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The effect of adding duckweed (*Lemna minor*) on the physicochemical and sensory properties of chicken balls

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Abstract

Meat and meat products are highly nutritious and contain essential nutrients needed for human sustenance, but they are deficient in dietary fibre. Therefore, the potential of numerous plants to increase the dietary fibre content in meat products has been explored because they are typically rich in dietary fibres and bioactive compounds. *Lemna minor* is a member of the family *Lemnaceae* and grows in slow-moving water bodies. This study evaluated the dried *L. minor* and its effects on the proximate composition, physicochemical, and sensorial properties of chicken balls. The present study revealed that steamed and oven-dried duckweed contained high dietary fibre. The chicken balls were formulated as F0 control (0% duckweed), F1 (2% duckweed), F2 (4% duckweed), and F3 (6% duckweed). Adding *L. minor* powder significantly increased ($p<0.05$) the protein, ash, lipid, crude fibre, and dietary fibre of chicken balls. Moreover, increasing the concentration of *L. minor* powder resulted in a lower cooking loss, L*, and a* values of chicken balls. However, there was no significant difference ($p>0.05$) in terms of the water holding capacity among the treatments. The addition of duckweed altered the textural parameters of chicken balls as the product became harder and more cohesive at high *L. minor* concentrations. Compared to other formulations, F1 was most liked by sensory panellists. Duckweed also inhibited lipid oxidation in chicken balls, thereby enhancing their storage stability for up to 30 days. In conclusion, *L. minor* shows potential for improving the physicochemical properties and sensory quality of chicken balls.

1. Introduction

Meat is one of the most nutritious foods consumed worldwide due to the presence of high-quality protein (Sulaiman, Zaini, Akanda *et al.*, 2024). In particular, chicken meat has the distinction of being the most preferred meat because it is free from any religious restrictions and suitable for processing due to its bland flavour, which can be enhanced by condiments (Akter *et al.*, 2022). Chicken meat is often subjected to complex processing operations to develop numerous products, such as meatballs, sausages, and patties, to fulfil the increasing demand for meat-based diets following the global development of industrialisation (Chiong *et al.*, 2024). However, while these products are good sources of protein and essential amino acids, they often lack dietary fibre and may contain high levels of cholesterol (Younis *et al.*, 2022).

Fibre is naturally present in most plants, and a lack of dietary fibre in consumption may cause various health implications, including colon cancer, cardiovascular diseases, and obesity (Das *et al.*, 2020). Previously, Santhi *et al.* (2020) observed a higher content of fibre in low-fat chicken meatballs via the incorporation of grape and carrot pomace powder. Montoya *et al.* (2022) reported that there is a greater probability of consuming

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meatballs when they have added fibre, are reduced in fat, or are preservative-free than traditional meatballs. Moreover, Zhao *et al.* (2021) found that the addition of insoluble dietary fibre from kiwi fruit pomace (0.5 – 3.0%) may reduce cholesterol concentration owing to its adsorption capacity.

Recently, duckweed has received increasing interest due to its intrinsic advantages, such as rapid growth and lack of competition for arable land (Guo *et al.*, 2020). Duckweed belongs to the *Lemnaceae* family and has five genera, namely, *Spirodela*, *Landoltia*, *Lemna*, *Wolffiella*, and *Wolffia*, with thirty-five distinct species (Sree and Appenroth, 2020; Sulaiman, Zaini, Ishak *et al.*, 2024). Duckweed can grow as a tiny aquatic plant in still and slow-flowing water, such as ponds and lakes, in all geographical regions worldwide except for polar regions. However, the growth of duckweed mainly depends on an optimum temperature range of 17.5°C to 30.0°C, adequate sunlight, and supplemental nutrients such as nitrogen, phosphorus, and potassium (Xu *et al.*, 2023). The sustainability of duckweed is particularly noteworthy due to its ability to adapt to diverse environmental conditions, rapid growth rate, and nutrient -rich composition. Moreover, duckweed contributes to environmental sustainability by purifying water through the absorption and concentration of contaminants from its surroundings (Ujong *et al.*, 2025). Duckweed is a promising novel food source due to its high content of protein and dietary fibre, bioactive compounds, and sufficient sources of essential amino acids (Guo *et al.*, 2020). For instance, duckweed contains 16.0% to 41.7% protein, 3.4% to 9.0% lipids, 3.5% to 26.0% ash, and 8.8% to 29.7% crude fibre (Guo *et al.*, 2020; Xu *et al.*, 2023).

The *Lemna* genus, also known as water lentils, stands out among the duckweed genera. In particular, *Lemna minor* shows an elliptical shape with an average diameter of 1.7 mm, 2 to 4 frond colonies, and a developed root system (Yahaya *et al.*, 2022). *L. minor* uses both roots and fronds for nutrient uptake, and thus this species is commonly used for phytoremediation research (Appenroth *et al.*, 2018). The nutrient content of *L. minor* can be altered depending on growth conditions such as salinity and light intensity (Sree and Appenroth, 2022). Previously, Yahaya *et al.* (2022) incorporated 2% dried *L. minor* in ice cream and reported a greater amount of protein, fibre, and ash with significantly lower fat content. Studies on the use and consumer acceptance of *L. minor* as a human food, particularly in meat products, are still scarce. Therefore, this study aimed to evaluate the nutritional content of *L. minor* powder (LMP) processed via the oven-drying method. Besides that, the objectives of the present study were to investigate the effects of LMP addition on the proximate content, physicochemical properties, and sensory preferences of chicken balls.

2. Materials and methods

2.1 Materials

The boneless chicken breast was obtained from Desa Hatchery Sdn Bhd, Sabah, Malaysia. The *L. minor* duckweed was supplied by Wong Aquaculture Sdn Bhd, Sabah, Malaysia. Potato starch, soy protein isolate, garlic powder, salt, and black pepper powder were obtained from a local market around Kota Kinabalu, Sabah, Malaysia. All the chemicals and solvents used were of analytical grade and obtained from Rinitek Sdn Bhd, Sabah, Malaysia.

2.2 Preparation of duckweed powder

Duckweed samples were washed with tap water to remove any impurities from the plants. Then, 1 kg of duckweed was steamed with 2 L of water at 98°C for 1 min. The samples were left to cool at room temperature (25°C), and excess water was drained. After that, the duckweed samples were dried in an oven (SMO28-2, Mrc Lab, UK) at 65°C for 24 h. The dried samples were ground in a blender (7010S, Waring Laboratory), sieved through a mesh size of 100 µm, and kept in an airtight container at -4°C until further use (Yahaya *et al.*, 2022).

2.3 Production of chicken balls

Four formulations of chicken balls containing different concentrations of LMP (0%, 2%, 4%, and 6%) were processed according to Sun *et al.* (2021) with certain modifications (Table 1). Firstly, 68 g of chicken breast was ground through a 7 mm plate in a meat grinder (VCB61, Hobart Mg. Co. Ltd., UK) and mixed with ice water for 1 min to extract the salt-soluble

Table 1. Chicken balls formulation.

Ingredients (%)	F0 (Control)	F1	F2	F3
Chicken meat	68.0	68.0	68.0	68.0
LMP	0	2.0	4.0	6.0
Ice water	18.0	16.0	14.0	12.0
Potato starch	8.0	8.0	8.0	8.0
Soy protein isolate	2.0	2.0	2.0	2.0
Garlic powder	2.0	2.0	2.0	2.0
Salt	1.8	1.8	1.8	1.8
Black pepper powder	0.2	0.2	0.2	0.2
Total	100.0	100.0	100.0	100.0

F0: Control, 0% LMP, F1: 2% LMP, F2: 4% LMP, and F3: 6% LMP.

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protein. Dry ingredients and LMP were added (Table 1) and mixed for 4 min. Chicken balls of 20±1 g weight were formed manually from the obtained meat batter and then frozen in a freezer at -18°C for 1 h to maintain shape. The samples were then boiled at 75°C in a water bath (WB-6, Daihan Scientific Co. Ltd., South Korea) for 2 to 3 min.

2.4 Proximate composition and fibre content of Lemma minor powder and chicken meatballs

A Soxhlet extraction apparatus (Soxtech Avanti 2050 Auto System, Foss Analytical, Denmark), a Kjedhal assembly (Kjeltech 2300 Analyser Unit, Foss Analytical, Denmark), a hot air oven, a muffle furnace, and a FibreBag Systems (FibreTherm, Gerhardt Analytical Systems, Germany) were used to determine the lipid, protein, moisture, ash, and crude fibre contents of the chicken balls with LMP, respectively. The carbohydrate content was calculated by difference, taking into account the percentages of moisture, protein, lipid, ash, and crude fibre. Meanwhile, dietary fibre was measured using a Total Dietary Fibre Assay Kit (Megazyme, Neogen, USA) as manufacturers' instructions. All analyses were conducted following the AOAC INTERNATIONAL methods.

2.5 Physicochemical properties of chicken meatballs

2.5.1 Cooking loss

The chicken balls were grilled for 15 min at 190°C. After that, the cooking loss of the samples was expressed as the percentage of the difference between the weights of the raw and cooked meatballs using the following equation (Erdem *et al.*, 2020).

$$\text{Cooking loss (\%)} = \frac{\text{Weight of raw sample} - \text{Weight of cooked sample}}{\text{Weight of cooked sample}} \times 100$$

2.5.2 Water holding capacity

The centrifugation technique was used to measure the water holding capacity (WHC) as described by Zaini *et al.* (2021) with certain modifications. Approximately 10 g of sample was mixed with 40 mL of distilled water and centrifuged (5430R, Eppendorf) at 3,000 rpm for 30 min. The WHC of the meatballs was calculated using the following equation:

$$\text{WHC (\%)} = \frac{\text{Weight of pellet}}{\text{Weight of samples before centrifugation}} \times 100$$

2.5.3 Colour

The colour of the chicken meatballs was determined using a colourimeter (ColourFlex EZ, HunterLab, USA). Readings were taken based on the CIE L*, a*, and b* parameters (Pindi *et al.*, 2024).

2.5.4 Texture profile analysis

An instrumental examination of the texture was conducted using a texture analyser (TA-XT Plus, Stable Micro Systems Co. Ltd., UK) based on a method described by Ramle *et al.* (2021). Cooked meatball samples were cut (2 cm x 2 cm) and subjected to two-cycle compression using a 5 kg load cell. The samples were compressed to 50% of their original height with a cylindrical probe at a constant crosshead speed of 5 mm/s. The determined parameters, namely hardness (N), cohesiveness (Dimensionless), and springiness (mm), were recorded using Texture Exponent 32 v. 5.1.2.0 software (Stable Micro Systems Co. Ltd., UK).

2.6 Sensory preference of chicken balls

The sensory evaluation was conducted using a nine-point hedonic scale (1-dislike extremely; 2-dislike very much; 3-dislike moderately; 4-dislike slightly; 5-neither like nor dislike; 6-like slightly; 7-like moderately; 8-like very much; 9-like extremely) by 50 consumer panellists to determine the preference level of chicken balls. Each panellist performed the test individually in a booth equipped with lighting to ensure consistent evaluation conditions. The samples were cut into cubes (2 cm × 2 cm), grilled in a pan for 15 min, and served in transparent containers coded with three-digit numbers. The panellists were also given a glass of drinking water to cleanse their palates. The samples were evaluated in terms of colour, aroma, taste, hardness, springiness, and overall acceptance.

2.7 Storage stability of chicken balls

The storage stability of the chicken balls was determined based on lipid oxidation, indicated by the formation of aldehydes during storage (Munsu *et al.*, 2021). Thiobarbituric acid reacting substances (TBARS) were measured on days 0, 7, 14, 21, and 30 after storage at 4°C. Briefly, 5 g of meatballs was mixed with 20 mL of 7.5% trichloroacetic acid (TCA) solution and homogenised for 2 min. Then, the supernatant was filtered through Whatman No. 1 filter paper, and the pellet was discarded due to the presence of insoluble residues that could interfere with the subsequent reaction between thiobarbituric acid and malondialdehyde in the supernatant. Approximately 2 mL of the supernatant was transferred to a test tube, and 2 mL of thiobarbituric acid (TBA) solution (0.02 M) was added to the mixture. After that, the tube was heated in a water bath (SSB-45 Wisebath, Sci Lab Sdn Bhd, Malaysia) at 95°C for 35 min. The absorbance of the samples was measured at 532 nm using a spectrophotometer (Lambda 25, PerkinElmer Inc., USA). The TBARS value was calculated from the malonaldehyde (MDA) standard curve and reported as

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mg malondialdehyde/kg sample using the following formula:

$$\text{TBARS (mg/kg)} = \frac{C \times V \times (V_1 + V_2)}{M \times V_1}$$

Where C represents the MDA concentration (μM/L), V is the volume of TCA (mL), V_1 is the volume of supernatant (mL), V_2 is the volume of TBA (mL), and M is the sample weight (g).

2.8 Statistical analysis

All experimental data were analyzed using SPSS v. 25.0 (IBM Corporation, USA) in a completely randomised study design, and all the values are reported as the mean ± standard deviation. An independent t-test was conducted to compare the fresh and oven-dried duckweed samples. One-way analysis of variance (ANOVA) was used to determine the significance of the differences among the treatment groups, while Tukey's HSD test was used for multiple comparisons. The statistical significance was set at $p<0.05$.

3. Results and discussion

3.1 Proximate composition and fibre content of duckweed powder

The proximate compositions of fresh and oven-dried duckweed are presented in Table 2. Drying is employed to reduce the moisture content of a sample to approximately 10%, thereby ensuring a longer shelf life of food products (Alibas *et al.*, 2021). Generally, there was an increase ($p<0.05$) in ash, protein, and lipid after oven drying. These results may be attributed to the concentration effect due to the easier extraction of nutrients resulting from the breakdown of cell membranes (Ifie *et al.*, 2021). Therefore, *L. minor* may serve as a valuable source of minerals to help address dietary micronutrient deficiencies, as evidenced by its high ash content, which indicates the presence of essential minerals (Emelike *et al.*, 2020). The findings in the present study were in contrast with those of Alibas *et al.* (2021), as drying at 50°C resulted in dramatic losses of protein due to the increase in the oxidation of the product caused by the longer drying time. Oven drying also increased ($p<0.05$) the fat content of duckweed, which aligned with the findings of Wickramasinghe *et al.* (2020). In Table 2, it was found that the dried sample had a greater amount of crude fibre (16.0%) and total dietary fibre (40.88%) than the fresh duckweed sample (1.95%, 4.98%). According to Oliveira-Alves *et al.* (2021), oven drying causes a modification in the structure of carbohydrates by exposing them to high temperatures, which can lead to changes like the breakdown of complex carbohydrates into simpler forms. Drying also enhances the structural rearrangement of insoluble polysaccharides and might result in a higher amount of total dietary fibre.

3.2 Proximate composition and fibre content of chicken balls

The proximate composition of the samples in terms of moisture, ash, protein, fat, and carbohydrates is presented in Table 3. The control chicken ball (F0) exhibited the highest moisture content (75.11%). Moreover, the lowest moisture content (71.63%) was found in F3, which contained 6% LMP. This result is directly related to the lower amount of ice water added to F3. The ash content refers to the inorganic residue that remains after the complete oxidation of organic substances and can also represent the mineral content in food products (Chiong *et al.*, 2024). This study found that the F3 sample has the highest ash content (1.31%), while F0 had the lowest ash content (0.78%) ($p<0.05$). The addition of LMP significantly increased ($p<0.05$) the ash content in chicken balls, which may be attributed to the high ash content in duckweed (8.36%) and the significant amount of minerals such as phosphorus and potassium (Chakrabarti *et al.*, 2018).

The protein content of the meatballs ranged from 14.96% (F0) to 18.60% (F3). Table 2 revealed that the LMP used in this study contained approximately 7.02% protein, increasing the protein content of chicken balls. Yahaya *et al.* (2022) reported similar findings, where ice cream formulated with 2% *L. minor* exhibited higher protein content over 30 days of storage. In addition, F3 (1.19%) had the highest fat content, followed by F2 (0.80%) and F1 (0.41%). According to Ifie *et al.* (2021), dried *L. minor* had 2.83% fat, which contributed to the higher fat content in meatballs containing duckweed. The authors also observed that samples containing a high protein had a low carbohydrate content, as shown by F3 and F2 in the present study. Nyaguthii *et al.* (2023) reported that the reduction in carbohydrate content may be caused by the relative increase in other proximate parameters, including protein and fat contents.

Crude fibre is a carbohydrate consisting of cellulose

Table 2. Proximate composition of LMP.

Treatments	Moisture (%)	Ash (%)	Protein (%)	Lipid (%)	Crude fibre (%)	Dietary fibre (%)
Fresh duckweed	90.40±1.82^a	0.90±0.12^b	0.79±0.09^b	0.33±0.45^b	1.95±0.53^b	4.98±0.17^b
Oven-dried powder	10.03±0.23^b	8.36±0.28^a	7.02±0.10^a	2.30±0.85^a	16.00±0.07^a	40.88±0.03^a

Values are presented as mean±SD. Values with different superscripts in the same column are statistically significantly different ($p<0.05$).

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Table 3. Proximate composition of chicken balls.

Treatments	Moisture (%)	Ash (%)	Protein (%)	Lipid (%)	Carbohydrate (%)	Crude fibre (%)	Dietary fibre (%)
F0	75.11±0.22^{a}	0.78±0.46^{c}	14.96±0.46^{c}	0.21±0.15^{d}	8.13±0.62^{a}	0.27±0.16^{d}	0.94±0.20^{d}
F1	74.21±0.23^{ab}	1.21±0.29^{b}	16.28±0.47^{b}	0.41±0.14^{c}	5.96±0.36^{b}	1.93±0.24^{c}	25.66±0.88^{c}
F2	73.14±1.08^{b}	1.28±0.21^{ab}	17.75±0.29^{a}	0.80±0.01^{b}	4.24±0.59^{c}	2.66±0.32^{b}	27.07±0.76^{b}
F3	71.63±0.69^{c}	1.31±0.36^{a}	18.60±0.51^{a}	1.19±0.05^{a}	3.74±0.58^{c}	3.57±0.69^{a}	31.63±0.19^{a}

Values are presented as mean±SD. Values with different superscripts in the same column are statistically significantly different ($p<0.05$).

and lignin that cannot be digested in human organs and is known as a non-nutritive substance, but helps in the release of faeces (Tapotubun *et al.*, 2020). As presented in Table 3, the addition of LMP significantly increased ($p<0.05$) the crude fibre content in chicken balls (1.93% to 3.57%) compared to that in F0 at 0.72%. Dietary fibre is an edible part of plants that can be completely or partially fermented in the large intestine and is undigested and unabsorbable in the human small intestine (He *et al.*, 2022). Meat does not contain dietary fibre, but a small amount of dietary fibre was detected in the control sample, which may be attributed to the presence of condiments and spices. Among the treatments, F3 had the highest dietary fibre content, with a 30.59% increase compared with that of F0. These results are mainly attributed to the high dietary fibre content of LMP used in the formulation (40.88%, Table 2). Similar findings were obtained by Munsu *et al.* (2021), who reported that the addition of seaweed increased the dietary fibre content of sausages and that this effect was more pronounced at higher levels of *Sargassum polycystum*.

3.3 Cooking loss and water holding capacity of chicken balls

Table 4 reveals that the higher addition of LMP in chicken ball formulation reduced the cooking loss, ranging from 13.23% to 17.99%, which was significantly lower ($p<0.05$) than that in F1 (25.24%). The inclusion of LMP reduced the cooking loss of chicken meatballs because duckweed contains dietary fibre with a potent ability to bind water. Feng *et al.* (2023) reported that fibres formed hydrogen bonds with moisture released during protein thermal denaturation, reducing cooking loss. According to a previous study, adding vegetable fibre improved the emulsion stability of fish sausage, thereby increasing its cooking efficiency (Mahdavi and Ariaii, 2021). Indeed, F3 (6% LMP) showed the highest WHC at 28.42% (Table 4). However, there was no significant difference ($p>0.05$) in the WHC among the treatments. These findings may be attributed to the formation of a stronger protein gel network by the fibres in LMP. Zaini *et al.* (2021) reported that the WHC of sausages increased with the incorporation of banana peel flour because the fibres held water through the void spaces in the protein network.

3.4 Colour of chicken balls

The appearance of chicken balls incorporated with LMP is shown in Figure 1. Generally, colour parameters are crucial in evaluating the quality of meat products because they can strongly influence consumers' purchase behaviours. Table 4 reveals that the addition of duckweed powder significantly reduced ($p<0.05$) the L* and a* values while increasing ($p<0.05$) the yellowness

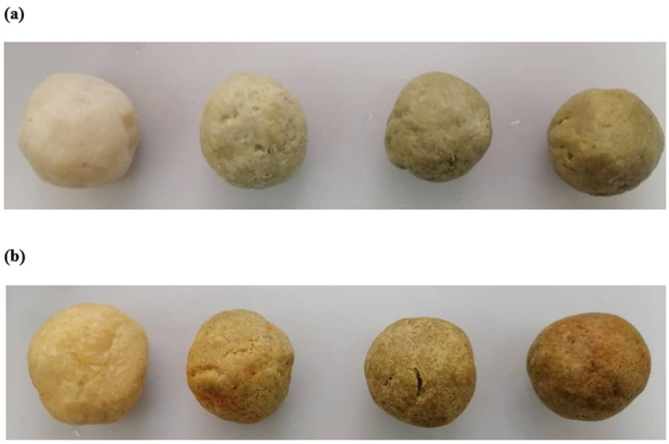


Figure 1. The appearance of raw (a) and cooked (b) chicken balls. From left: F0 (0% LMP), F1 (2% LMP), F2 (4% LMP), and F3 (6% LMP).

Table 4. Cooking loss, WHC, colour, and textural properties of chicken balls.

Treatments	Cooking loss (%)	WHC (%)	L*	a*	b*	Hardness (N)	Cohesiveness	Springiness (mm)
F0	25.24±0.40^{a}	25.16±1.94^{b}	69.15±1.60^{a}	2.82±0.92^{a}	22.71±1.63^{a}	33.61±3.17^{c}	0.58±0.38^{c}	4.60±0.16^{a}
F1	17.99±0.70^{b}	28.19±1.74^{a}	55.07±0.68^{b}	1.71±0.25^{b}	25.36±0.27^{b}	45.97±4.45^{b}	0.68±0.04^{b}	4.55±0.21^{a}
F2	14.85±0.50^{c}	27.32±2.57^{a}	52.89±1.13^{bc}	0.77±0.44^{bc}	26.09±0.10^{b}	65.32±4.57^{a}	0.78±0.03^{a}	4.35±0.26^{ab}
F3	13.23±0.66^{d}	28.42±0.69^{a}	50.72±1.04^{c}	0.25±0.15^{c}	26.29±0.21^{b}	73.64±5.33^{a}	0.79±0.13^{a}	4.08±0.22^{b}

Values are presented as mean±SD. Values with different superscripts in the same column are statistically significantly different ($p<0.05$).

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(b*) of chicken balls. The F3 sample (6% LMP) had the lowest L* (50.72) and a* (0.25) with the highest b* (26.29) among the samples. The green hue of duckweed resulted in a darker colour of the samples, as indicated by the low lightness and redness values. Moreover, fat globules typically contribute to the lightness of meat products, which causes greater light reflection (Wang *et al.*, 2018). In the present study, the only source of fat was chicken breast, and its effects might have been masked by the high chlorophyll content in LMP. In contrast, the increased b* values with LMP addition might be attributed to the presence of carotenoid pigments in duckweed (Stewart *et al.*, 2020). Similar results were reported by Rasak *et al.* (2021), who reported that carotenoid content in Moringa oleifera leaf powder increased the b* values of beef meatballs.

3.5 Textural properties of chicken balls

As shown in Table 4, F3 had the highest ($p<0.05$) hardness (73.64 N) and cohesiveness (0.79), indicating that the increasing duckweed concentrations resulted in greater hardness and cohesiveness values of meatballs. In contrast, the addition of LMP at a 6% concentration significantly reduced ($p<0.05$) the springiness of the sample. Similar findings were reported by Mena *et al.* (2020), in which the hardness of beef meatballs increased with the addition of sugarcane fibre due to the ability of dietary fibre to form a strong three-dimensional network. Moreover, the harder chicken balls with LMP compared to the control may be attributed to the lower water content in the formulation. According to McKee (2010), a higher fat content is responsible for increased cohesiveness in meat products. Therefore, one possible reason for the high cohesiveness recorded in F3 (0.79) may be the increase in the fat content of this sample (Table 3). In contrast, F3 showed the lowest springiness value at 4.08 mm, followed by F2 (4.35 mm) and F1 (4.55 mm). Zaini *et al.* (2020) reported that chicken sausages containing 2 to 6% banana peel powder showed lower springiness than the control sample owing to the stronger protein network, which had better resistance to compression.

3.6 Sensory preference of chicken balls

The consumer preference of the chicken balls incorporated with LMP was measured using a 9-point hedonic scale (Table 5). Among the treatments, F1 (2% LMP) received the highest colour, aroma, taste, texture, and overall acceptance scores of 6.11, 5.93, 7.02, 6.11, and 6.65, respectively. Moreover, F1 and F2 showed no significant difference ($p>0.05$) in terms of hardness and chewiness compared with the F0 control.

Generally, the addition of LMP significantly reduced ($p<0.05$) the colour scores of chicken balls. However, the colour of meat products is not as relevant to consumers who purchase products because of the perceived healthiness associated with it (Mohammed *et al.*, 2022). Additionally, this result may be related to the darker colour of the chicken balls, as indicated by the low L* values (Table 4). Cáceres *et al.* (2006) reported that consumers associated cooked meat products with a bright colour, and thus, a brighter product was preferred from their point of view. Moreover, F3 (6% LMP) had the lowest score for aroma (5.07) and taste (5.41), which may be attributed to the storage conditions of the sample. According to Nieuwland *et al.* (2021), freezing may result in a bitter taste in duckweed. Moreover, duckweed contains aromatic chemicals such as flavonoids and phenolic compounds, which have been reported to degrade the taste and odour of products (Larasanti *et al.*, 2019). The addition of 6% LMP significantly reduced ($p<0.05$) the sensory scores for both textural attributes, which may be due to the greater hardness and low springiness of F3. Similar findings were reported by Gorachiya *et al.* (2022), in which the addition of dietary fibre caused lower scores for texture and juiciness owing to the hard consistency of chicken sausages. Additionally, only F1 received an overall acceptance score above 6.3, meaning that the treatment is considered acceptable by consumers (Pires *et al.*, 2019).

3.7 Storage stability of chicken balls

The effect of incorporating LMP in chicken meatballs on preventing lipid oxidation was evaluated by measuring the changes in thiobarbituric acid reactive substances (TBARS). According to Cong *et al.* (2020), food products with a TBARS value less than 0.576 mg MDA/kg are considered fresh. Meanwhile, those with a TBARS value of 0.65-1.44 mg MDA/kg are considered rancid but still acceptable, and products with a TBARS

Table 5. Sensory evaluation of chicken balls.

Treatments	Colour	Aroma	Taste	Hardness	Chewiness	Overall acceptance
F0	7.13±1.92^{a}	6.93±1.53^{a}	7.56±1.27^{a}	6.61±1.65^{a}	6.67±1.68^{a}	7.41±1.24^{a}
F1	6.11±1.88^{b}	5.93±1.77^{b}	7.02±1.60^{a}	6.11±1.70^{a}	5.85±1.75^{a}	6.65±1.56^{ab}
F2	5.06±2.23^{c}	5.24±2.00^{b}	5.80±1.99^{b}	5.74±1.81^{a}	5.78±1.99^{a}	5.93±1.98^{b}
F3	4.43±1.81^{c}	5.07±2.22^{b}	5.41±1.94^{b}	4.61±2.12^{b}	4.35±1.90^{b}	4.96±1.77^{c}

Values are presented as mean±SD. Values with different superscripts in the same column are statistically significantly different ($p<0.05$).

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value greater than 1.5 mg MDA/kg are considered rancid and unacceptable for consumption (Cong *et al.*, 2020). As illustrated in Figure 2, lipid oxidation due to fat oxidation and the generation of volatile metabolites occurred in all the samples. However, the TBARS values were well below the minimum threshold required to detect negative changes in sensory qualities.

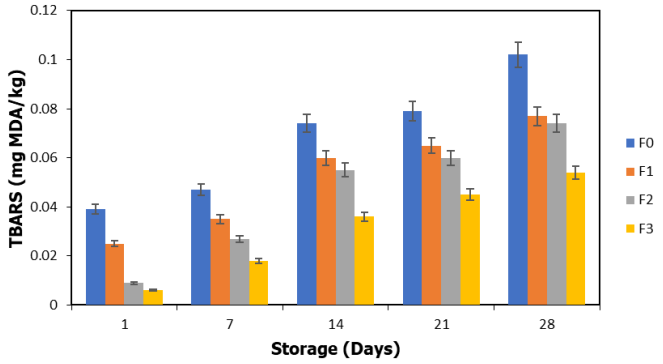


Figure 2. Changes in TBARS values of chicken balls during storage.

The F0 chicken balls showed the highest lipid oxidation rate after 30 days of storage, as indicated by the greater amount of TBARS. In contrast, the samples treated with LMP displayed a delay in lipid oxidation at the end of the storage day. Moreover, the addition of LMP resulted in lower TBARS values during storage (Figure 2). These findings may be attributed to the scavenging of free radicals by antioxidants found in duckweed, including carotenoids (722.8 µg/g) and ascorbic acid (70.02 mg/100 g) (Yadav *et al.*, 2024). A previous study reported a decrease in TBARS in ground beef supplemented with *Moringa oleifera* leaves due to the ability of polyphenols to adsorb and neutralise free radicals, leading to the prevention of lipid oxidation (Mashau *et al.*, 2021).

4. Conclusion

Oven-drying concentrated nutrients in duckweed resulted in significantly higher protein, lipid, ash, carbohydrate, crude fibre, and dietary fibre contents. The present study revealed that adding 2%, 4%, or 6% LMP to chicken balls increased the protein, lipid, and ash content, but not the moisture or carbohydrate content. Thus, LMP could also provide health benefits by increasing the total dietary fibre of chicken balls. Moreover, LMP reduced the cooking loss due to greater water-holding capacity. The incorporation of LMP increased hardness and cohesiveness. However, F1 (2% LMP) and F2 (4% LMP) showed no significant differences in springiness compared to the control. Among the treatments, F1 obtained the greatest overall acceptability scores due to its highly accepted colour, aroma, taste, hardness, and chewiness. Hence, this study demonstrated the potential of duckweed powder to produce chicken balls with a low-fat content.

Conflict of interest

The authors declare no conflict of interest.

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