mould count (TYMC) increased during the storage of meatballs (Figure 02). From 0 to 5 days at 44±1 °C. TVPC values were within the acceptable limit (5×10^6cfu/g). However, the yeast and mould count exceeded the acceptable limit (1×10^3cfu/g) in all the samples (Ministry of Health, Sri Lanka, 2019). This may be due to environmental cross-contamination. On the 3rd day, the TVPC exceeded the acceptable limit (Control=5.9×10^6cfu/g; T2= 5.23×10^6cfu/g and T4= 5.13×10^6cfu/g). From this experiment, the final products can be stored up to Day 03 at 4±1 °C with aerobic packaging. However, further studies are required to confirm the shelf-life of the product in different packaging methods and storage temperatures. During the storage period, microbial counts for T2 and T4 were slightly less than the control samples. The presence of some antibacterial agent in Palmyrah flour (Jansz, Wickremasekara and Sumuduni, 2002), which reduces the growth of the microorganisms in the processed products, may have resulted in lower microbial counts in T2 and T4 than in the control.

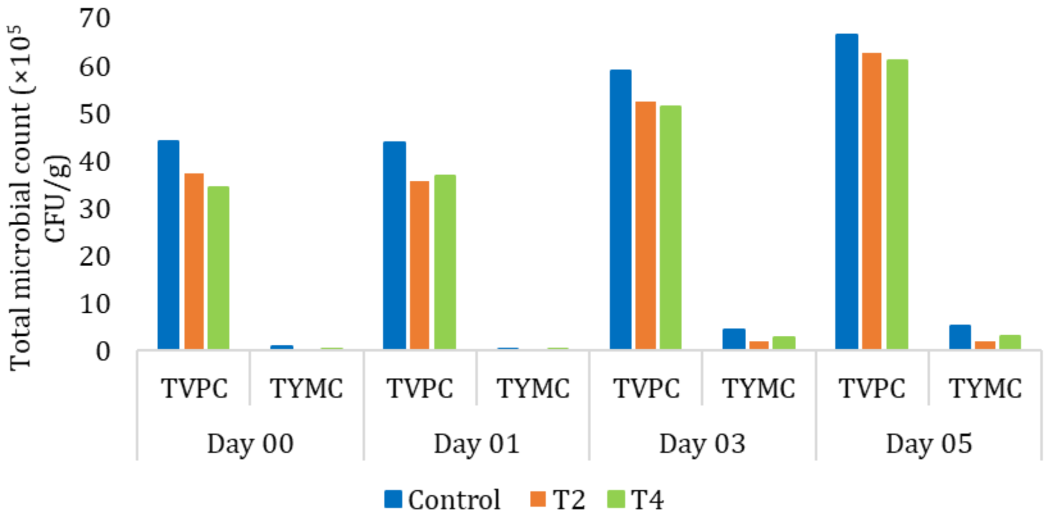

Figure 2: Microbiological analysis of meatball samples stored at 4 ± 1 °C

Table 4: Cost estimation in LKR per 100 g of each formulation

Ingredients	Control (LKR)	T2 (LKR)	T4 (LKR)
Meat	975.00	975.00	975.00
Other non-ingredients	68.35	68.35	68.35
Wheat Flour	50.25	16.75	16.75
Odiyal flour	-	33.50	-
Plukodiyal flour	-	-	110.00
Total price (1kg)	1093.59	1093.59	1170.09
Total price (100 g)	109.36	109.36	117.01

Control- 15% Wheat flour, T2 - 10% of Palmyrah unboiled flour + 5% of Wheat flour, T4- 10% of Palmyrah boiled flour + 5% of Wheat flour.

During the overall storage period, the coliform counts of all the meatball samples were zero, which indicated no faecal contamination in the final products. Coliforms indicate contamination of human, avian, or polluted water usage during washing (Ferawati et al., 2017). The findings of this investigation indicate that satisfactory handling procedures have been used, and that the hands and the equipment were cleansed.

Cost estimation

The total cost for the different formulated meatballs was calculated and estimated for 100g of product without processing, packaging, and storage costs (Table 4).

The cost of the 100g recipe of *Odiyal* meatball and control was found to be LKR. 109.36, whilst the *Plukodiyal* meatball cost was LKR. 117.01. Because the price of *Plukodiyal* flour was higher than that of the other two flours, it is cheaper than commercial meatballs. The price of 100 g of commercial meatball started from LKR. 190.00. However, it is important to conduct a complete cost analysis to estimate the total production cost.

CONCLUSION

The incorporation of Palmyrah flours was positively associated with processing yield, moisture retention, diameter reduction, sensory properties, and nutrient contents. Under aerobic packaging and refrigeration (4±1 °C) storage, the incorporation of Palmyrah flours in the product can improve its microbiological quality. However, future studies need to confirm the shelf-life of this product under different conditions. The inclusion of 10% (w/w) of *Odiyal* flour or 10% of *Plukodiyal* flour can significantly improve the consumer preference for meatballs, particularly the taste. The results of the present study recommend that Palmyrah flour has great potential in the formulation of healthy chicken meatballs compared with wheat flour. Thus, Palmyrah flour, a valuable source often unnoticed, could be utilised in processing meat products. Compared to the 10% *Plukodiyal*, 10% *Odiyal* flour incorporation in chicken meatballs is more suitable as a natural binder for meat-based products.

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