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# Development of muffins fortified with *Nelumbo nucifera* dried flower flour as a source of dietary fibre: analysis of quality, nutritional value, and consumer acceptability

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Muffins are popular baked products that can be fortified nutritionally incorporating high-fibre natural flours such as millet, lotus dried flower flour, and flours obtained from by-products of fruits and vegetables. Also, the increasing demand for healthier food choices prompted the exploration of functional ingredients that can improve the nutritional profile of baked goods. A deep insight into the connected literature has highlighted the applications of various alternative flours in baked products as nutritional fortifying agents, but very limited research was documented, specifically on the use of lotus dried flower flour in muffin formulations. Consequently, the present research aimed to examine the potential of lotus dried flower flour as a source of dietary fibre in muffin preparations, focusing on the nutritional quality (physical and sensory attributes) and consumer acceptability of the developed muffins. Muffins were made using a combination of refined wheat flour and lotus-dried flower flour in comparison with 100% refined wheat flour muffins (control). The flour ratios used were 95% Refined Wheat Flour (RWF) to 5% Lotus Flower Flour (LFF) *i.e.*, (T1), 90% RWF to 10% LFF *i.e.*, (T2), and 80% RWF to 20% LFF (T3). The physical, textural, nutritional, and sensory properties, shelf life, and consumer acceptability of the developed muffins were investigated. The sensory evaluation revealed statistically significant differences ($p < 0.05$) among treatments, with overall acceptability (OAA) scores decreasing from $8.73 \pm 0.49$ in the control to $7.21 \pm 0.60$ in T3. The T2 formulation (10% LFF) maintained high acceptability with an OAA score of $8.26 \pm 0.60$. In contrast, colour analysis showed a darkening effect and shifts towards reddish and bluish hues. Physical characteristics revealed increased baking loss and altered texture as the level of lotus flour increased. Nutritional analysis indicated higher ash content (0.91 g *vs.* 0.83 g) and crude fibre (2.33 g *vs.* 1.97 g) in LFF muffins compared to the control, with minimal changes in energy content (366.96 kcal *vs.* 370.69 kcal). With this, the study concludes that lotus flower flour can effectively replace up to 10% of wheat flour in muffin preparation without compromising sensory and nutritional quality, making it a viable option for nutritionally enriched product development.

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## Sustainability spotlight

In this study, we explored how dried lotus flower flour, a fibre-rich ingredient, can contribute to healthier muffin formulations. We partially replaced regular wheat flour with lotus flower flour and assessed the impact on the muffins' quality, including both measurable and perceived attributes, nutritional value, and shelf life. Our results showed that incorporating up to 10% lotus flower flour improved the muffins' nutritional profile without compromising quality. This suggests that lotus flower flour holds promise as a sustainable and functional ingredient in bakery products. Our work connects well with global goals like: SDG 2 (Zero Hunger): this research supports SDG 2 (Zero Hunger) by contributing to the development of more nutritious food products and by promoting the use of underutilised plant species such as lotus flower. SDG 3 (Good Health and Well-being): by supporting healthier eating. SDG 12 (Responsible Consumption and Production): by sustainably using natural, plant-based ingredients.

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## Introduction

Creating food products with composite flour is one of several current trends in the baking sector. Increased interest in such classes of food products is attributed to their superior nutritional value. Production of bread from composite (or) nonwheat flours has been thoroughly explored for various reasons including reduced wheat importation, prevention of gluten-related health implications, and promotion and utilization of locally available indigenous crops. The carried-out studies have conceded insignificant levels of success in terms of bread quality attributes such as colour, texture, aroma, other sensory characteristics, and specific volume as measured by standards defined by the Food Safety and Standards Authority of India (FSSAI).[1] The factors that play foremost roles in the final qualities of bread were noticed as flour type, starch, and water content. Among these factors flour type is, however, arguably the major factor owing to variation in the gluten content, and it plays a decisive role in the appearance, structure, and texture of bread.[2]

The incorporation of nutrient-dense plant foods with therapeutic properties is necessary for addressing consumer requirements and benefits. Effective supplementation of cereal products with an underutilized edible plant such as lotus is one of the promising approaches to address consumer nutritional demands while bringing wellness to the user.[3] Lotus is taxonomically classified as *Nelumbo nucifera* and is a functional aquatic edible plant variety that has been cultivated and consumed for thousands of years, across the globe and predominantly in the Asian continent. The edible parts of the lotus plant *i.e.* roots, seeds, leaves, and flowers provide a wide range of culinary and nutritional benefits. Incorporating dried lotus flower flour into muffin recipes is a novel approach to enhancing the dietary fibre content of a popular baked product such as a muffin. Research has shown that wheat-based muffins typically have low nutrient density, mainly in dietary fibre, which is considered to be vital for maintaining health and also aids in preventing several chronic diseases, including hypercholesterolemia and colon cancer.[4] Muffins are a favourite bakery product among consumers, owing to their soft texture and delicious taste. Nevertheless, muffins have a low nutrient density, as they are high in sugar and fat but low in dietary fibre.[5,6] Literature studies envisaged that various plant-based ingredients can replace wheat flour in muffin recipes, leading to improved nutritional profiles of the product, without sacrificing the sensory attributes.[7]

For example, the addition of dietary fibre from kimchi by-products at 1–5 per cent has been shown to enhance the fibre content of muffins while preserving acceptable sensory properties.[4] Incorporating different forms of dietary fibre into muffin compositions is a potential way to boost their health benefits while retaining their appealing attributes. Recent research has demonstrated that a variety of plant-based components, including vegetable and fruit byproducts, could efficiently substitute standard wheat flour, resulting in muffins with increased fibre content and better nutritional properties. The approach is consistent with the growing trend of employing food industry byproducts to generate enriched products that are healthier.[8] Lotus dried flower flour is an excellent substitute for conventional flour in muffin recipes due to its high dietary fibre content (11.73 g/100 g) and notable nutritional values particularly rich in essential minerals such as calcium (880.93 mg $kg^{-1}$), potassium (5040.84 mg $kg^{-1}$), magnesium (1524.83 mg $kg^{-1}$), and iron (290.30 mg $kg^{-1}$), while also providing a good protein content (7.42 g/100 g) and low fat (0.54 g/100 g).[9,10] Understanding the research hitherto stated, it is proposed that lotus-dried flower flour could potentially be utilized in baked products as a blend with other flours. Therefore, the current study aimed to evaluate the possible efficacy of incorporating lotus (*Nelumbo nucifera*) dried flower flour into muffin preparation and further examine the physical, nutritional, and sensory qualities of muffins prepared with dried lotus flower flour. The findings will provide insights into the use of lotus flower flour as a dietary supplement and nutritious ingredient in muffin preparations, thereby enhancing both health benefits and customer acceptance.

## Materials and methods

Fresh lotus flowers were procured from the farmers of Kanchipuram and Madurai districts of Tamil Nadu. Details of the lotus flowers, including photographic documentation, are presented in Fig. 1 and further described in the research.[9] All the other ingredients required for the development of muffins were procured from local markets of Bangalore and were stored at ambient temperature for further muffin preparation.

### Processing of lotus flower

The lotus flowers were subjected to drying in a tray dryer (SST0331717 Dryer, Scientek Services) at a temperature of 60 °C for 3 h. Drying was continued till the flowers became completely dry and crisp and attained steady weight. The dry materials were ground into flour using a Sujata Dynamix mixer grinder (Dynamix, Mittal Electronics, India) and sieved using a 72 μm mesh sieve. The prepared flour was packed and stored in an airtight container for further investigation.

### Lotus dried flower flour muffins (LFFM)

The muffins were developed by combining lotus flower flour and refined wheat flour. Three muffin variations were developed by replacing refined wheat flour with lotus flower flour at

Fig. 1 Lotus flowers and its petals.

 

Table 1 Composition of muffins[a]

| | | Quantity (g) | | | |
|---|---|---|---|---|---|
| Sl. no. | Ingredients | C | T1 | T2 | T3 |
| 1 | Refined wheat flour | 50 | 47.50 | 45 | 40 |
| 2 | Lotus flower flour | — | 2.50 | 5 | 10 |
| 3 | Sugar | 50 | 50 | 50 | 50 |
| 4 | Fat | 50 | 50 | 50 | 50 |
| 5 | Egg | 1 no. | 1 no. | 1 no. | 1 no. |
| 6 | Milk powder | 10 | 10 | 10 | 10 |
| 7 | Vanilla essence | 1 | 1 | 1 | 1 |
| 8 | Baking powder | 0.25 | 0.25 | 0.25 | 0.25 |

[a] C = control (0% LFFM), T1 = 5% LFFM, T2 = 10% LFFM, T3 = 20% LFFM.

varying percentages (5%, 10%, and 20%). The control sample was prepared using only refined wheat flour, without the addition of lotus flower flour. All samples were compared as represented in Table 1.

### Preparation of muffins

The muffins were prepared according to the procedure with some modifications using the traditional creaming method.[11] Eggs were broken into a bowl, mixed with vanilla essence, and beaten manually for 5 minutes. In a separate bowl, fat, granulated sugar, and milk powder were creamed by hand until light and fluffy. The beaten egg mixture was then gradually added and mixed thoroughly. Refined wheat flour, lotus flower flour, and baking soda were sifted together and incorporated into the wet mixture. Milk was added gradually to achieve a dropping consistency. The batter was poured into paper liners placed in baking trays and baked in a preheated oven (Baking Oven, Scientek Services, Bangalore) at 180 °C for 15–20 minutes. After baking, the muffins were cooled at room temperature and packed for analysis. The preparation steps are illustrated in Fig. 2.

### Physical characteristics assessment studies of the developed products

**Colour.** The colour was measured using a reflective colorimeter, Hunter Lab colorimeter (Chroma Meter CR-300), on powdered muffin samples to ensure uniformity and eliminate surface variability. The chromatic readings $L^*$, $a^*$, and $b^*$ were documented, with each value representing the mean of three distinct measurements of the muffin samples. The $L^*$ parameter gauges luminosity, spanning from 100 for white to 0 for complete blackness. Conversely, the $a^*$ and $b^*$ values denote chromatic intensity, where a positive $a^*$ signifies redness and a negative value indicates greenness, while a positive $b^*$ correlates with yellowness and a negative with blueness.

**Baking loss (%).** Baking loss was calculated as the difference in mass between the dough or batter before baking and after baking (when it emerges as a baked product).[12] The loss of mass in a product as a result of baking is said to be baking loss. Baking loss of muffins was calculated by using formula (1):

$$\text{Baking loss}(\%) = \frac{\text{weight before baking} - \text{weight after baking}}{\text{weight before baking}} \times 100 \tag{1}$$

### Textural properties of the developed muffins

The textural profile of the muffins was determined using a Texture Profile Analysis (TPA) test performed with a TA.HD Plus texture analyzer (Stable Micro Systems, UK). The settings used were a pre-test speed of 1.0 mm s$^{-1}$, test speed of 5.0 mm s$^{-1}$, post-test speed of 5.0 mm s$^{-1}$, and a compression distance of 10 mm, using a 2 mm cylindrical probe. A 100 kg load cell was

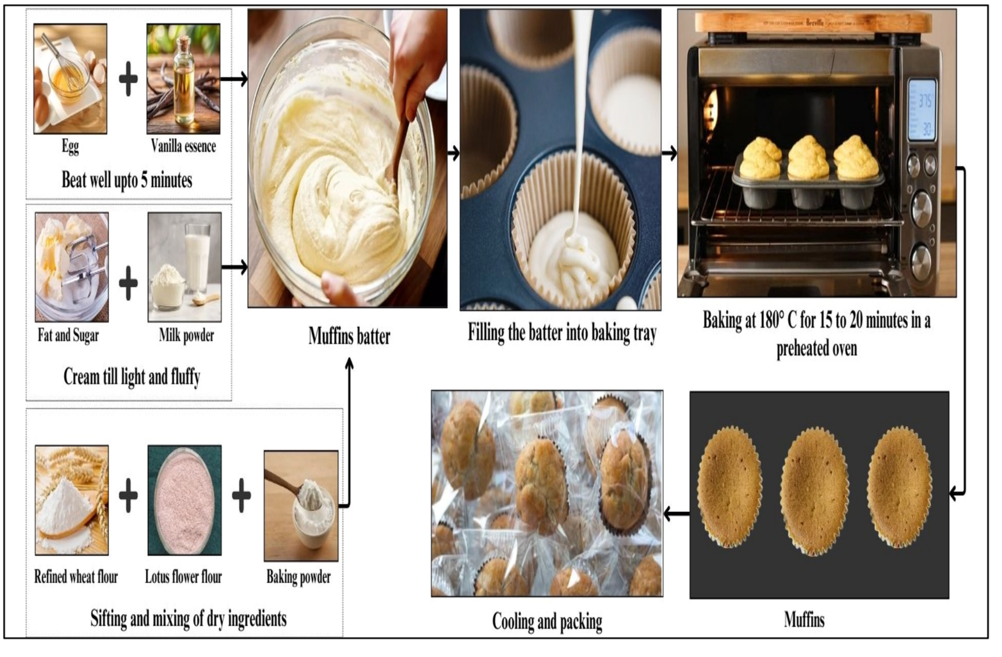


Fig. 2 Procedure for the preparation of lotus dried flower flour muffins.

employed. Each muffin was placed on a heavy-duty platform with a holed plate, and the probe compressed the sample to record parameters such as hardness. The measurements were taken on the day of baking and the analysis was performed in triplicate.

### Sensory evaluation and consumer acceptability of the developed products

The baked muffins were evaluated by a semi-trained panel of 21 participants using a nine-point hedonic scale to assess sensory attributes, including appearance, colour, consistency, taste, flavour, and overall acceptability.[13] Each formulation was evaluated individually, and samples were presented in a randomized order with three-digit codes to ensure anonymity and reduce bias. Panellists were instructed to rinse their mouths with water between samples to prevent flavour from mixing. These instructions were included in the sensory evaluation questionnaire. Informed consent was obtained from all participants prior to the evaluation.

For consumer acceptability, the best accepted products were served to the consumers to test the general acceptance pattern. Consumers were randomly selected and distributed the products to find out the level of acceptance by using a five-point hedonic scale (from 1 – 'Poor' to 5 – 'Excellent) for the attributes like appearance, taste, texture, flavour and overall acceptability.

### Proximate analysis of the best accepted products

The control and best accepted products were subjected to proximate analysis. The nutrients analyzed were moisture, protein, fat, crude fibre and ash by using standard AOAC 2005 methods.[14] Carbohydrates and energy were calculated by a differential method using the following formulas (2) and (3). All proximate composition values (protein, fat, moisture, and ash) were expressed in g/100 g of sample and used accordingly in the carbohydrate and energy calculations.

$$\text{CHO (g/100 g)} = 100 - [\text{protein (g)} + \text{fat (g)} + \text{ash (g)} + \text{moisture (g)}] \tag{2}$$

$$\text{Energy (kcal)} = [\text{protein (g)} \times 4] + [\text{carbohydrate (g)} \times 4] + [\text{fat (g)} \times 9] \tag{3}$$

### Elemental analysis by ICP-OES

Elemental analysis was carried out using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES; Model: SPECTRO GENESIS, Config: FES27, SPECTRO Analytical Instruments, Germany) at the Bioenergy Research and Quality Assurance Laboratory, University of Agricultural Sciences, Bengaluru. This analysis aimed to quantitatively determine the presence of specific minerals. In the analytical procedure, 0.25 g of sample was digested with 5 mL of concentrated nitric acid ($HNO_3$) and 1 mL of hydrogen peroxide ($H_2O_2$). To ensure complete decomposition, the sample was subjected to microwave digestion using a compact microwave digestion system (Model: ETHOS LEAN, Manufacturer: MWT AG, Production factory: Milestone Srl, Italy). The digested solution was then diluted to a final volume of 25 mL with distilled water. The prepared sample was introduced into the ICP-OES instrument for mineral quantification. Calibration curves were established for each element using certified standard solutions of known concentrations to ensure accuracy and reliability. The concentrations of minerals are expressed as milligrams per 100 grams of sample (mg/100 g).

### Shelf life study of the best accepted products

The developed products were stored in polypropylene (PP) pouches and kept under ambient conditions. The products were evaluated for their organoleptic acceptability, quality parameters (moisture, free fatty acid, and peroxide value), and total microbial load at a 5 day interval of 10 days duration.

**Moisture.** Moisture was determined by weighing 10 g of the sample in a Petri plate and drying in an oven at 105 °C for 2–3 hours until the weight remained constant. The dehydrated samples were weighed, and the results were subtracted from the initial weight of the sample to obtain the moisture content using formula (4):

$$\text{Moisture percent} = \frac{\text{initial weight(g)} - \text{final weight(g)}}{\text{initial weight(g)}} \times 100 \tag{4}$$

**Peroxide value.** Peroxide value (PV) measures the extent of fat oxidation by detecting peroxides formed when fats react with oxygen. The PV was determined following the reported method.[15] In the method, 0.5–1 g of fat was dissolved in an acetic acid–chloroform mixture, and then potassium iodide was added. The peroxides release iodine, which was titrated with sodium thiosulphate using starch as an indicator. A blank test without fat was also performed.

$$\text{Peroxide value of oil}(\text{mEqO}_2 \text{ per kg}) = \frac{(\text{titre} - \text{blank}) \times N \times 1000}{\text{wt of the oil(g)}} \tag{5}$$

where titre refers to the volume (in mL) of sodium thiosulphate used to titrate the sample, blank is the volume (in mL) used in the blank titration without the sample, $N$ is the normality of the sodium thiosulphate solution, and weight of sample is the mass of the fat sample in grams.

**Free fatty acid.** The free fatty acid (FFA) content was determined following the AOAC method.[14] Approximately 10 g of oil was dissolved in a neutralized mixture of alcohol and ether with phenolphthalein as an indicator. The solution was titrated with 0.1 N KOH until a persistent pink colour appeared. The FFA percentage was calculated using the titration volume and expressed as percent oleic acid.

### Microbial analysis

The developed products were stored in polypropylene pouches at room temperature for 10 days. Microbial counts (total bacteria, *E. coli*, and fungi) were assessed on the 1st, 5th, and

 

10th days using the standard plate count method with serial dilutions. Nutrient Agar (NA) was used for total bacterial count, Eosin Methylene Blue Agar (EMB) for *E. coli*, and Potato Dextrose Agar (PDA) for fungi. Samples (1 g) were serially diluted, and 1 mL of the appropriate dilution was plated on each specific medium. Plates were incubated in an inverted position: bacterial and *E. coli* plates at 30 ± 2 °C for 24–48 hours, and fungal plates at 25 ± 2 °C for 48–72 hours. Colony-forming units were counted and expressed as CFU per g of sample.

### Statistical analysis

All analytical measurements, including colour, baking loss, texture, moisture, peroxide value, free fatty acids, and microbial counts, were performed in triplicate unless otherwise specified. The data were subjected to one-way analysis of variance (ANOVA) to evaluate the significance of differences among the physical and sensory properties of the developed muffin formulations. When significant differences were detected ($p < 0.05$), Tukey's *post hoc* test was applied to identify homogeneous groups. Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS), version 12.0.[16] The results are reported as mean ± standard deviation.

## Results and discussion

### Physical characterization of the developed products

**Colour parameters of lotus dried flower flour muffins.** The colour characteristics of lotus dried flower flour muffins were analyzed and compared to a control sample represented in Table 2. The $L^*$, $a^*$, and $b^*$ values indicate the lightness, red-greenness, and yellow-blueness of the muffins, respectively. The $c$ value represents the chroma, which is a measure of the colour's saturation. The $h$ value represents the hue angle, which is a measure of the colour's dominant wavelength. The $\Delta E$ value shows the overall colour difference between the muffin and standard white colour. The control muffin exhibited an $L^*$ value of 70.10, indicating a relatively high level of lightness, while its $a^*$ and $b^*$ values were 0.29 and 18.26, respectively. These values suggest that the control muffin had a principally yellow colour with a slight red-green tint. The total colour difference ($\Delta E$) between the control muffin was 35.26, serving as a reference for comparing the other samples.

Three different treatment groups (T1, T2, and T3) were evaluated. Notably, all treatment group's $L^*$ values declined as compared to the control, suggesting a darker appearance. The muffin with T2 had the darkest appearance among all the muffins examined, shown by its lowest $L^*$ value of 47.20. The reduction in the $L^*$ value from control to T3 is most likely due to the presence of anthocyanin pigment in the lotus dried flower flour. Many fruits and vegetables have red, purple, and blue hues representing the presence of a rich antioxidant flavonoid named anthocyanins. Furthermore, there was a shift toward more reddish and blue hues in the treatment groups, as indicated by an increase in the $a^*$ and $b^*$ values. T2 exhibited a shift toward red and blue colours, with the highest $b^*$ value (19.66) and highest $a^*$ value (6.70).

As the amount of lotus dried flower flour increased, $c$ values of the muffins all declined from the control to T3, suggesting that the muffins became less saturated. The anthocyanins in lotus dried flower flour may interact with other ingredients in the muffin batter, such as proteins or carbohydrates, to form complexes. This interaction is suggested by the reduction in the $c$ value from the control to the T3 group, indicating that complex formation can lead to a decrease in the colour intensity of the muffins. However, with the addition of lotus flower flour, the dominant wavelength of the muffins did not change considerably, as evidenced by the $h$ values of the muffins remaining relatively consistent. The comparatively stable $h$ values of the muffins indicate that the addition of lotus dried flower flour did not significantly alter the dominant wavelength of the muffins. This implies that lotus dried flower flour's anthocyanins do not absorb light at a particular wavelength. The total colour differences ($\Delta E$) for the treatment groups (T1, T2, and T3) were 52.83, 56.73, and 54.40, respectively, when compared to the control muffin. The increase in $\Delta E$ values from the control to T3 suggests that the muffins became darkened compared to the standard white colour, as the amount of lotus dried flower flour increased. The darkened nature of developed muffins is likely due to the combined effects of the decrease in $L^*$ and $c$ values, respectively.

A study[17] investigated the qualitative parameters of cookies made with lotus dried leaf powder. The results showed that adding lotus dried leaf flour to cookies decreased the $L^*$ and $c^*$ values, suggesting that lotus leaf flour darkens cookies and makes them less saturated. Another study[18] investigated the effects of anthocyanin-rich popping maize flour on the phenolic profile, antioxidant capacity, and the physical and sensory properties of bread, highlighting its potential to enhance both quality and nutritional value. Study results showed that anthocyanin-rich maize flour changed the breadcrumb colour

Table 2 Colour parameters of control and treatment groups derived from lotus dried flower flour muffins[a]

| Muffin | $L^*$ | $a^*$ | $b^*$ | $c$ | $h$ | $\Delta E$ |
|---|---|---|---|---|---|---|
| Control | $70.10 \pm 1.38^a$ | $0.29 \pm 0.02^d$ | $18.26 \pm 0.40^b$ | $18.60 \pm 0.15^c$ | $89.33 \pm 1.34^a$ | $35.26 \pm 0.96^d$ |
| T1 | $50.40 \pm 1.32^b$ | $3.50 \pm 0.12^c$ | $17.70 \pm 0.45^b$ | $18.26 \pm 0.32^c$ | $79.00 \pm 1.51^b$ | $52.83 \pm 1.16^c$ |
| T2 | $47.20 \pm 1.75^c$ | $6.70 \pm 0.22^a$ | $19.66 \pm 0.75^a$ | $20.60 \pm 0.45^a$ | $71.06 \pm 1.77^c$ | $56.73 \pm 1.47^a$ |
| T3 | $49.43 \pm 1.27^b$ | $6.30 \pm 0.14^b$ | $19.00 \pm 0.26^{ab}$ | $20.00 \pm 0.43^b$ | $71.73 \pm 0.95^c$ | $54.40 \pm 0.65^b$ |

[a] Means with different letters in superscript within a column differ significantly ($P \leq 0.05$), C = control (0% LFFM), T1 = 5% LFFM, T2 = 10% LFFM, T3 = 20% LFFM, $L^*$ = lightness; $a^*$ = redness; $b^*$ = yellowness, $c$ = chroma, $h$ = hue, $\Delta E$ = colour difference.

to a brick-red range. Replacement of 30% of wheat flour with wholegrain blue and dark-red popping maize flour rich in phenolic compounds improved the functional profiles of the end product by increasing the content of total phenolic compounds, anthocyanins, and phenolic acids in maize mixed bread. The study envisaged that, despite thermal degradation during baking, anthocyanins from maize flour could significantly contribute to the health benefits of bread, as well as its desirable colour. The present results were in accordance with the mentioned study and a similar trend was observed with respect to the colour indicating that colour played a significant role because of the pigments present on the LFF.

Therefore, the findings indicate that the LFF incorporated in the muffins had a considerable impact on the colour and the muffins were found to be less saturated and darker. An increase in the content of LFF causes the change of colour of muffins from the usual white to a darkened colour. The colour properties of LFFM may be influenced by various treatments. These findings can assist in evaluating consumer acceptance of the product. Additionally, the presence of anthocyanins in lotus dried flower flour contributes notable health benefits.

**Baking characteristics of lotus dried flower flour muffins.** Table 3 presents the baking characteristics of lotus dried flower flour muffin (LFFM) samples with different levels of LFFM content. The control group (C) had a baking loss of approximately 19.66%, while the experimental groups (T1, T2, and T3) exhibited higher baking losses, ranging from 26.31% to 33.9%, and the findings suggest that the incorporation of LFF into the muffin recipes resulted in a greater reduction in weight during the baking process.

The T3, with 20% LFFM, had the highest baking loss, while T1 and T2, with 5% and 10% LFFM, exhibited relatively comparable baking losses. This behaviour is consistent with studies on other non-wheat flours, such as *Perilla* leaves powder, where baking loss increased proportionally with higher additive concentrations.[19] The higher baking loss in muffins with LFF could be attributed to the greater water absorption capacity of lotus flower flour, which results in more moisture being lost during baking. Additionally, the presence of LFF in the batter may have interfered with the formation of the gluten network, leading to a weaker structure and greater baking loss.

Table 3 Baking physical characteristics of lotus dried flower flour muffins[a]

| Sample | Baking loss (%) |
|---|---|
| C | $19.66 \pm 3.34^{a}$ |
| T1 | $26.31 \pm 4.84^{ab}$ |
| T2 | $26.25 \pm 4.37^{ab}$ |
| T3 | $33.9 \pm 5.28^{a}$ |
| *F*-Value | * |
| SEm± | 2.61 |
| CD @ 5% | 8.64 |

[a] Means with different letters in superscript within a column differ significantly ($P \leq 0.05$), * = significant, C = control (0% LFFM), T1 = 5% LFFM, T2 = 10% LFFM, T3 = 20% LFFM. SEm± = standard error of mean, CD @ 5% = critical difference at 5% level.

**Texture profile analysis of lotus dried flower flour muffins.** The texture parameters, including hardness, fracturability, springiness, cohesiveness, gumminess, and chewiness of the studied muffins, are presented in Table 4. The incorporation of LFF into muffins produced a texture that was harder than the control. Similarly, a study reported that the addition of legume flours to gluten-free cakes significantly increased hardness values from 4.5 N in the control to 6.3–6.6 N with chickpea, pea, and bean flours.[20] In a study,[21] a comparable trend was observed in rice-based muffins, where the control had a hardness of 174.6 g, while legume flour muffins ranged from 440.5 to 663.7 g, depending on the legume type.

It is observed from the study that the properties vital for muffin quality *i.e.* cohesiveness (0.258 to 0.363), gumminess (78.76 to 260.66), and chewiness (27.01 to 114.04) increased with higher LFFM incorporation levels. Springiness values measure the capacity of muffins to recover their original shape after compression. Increasing springiness values of the tested samples T1, T2, and T3 (0.977, 0.514, and 0.429) suggested an increase in elasticity of muffins in comparison with the control muffin's springiness values (0.343) representing the quality of the developed muffins over the control. It is observed from the studies that the muffins became less elastic and more brittle as the LFF content increased, demonstrated a decrease in springiness values.

Increasing LFF content also increased the chewiness and gumminess, probably due to LFF having a high fibre content, which helps produce a denser, more compact structure by binding with water molecules. The texture of muffins might be changed by adding LFF, and the inclusion of LFF makes muffins denser, less springy, less cohesive, gummier, and chewier. Interaction of LFF with other proteins and gluten in the muffin mix might be the cause of these variations in textural properties.

**Sensory evaluation of lotus dried flower flour muffins.** The sensory evaluation is critical in assessing the overall quality and acceptability of the muffins based on various attributes. The developed LFFM sensory evaluation reports are discussed in Table 5. The results indicated that, as the percentage of LFF increased, the sensory scores decreased for all attributes, specifically, the control group had the highest scores for all attributes, while the group with 20% LFF had the lowest sensory scores. Appearance scores for all muffin varieties were relatively high, with the control group having the highest score ($8.85 \pm 0.35$) and the group with 20% LFF having the lowest ($7.14 \pm 0.85$). The texture scores followed a similar trend, with the control group having the highest score of $8.66 \pm 0.57$ and the group with 20% LFF having the lowest score of $7.19 \pm 0.82$.

The colour scores of all groups were likewise relatively high; the control group scored the highest ($8.71 \pm 0.46$), whereas the group with 20% LFF scored the lowest ($7.07 \pm 0.67$). As the percentage of LFF increased, flavour and taste scores showed a more significant decrease. The addition of lotus flower flour (LFF) influenced the sensory attributes of flavour and taste in

 

Table 4 Textural profile analysis of lotus dried flower flour muffins[a]

| Muffin | Hardness (N) | Fracturability (N) | Springiness | Cohesiveness | Gumminess (N) | Chewiness (N) |
|---|---|---|---|---|---|---|
| Control | $304.76 \pm 2.35^d$ | $2.81 \pm 0.05^a$ | $0.343 \pm 0.003^d$ | $0.258 \pm 0.001^b$ | $78.76 \pm 0.48^d$ | $27.01 \pm 0.50^d$ |
| T1 | $321.26 \pm 0.92^c$ | — | $0.977 \pm 0.001^a$ | $0.363 \pm 0.002^a$ | $116.68 \pm 0.45^c$ | $114.04 \pm 0.25^a$ |
| T2 | $544.64 \pm 2.31^b$ | — | $0.514 \pm 0.003^b$ | $0.318 \pm 0.001^{ab}$ | $173.22 \pm 1.68^b$ | $89.06 \pm 0.32^c$ |
| T3 | $731.82 \pm 2.46^a$ | $0.37 \pm 0.01^b$ | $0.429 \pm 0.002^c$ | $0.356 \pm 0.001^a$ | $260.66 \pm 0.64^a$ | $111.71 \pm 0.43^b$ |

[a] Different superscripts in the same columns are statistically significant ($p < 0.05$).

Table 5 Sensory evaluation of lotus dried flower flour muffins[a]

| Variation | Appearance | Texture | Colour | Flavour | Taste | Consistency | OAA |
|---|---|---|---|---|---|---|---|
| C | $8.85 \pm 0.35^a$ | $8.66 \pm 0.57^a$ | $8.71 \pm 0.46^a$ | $8.71 \pm 0.64^a$ | $8.66 \pm 0.55^a$ | $8.66 \pm 0.48^a$ | $8.73 \pm 0.49^a$ |
| T1 | $8.23 \pm 0.62^b$ | $8.02 \pm 0.74^b$ | $8.30 \pm 0.51^b$ | $8.11 \pm 0.54^b$ | $8.00 \pm 0.65^b$ | $7.92 \pm 0.74^b$ | $8.09 \pm 0.56^b$ |
| T2 | $7.54 \pm 0.77^c$ | $7.85 \pm 0.79^b$ | $7.54 \pm 0.63^c$ | $8.19 \pm 0.67^b$ | $8.16 \pm 0.65^b$ | $7.92 \pm 0.85^b$ | $8.26 \pm 0.60^b$ |
| T3 | $7.14 \pm 0.85^c$ | $7.19 \pm 0.82^c$ | $7.07 \pm 0.67^d$ | $7.21 \pm 0.60^c$ | $7.27 \pm 0.54^c$ | $7.19 \pm 0.76^c$ | $7.21 \pm 0.60^c$ |
| Mean ± SD | 7.94 ± 0.93 | 7.93 ± 0.90 | 7.91 ± 0.85 | 8.05 ± 0.81 | 8.03 ± 0.77 | 7.92 ± 0.88 | 8.07 ± 0.78 |
| *F*-Value | * | * | * | * | * | * | * |
| SEm± | 0.39 | 0.43 | 0.33 | 0.36 | 0.35 | 0.42 | 0.33 |
| CD @ 5% | 1.10 | 1.21 | 0.93 | 1.00 | 0.98 | 1.17 | 0.92 |

[a] Different superscripts in the same columns are statistically significant ($p < 0.05$), * = significant, C = control (0% LFFM), T1 = 5% LFFM, T2 = 10% LFFM, T3 = 20% LFFM, OAA – overall acceptability.

the muffins. The control group had the highest scores for both attributes, with scores of 8.71 ± 0.64 and 8.66 ± 0.55, respectively. The group with 20% LFF had the lowest scores for both attributes, representing scores of 7.21 ± 0.60 and 7.27 ± 0.54, respectively. This reduction may be attributed to the characteristic earthy or floral notes introduced by LFF, which could be less familiar or desirable to some panellists. The consistency scores followed a similar trend, with the control group having the highest score of 8.66 ± 0.48 and the group with 20% LFF having the lowest score of 7.19 ± 0.76. A decrease in overall acceptance has also been reported in muffins formulated with alternative plant-based ingredients, such as legumes, potentially due to changes in taste and flavour.[21] While the specific sensory profiles differ, a similar downward trend in overall acceptance was observed in the present study with increasing levels of lotus flower flour, likely reflecting a shift in flavour and texture perception among consumers.

Overall, the sensory evaluation results suggested that the addition of LFF to muffins negatively affects their sensory attributes, with the highest scores observed in the control group containing 0% LFF. However, the muffins scored relatively high for all the attributes, including the muffins prepared with 20% LFF. Hence, results indicated that LFFM can be used to make muffins with acceptable sensory characteristics at replacement levels of wheat flour up to 10%. Muffins are considered a sweet baked good, which often compensates for the bitterness of whole wheat flour. However, studies have shown that the addition of ingredients with fibre broadly reduces sweetness and flavour intensity in muffin formulations.[22] This might be the reason that the LFF having more fibre content caused the sensory attributes to decrease as its incorporation increased in the muffin. Dietary fibre can increase the density of baked goods and make them less tender.

### Nutritional composition of lotus dried flower flour muffins

*Proximate composition of the best accepted lotus dried flower flour muffins.* Nutritional constituents of control and best accepted LFFM are compared in Table 6. The moisture content of muffins incorporated LFF was 24.56%, which was slightly less than the moisture level of muffins made with wheat flour (25.43%). Reduction in moisture content might contribute to a denser texture in the LFFM. The protein content is marginally lower in the LFF based muffin (4.86 g) compared to the control (5.35 g), which could be attributed to the lower protein content of the LFFM compared to that of wheat flour. The total fat content of the LFF incorporating muffins and refined wheat flour muffins was reported to be 15.52 and 15.61 g, respectively.

Interestingly, the LFF based muffin has a slightly higher ash content (0.91 g) and crude fibre content (2.33 g) than the control, indicating a potential benefit in terms of mineral and dietary fibre intake. However, the LFF muffins had a carbohydrate content of 51.96 g, as well as a lower energy value (366.96

Table 6 Proximate composition of control muffins and the best accepted lotus dried flower flour muffins (10% LFFM) (g/100 g)[a]

| Nutrients | Control | LFFM |
|---|---|---|
| Moisture (%) | $25.43 \pm 0.20^a$ | $24.56 \pm 0.22^b$ |
| Protein (g) | $5.35 \pm 0.04^a$ | $4.86 \pm 0.03^b$ |
| Fat (g) | $15.61 \pm 0.25^a$ | $15.52 \pm 0.20^a$ |
| Ash (g) | $0.83 \pm 0.02^b$ | $0.91 \pm 0.01^a$ |
| Crude fibre (g) | $1.97 \pm 0.02^b$ | $2.33 \pm 0.07^a$ |
| Carbohydrates* (g) | $52.20 \pm 0.26^a$ | $51.96 \pm 0.15^a$ |
| Energy* (kcal) | $370.69 \pm 0.65^a$ | $366.96 \pm 0.41^b$ |

[a] Different superscripts in the same row are statistically significant ($p < 0.05$), all values are expressed as g/100 g of sample, except energy (kcal). *Carbohydrates and energy values are computed.

kcal) in comparison with the control. The nutrient composition of Hibiscus cake is as follows: total carbohydrates (45.86 g), protein (6.45 g), fat (23.95 g), fibre (0.64 g) and moisture (21.40 g) content.[23] The present study showed on-par nutrient content in comparison with results obtained from the study,[23] principally due to the incorporation of LFF.

*Elemental analysis of the best accepted lotus dried flower flour muffins.* The elemental analysis of the best-accepted LFFM is presented in Table 7. The analysis compares the control muffin (refined wheat flour) with the LFFM. In terms of macrominerals, the incorporation of LFF has led to a significant increase in calcium (Ca) content, with LFFM containing 1474.91 mg kg$^{-1}$ compared to the control muffin (793.48 mg kg$^{-1}$). Additionally, potassium (K) and magnesium (Mg) levels have also substantially risen in LFFM, standing at 2527.25 mg kg$^{-1}$ and 366.43 mg kg$^{-1}$, respectively, in contrast to 1502.96 mg kg$^{-1}$ and 211.68 mg kg$^{-1}$ in the control muffin. Sodium (Na) content has slightly increased from 1719.12 mg kg$^{-1}$ to 1894.33 mg kg$^{-1}$ in LFFM. These macrominerals are essential for various physiological processes, including muscle function, nerve transmission, and bone health, and their higher levels in LFFM underscore its potential as a more nutritious option.

However, the microelements, iron (Fe) and copper (Cu) contents, in LFFM are slightly elevated at 16.75 mg kg$^{-1}$ and 1.63 mg kg$^{-1}$, respectively, compared to 16.24 mg kg$^{-1}$ and 0.37 mg kg$^{-1}$ in the control. No changes were observed in zinc (Zn), manganese (Mn), or chromium (Cr) levels. Although the variations might not be significant, microelements are important for enzymatic activity and health in general and enhance the nutritional value of LFFM. Furthermore, both the LFFM and control muffins exhibit very low concentrations of harmful metals like lead (Pb), cadmium (Cd), and cobalt (Co). This ensures the safety of consuming LFF muffins concerning heavy metal contamination.

*Shelf-life study of the best accepted lotus dried flower flour muffins.* The moisture, peroxide value, and free fatty acids in the shelf-life study of bakery products are primarily related to their oxidative stability and overall quality. These factors can be used as indicators of product deterioration and can help in determining the product's quality. The best accepted LFF muffin and control muffins were subjected to shelf life analysis.

*Effect of storage on moisture, peroxide value (PV), and free fatty acid (FFA) of the best accepted lotus dried flower flour muffins.* The effect of storage on the moisture content, peroxide value (PV), and free fatty acid (FFA) of the best accepted LFFM was evaluated and the results are presented in Table 8. The moisture content of LFFM decreased significantly during storage, with the initial value of 25.43 ± 0.42 g to 22.60 ± 0.37 g on the 10th day of the storage. This decrease in moisture content could be attributed to the loss of water through evaporation or migration to the surrounding environment.

A study[24] investigated the sensory and physical qualities of muffins manufactured with waxy whole wheat flour. The amount of moisture was found to be higher on the initial day than on all subsequent sample days but eventually remained constant across all formulations. For example, control muffins at day 0 had 38.0 g$H_2O$/100 g. By day 4, the moisture had decreased to 34.7 g$H_2O$/100 g. A similar trend was observed in the present study. It has been found that most baked goods experience a rapid decrease of moisture in the first 24 h to 36 h of storage and have much smaller changes in moisture during the further stages of product storage.[25,26]

The peroxide value (PV) is an indicator of lipid oxidation. PV values of the tested muffins showed a significant increase during the 10 days of storage. The initial PV was 12.71 ± 0.20 mEq$O_2$ per kg, which increased to 13.47 ± 0.22 mEq$O_2$ per kg on the 5th day and 14.50 ± 0.12 mEq$O_2$ per kg on the 10th day, due to the complex interactions between the various components of the muffins, such as fats, proteins, and antioxidants. Among both samples, the muffins supplemented with LFF showed lower peroxide values throughout the storage period than the control sample. A higher peroxide value indicates auto-oxidations of fat present in muffins. Also, it might be due to the antioxidant properties of LFF, and comparatively lower peroxide value regarding the control. Significant variations were found in peroxide value concerning storage conditions and storage period. The present study results agreed with the study investigating the effect of storage on the PV of guar flour-supplemented muffins.[27] The results showed that the PV values of the muffins increased with storage, but the increase was lower in the guar flour-supplemented muffins compared to the control. Inference suggests that the antioxidant properties of guar flour might be responsible for the lower PV in the supplemented muffins.

The free fatty acid (FFA) content of LFFM, which is another indicator of lipid oxidation, showed a significant decrease during storage. The initial FFA value of 2.34 ± 0.032 decreased to 1.47 ± 0.16 on the 10th day attributed to the consumption of free fatty acids during the initial stages of lipid oxidation.

The overall results of the present investigation are compatible with the study[28] findings since the PV of the LFFM samples increased significantly during storage. However, the decrease in moisture content and increase in PV and FFA readings can be attributed to the sample's oxidation while being stored.

*Effect of storage on the microbial population of the best accepted lotus dried flower flour muffins.* Table 9 presents the effect of storage on the microbial population of LFF based muffins (LFFM) compared to a control group. In the initial assessment, both the control and LFF muffins showed non-detectable levels of total bacterial, fungal, and coliform counts indicating the freshly baked muffins were free from the microorganisms.

Table 7 Elemental analysis of control muffins and the best accepted lotus dried flower flour muffins (10% LFFM) (mg kg$^{-1}$)

| Elements | Control | LFFM |
|---|---|---|
| Aluminium (Al) | 24.54 | 51.70 |
| Boron (B) | 0.00 | 25.43 |
| Calcium (Ca) | 793.48 | 1474.91 |
| Copper (Cu) | 0.37 | 1.63 |
| Iron (Fe) | 16.24 | 16.75 |
| Potassium (K) | 1502.96 | 2527.25 |
| Magnesium (Mg) | 211.68 | 366.43 |
| Sodium (Na) | 1719.12 | 1894.33 |
| Lead (Pb) | 0.62 | 0.68 |
| Strontium (Sr) | 1.63 | 4.61 |

 

Table 8 Effect of storage on moisture, peroxide value (PV) and free fatty acid (FFA) of control muffins and the best accepted lotus dried flower flour muffins (10% LFFM)[a]

| | Moisture (g) | | Peroxide value (mEq$O_2$ per kg) | | Free fatty acids (% of oleic acid) | |
|---|---|---|---|---|---|---|
| Storage days | Control | LFFM | Control | LFFM | Control | LFFM |
| Initial day | $25.43 \pm 0.42^a$ | $24.56 \pm 0.27^a$ | $12.71 \pm 0.20^c$ | $11.84 \pm 0.18^c$ | $2.34 \pm 0.032^a$ | $2.29 \pm 0.16^a$ |
| 5th day | $23.48 \pm 0.37^b$ | $22.40 \pm 0.26^b$ | $13.47 \pm 0.22^b$ | $12.59 \pm 0.25^b$ | $1.58 \pm 0.24^b$ | $1.38 \pm 0.14^b$ |
| 10th day | $22.60 \pm 0.37^c$ | $21.30 \pm 0.16^c$ | $14.50 \pm 0.12^a$ | $13.52 \pm 0.41^a$ | $1.47 \pm 0.16^b$ | $1.25 \pm 0.06^b$ |

[a] Means with different letters in superscript within a column differ significantly ($P \leq 0.05$).

However, after 5 days of storage, a slight increase in microbial content was noticed. In the control muffins, the total bacterial count was 45 CFU $g^{-1}$, while the LFF muffins had a slightly lower count of 34 CFU $g^{-1}$. The fungal counts were 23 CFU $g^{-1}$ for the control and 29 CFU $g^{-1}$ for LFFM. Notably, coliforms remained undetectable in both samples.

By the tenth day of storage, a further increase in microbial load was recorded. The total bacterial count in the control muffins rose to 72 CFU $g^{-1}$, whereas the LFF muffins displayed a slightly lower count of 67 CFU $g^{-1}$. Similarly, the fungal counts increased to 52 CFU $g^{-1}$ in the control and 56 CFU $g^{-1}$ in LFF muffins. Coliform counts remained non-detectable in both cases throughout the storage. Despite this rise, the values remained well below established safety limits. According to microbial quality standards for bakery products, aerobic plate counts should not exceed 5 to 6 log10 CFU $g^{-1}$ (*i.e.*, 100 000–1 000 000 CFU $g^{-1}$)[29] and according to the generic microbiological standard for cakes and pastries, which was published by the Institute of Food Science and Technology (IFST), yeast and mold counts must remain below 5 log10 CFU $g^{-1}$ (100 000 CFU $g^{-1}$) and 4 log10 CFU $g^{-1}$ (10 000 CFU $g^{-1}$), respectively.[30] The microbial loads in both control and LFF muffins at all time points were significantly below these thresholds, confirming that the muffins were safe for consumption up to 10 days of storage. These findings suggest that prolonged storage can lead to a gradual increase in the microbial populations in muffins, with LFF muffins showing microbial counts comparable to or slightly lower than the control muffins.

Microbiological study of the muffins revealed an increase in microbial growth as the number of days of storage increased. This could be due to contamination with the raw materials, processing, handling, storage methods, or an increase in moisture content during storage. The bacterial and mold population was lower than that of the control throughout the storage period, which may again be attributed to the anthocyanins present in LFF. However, both the control and muffins incorporated with 10% LFF were safe for consumption for up to 10 days, according to the results. Usually, bakery products are packaged in plastic films after baking and cooling, and they are consumed within 1 or 2 months. Furthermore, post-process contamination is unavoidable.[31]

Table 9 Effect of storage on the microbial population of control muffins and the best accepted lotus dried flower flour muffins (10% LFFM)[a]

| | Total bacterial count (CFU $g^{-1}$) | | Fungi count (CFU $g^{-1}$) | | Coliform count (CFU $g^{-1}$) | |
|---|---|---|---|---|---|---|
| Storage days | Control | LFFM | Control | LFFM | Control | LFFM |
| Initial day | ND | ND | ND | ND | ND | ND |
| 5th day | 45 | 34 | 23 | 29 | ND | ND |
| 10th day | 72 | 67 | 52 | 56 | ND | ND |

[a] ND = not detected.

**Sensory evaluation of lotus dried flower flour muffins on storage.** The sensory quality of LFFM was investigated to assess the impact of storage duration on various attributes, such as appearance, texture, colour, flavour, taste, consistency, and overall acceptability (OAA) (Table 10).

The results revealed that the control group, on the initial day, exhibited high sensory ratings in all aspects, with appearance, texture, colour, flavour, taste, consistency, and overall acceptability scoring approximately 8.85, 8.66, 8.71, 8.71, 8.66, 8.28, and 8.73, respectively. However, as storage increased to the fifth and tenth days, sensory parameters declined with all variables exhibiting statistically significant reductions. Notably, the appearance and texture ratings declined most significantly, reaching 8.09 and 7.95 on the fifth day and then falling to 7.95 and 7.73 on the tenth day, respectively. The findings imply that long-term storage has a detrimental effect on LFF muffin's sensory attributes. Comparatively, the LFFM product group had equivalent initial sensory scores for flavour, taste, consistency, and overall acceptability but slightly lower scores for appearance, texture, and colour. The sensory quality of the LFF muffins declined with time, with the texture experiencing the greatest reduction, reaching 7.31 on the fifth day and 7.19 on the tenth. By the fifth and tenth days of storage, the control group sensory scores had significantly decreased. Similar patterns were observed in the LFFM product group, indicating that both products are subject to sensory decline while storage.

These results were in line with the studies reporting that organoleptic characteristics drastically declined during the storage studies in muffins and cakes which might be due to the growth of fungus, moisture, storage conditions, *etc.*[32,33]

**Consumer acceptability of lotus dried flower flour muffins.** Fig. 3 shows the level of acceptability of LFFM and their sensory characteristics, such as appearance, texture, taste, flavour, and overall acceptability (OAA). The results of the study indicated that the majority of participants found the LFFM to be highly acceptable. Specifically, 23 participants rated the appearance as "Very good," while 17 found it "Excellent." In terms of texture,

Table 10 Effect of storage on the sensory quality of control muffins and the best accepted lotus dried flower flour muffins (10% LFFM)[a]

| Product | Duration | Appearance | Texture | Colour | Flavour | Taste | Consistency | OAA |
|---|---|---|---|---|---|---|---|---|
| Control | Initial day | $8.85 \pm 0.35^a$ | $8.66 \pm 0.57^a$ | $8.71 \pm 0.46^a$ | $8.71 \pm 0.64^a$ | $8.66 \pm 0.55^a$ | $8.28 \pm 0.48^a$ | $8.73 \pm 0.49^a$ |
| | 5th day | $8.09 \pm 0.76^b$ | $7.95 \pm 0.58^b$ | $8.23 \pm 0.58^b$ | $8.00 \pm 0.54^b$ | $7.97 \pm 0.58^b$ | $7.90 \pm 0.60^b$ | $7.97 \pm 0.55^b$ |
| | 10th day | $7.95 \pm 0.77^b$ | $7.73 \pm 0.84^b$ | $8.00 \pm 0.72^b$ | $7.73 \pm 0.64^b$ | $7.69 \pm 0.67^b$ | $7.71 \pm 0.76^b$ | $7.71 \pm 0.66^b$ |
| LFFM | Initial day | $7.54 \pm 0.77^a$ | $7.85 \pm 0.79^a$ | $7.54 \pm 0.63^a$ | $8.19 \pm 0.67^a$ | $8.16 \pm 0.65^a$ | $7.92 \pm 0.85^a$ | $8.26 \pm 0.60^a$ |
| | 5th day | $7.33 \pm 0.48^a$ | $7.31 \pm 0.51^b$ | $7.26 \pm 0.73^{ab}$ | $7.71 \pm 0.58^b$ | $7.88 \pm 0.65^a$ | $7.50 \pm 0.47^{ab}$ | $7.78 \pm 0.60^b$ |
| | 10th day | $7.14 \pm 0.85^a$ | $7.19 \pm 0.82^b$ | $7.07 \pm 0.67^b$ | $7.21 \pm 0.60^c$ | $7.27 \pm 0.54^b$ | $7.19 \pm 0.76^b$ | $7.21 \pm 0.60^c$ |

[a] Within each muffin type (control or LFFM), means in the same column with different superscript letters differ significantly ($P \leq 0.05$) over the storage period. OAA = overall acceptability.

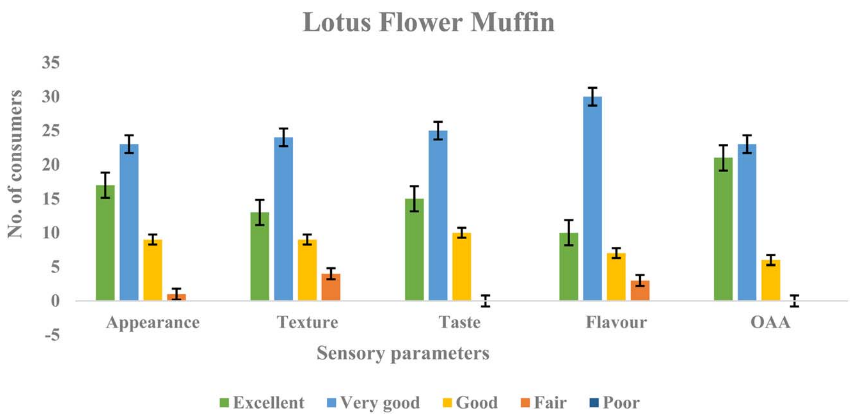


Fig. 3 Consumer acceptability of lotus dried flower flour muffins.

24 participants rated it as "Very good," and 13 as "Excellent." The studies suggest that the LFFM was visually and texturally appealing to a significant proportion of the participants. When it comes to the sensory attributes of taste and flavour of the LFFM, 25 participants rated the taste as "Very good," and 15 as "Excellent." For flavour, 30 participants found it "Very good," and 10 rated it as "Excellent", suggesting that the LFFM not only appealed to the visual and textural senses but also to the gustatory senses of the participants. Overall acceptability, as indicated by the OAA, further underscores the positive reception of the LFFM. A substantial majority of 21 participants rated the muffins as "Excellent" in terms of overall acceptability, while 23 rated them as "Very good." The data demonstrate that the LFFM was well-received and appreciated by the majority of the participants in the study.

# Conclusion

In the present study, LFF blended refined wheat flour based muffins were developed and analyzed for different physical characteristics, sensory evaluation, colour parameters, nutritional composition, shelf life, and consumer acceptability studies of LFFM at various incorporation levels (0%, 5%, 10%, and 20%) in comparison with the control. The results showed that up to 10% LFF could be included in muffin formulation without any significant interference with the sensory acceptability of the muffins. Also, consumer acceptability revealed high ratings for appearance, texture, taste, flavour, and overall acceptability, emphasizing the palatability of LFFM. Therefore, LFF may be considered a promising ingredient for partial substitution in bakery products, enhancing both nutritional value and consumer acceptability. Further studies, including detailed profiling of bioactive compounds in the final product, are recommended.

# Data availability

The supporting data are available with the corresponding author and will be provided at any point of time upon reasonable request.

# Conflicts of interest

There are no conflicts to declare.

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