International Journal of Food Science + Technology

International Journal of Food Science and Technology 2022, 57, 7107–7115

Original article

Influence of different oilseed cake incorporation on batter rheology, proximate composition, texture, antioxidant and sensory properties of wheat flour muffins

Manpreet Kaur,[1] Balwinder Singh[2*] & Amritpal Kaur[1*]

1 Department of Food Science and Technology, Guru Nanak Dev University, Amritsar 143005, Punjab, India
2 P.G. Department of Botany, Khalsa College, Amritsar 143002, Punjab, India

(Received 1 April 2022; Accepted in revised form 30 August 2022)

Summary Oilseed cake flour (OCF) can be incorporated into baked foods to improve nutritional properties and solve problems related to the food sustainability. In this study, wheat flour muffins were prepared by incorporating flaxseed (FCF), sesame (SCF), mustard (MCF), nigella (NCF) and groundnut (GCF) cake flour at 10%, 20% and 30% levels. The batters prepared by incorporating different OCF were evaluated for viscoelasticity (G', G'' and tan δ) and the changes in proximate composition, texture, antioxidant activity, sensory properties and shelf life of muffins were studied. The OCF incorporation had increased the batter viscoelasticity (increased G' and G"), hardness, springiness and gumminess while decreased the cohesiveness of muffins. The ash, fat, protein, phenolic content and radical scavenging activity increased, while moisture content, colour values (crust and crumb), bake loss, specific volume and height of muffins decreased with OCF incorporation. The 30%NCF-incorporated muffins had longer shelf life and lower sensory scores for colour, taste, odour, texture and overall acceptability. The 10%FCF- and 10%SCF-incorporated muffins had better texture, nutritional profile and shelf life while wheat-alone muffins had comparable hardness, cohesiveness, specific volume and sensory properties.

Keywords Antioxidant properties, oilseed cake flour, rheology, sensory analysis, wheat muffins.

Introduction

Oilseeds are domesticated primarily as sources of edible oils and dietary proteins in human diet. Oilseed cakes (OCs), an agro-industrial by-products rich in protein and fibre, are incurred after squeezing oil from oilseeds in edible oil industries (Kotecka-Majchrzak *et al.*, 2020). Interestingly, the solid residues generated in large amounts as OCs are promising source of nutrients and bioactive components that can be used as functional food ingredients (Kaur *et al.*, 2021). OCs are generally used as components of feed for livestock and generally underestimated as source of dietary fibre and protein for human consumption (Kotecka-Majchrzak *et al.*, 2020). The oilseed by-products can be utilised in the preparation of low-cost healthy foods as they are promising sources of dietary fibre, proteins, minerals, essential amino acids vitamins and antioxidants (Kaur *et al.*, 2021).

*Correspondent: E-mail:
amritft33@yahoo.co.in, amrit.food@gndu.ac.in (A. K.);
bbs171@rediffmail.com, balwindersingh@khalsacollege.edu.in (B. W.)

They can also be used as functional food ingredients and dietary supplements owing to their antioxidant and health-promoting bioactivities (Kaur *et al.*, 2021). The use of OCs in food products is a feasible alternative that can reduce the waste disposal problems of oilseed industries and increase the availability of proteins, fatty acids and bioactive constituents of plant origin (Kaur *et al.*, 2021; Pojić *et al.*, 2018).

The OCs of edible oilseeds can be used for human food supplementation by incorporating in different baked foods (Aranibar *et al.*, 2019). The popularity of muffins as bakery products is increasing tremendously among consumers due to their characteristic taste, flavour and soft texture (Jeong & Chung, 2019). Muffins are ready-to-eat food products mainly prepared using wheat flour, milk, egg, fat, sugar and baking powder and are appreciated among consumers of all age groups (Jeong & Chung, 2019; Singh *et al.*, 2015). The previous studies reported that the muffins supplemented with partially deoiled chia meal (Aranibar *et al.*, 2019), virgin coconut oil cake (Beegum *et al.*, 2017), pecan nut expeller meal (Marchetti

doi:10.1111/ijfs.16050

et al., 2018) and cold-pressed aniseed flour (Gökşen & Ekiz, 2021) had improved nutritional and functional properties. An association between human diets rich in bioactive constituents and reduced risk of common diseases has been established (Marchetti *et al.*, 2018). There has been an emerging trend towards the production of bakery products rich in dietary fibre and antioxidants due to their health benefits, and there is a large market for such type of fibre and antioxidant-rich baked products (Singh *et al.*, 2015). Bakery products are universally consumed and suitable for incorporation of functional ingredients (Marchetti *et al.*, 2018). OCs can be included as partial substitute of wheat flour to enrich the nutritive value of muffins. Incorporation of OCs in muffins would enhance their utilisation in the diets of malnourished people and solve current problems associated with food sustainability in the developing countries (Gökşen & Ekiz, 2021).

In the previous study, we reported that flaxseed cake has higher antioxidant activity and water absorption capacity and is rich in minerals; nigella seed cake has higher total flavonoids, oil absorption capacity and emulsifying activity; groundnut seed cake has higher protein content, amino acids and emulsion stability; sesame seed cake has more ash and fat contents, while mustard seed cake has more total phenolics (Kaur *et al.*, 2021). The detailed and comparative research on exploring the possibility of oilseed cake flour (OCF) incorporation in wheat muffins is not available in literature. The present investigation was planned to evaluate and compare the impact of partial replacement of wheat flour with flaxseed (FCF), sesame (SCF), mustard (MCF), nigella (NCF) and groundnut (GCF) cake flour at 10%, 20% and 30% levels on the physicochemical, nutritional, sensory properties and shelf life of muffins.

Materials and methods

Materials

Wheat flour, baking powder containing sodium bicarbonate, sodium aluminium sulphate and corn flour (Weikfield Foods Pvt. Ltd., India), xanthan gum (Authentic foods), powdered sugar, refined soybean oil (Fortune, India), 100% whey protein concentrate (Scitron) and milk powder containing 18.1% fats, 17.4% proteins and 50.3% carbohydrates (Nestle, India) were purchased from a local market. The flaxseed, sesame, mustard, nigella and groundnut cakes obtained in our previous report (Kaur *et al.*, 2021) were finely ground and sieved (35 µm) to obtain flour. The chemical composition of wheat flour and OCF is given in Table S1. The analytical grade chemicals, solvents and standards of Sigma-Aldrich were used.

Batter and muffin preparation

The wheat flour was replaced with flaxseed (FCF), sesame (SCF), mustard (MCF), nigella (NCF) and groundnut (GCF) cake flour at 10%, 20% and 30% levels (Table S2). Muffins were prepared according to Singh *et al.* (2015) with minor modifications. The protein emulsion was prepared by mixing 0.5 g xanthan gum and 88.5 g whey protein in 100 mL of water. The muffin batter was prepared by mixing OCF-incorporated wheat flour (50 g), baking powder (3 g) and ground sugar (25 g) for 1 min by a pin mixer. Then, protein emulsion (30 g), milk powder (8 g), soybean oil (30 mL) and water (42 mL) were added and mixed slowly for 5 min. The muffin cups were filled with OCF-incorporated batter (35 g) having moisture content in the range of 32.11%–34.54% (Table S3) and baked for 15 min at 170 °C in a preheated oven having rotating racks. Muffins were cooled at room temperature for 20 min, enclosed in PET jars, and stored for further studies.

Batter rheology

The viscoelastic parameters (storage modulus [G′], loss modulus [G″] and loss tangent [tan δ = G″/G′]) of batters were determined using MCR-102 rheometer (Anton Paar, Austria) fitted with Peltier temperature controller and 40-mm cone plate according to Kaur *et al.* (2022). The frequency range of 0.1–100 rad s^{-1} in a linear viscoelastic region at a constant stress (1 Pa) was used in stress-sweep tests at constant temperature of 25 °C. The muffin batter was placed on the geometry and upper plate was slowly pushed down (gap size 1 mm). The excess batter was trimmed off carefully with a razor blade and silicon oil was applied on the batter edges. This stage was followed by relaxing the batter for 5 min in between two plates before measurements.

Proximate composition of muffins

The ash, moisture, protein and fat contents of OCF-incorporated muffins were estimated using methods 44-19, 30-20, 46-12 and 08-01, respectively (AACC, 2000). Megazyme (K-TDFR-200A) assay kit was used for the estimation of total dietary fibre (TDF) content.

Antioxidant properties of muffins

The muffins defatted using hexane was dried, ground and passed through a 60-mesh sieve for the analysis of antioxidant properties. One gram of muffin sample was extracted twice with 10 mL of 80% methanol by shaking (at 200 rpm for 2 h) and centrifugation (at 4000 ***g*** for 10 min). The supernatants collected were pooled, filtered and used for the estimation of total phenolic content (TPC) and radical scavenging capacity (RSC) according to Kaur *et al.* (2021). In brief, muffin extract (100 μL), Folin–Ciocalteu reagent (300 μL) and deionised water (4.8 mL) were homogenised and kept for 8 min. Then, 20% Na_2CO_3 (900 μL) added, vortexed and incubated for 30 min at 40 °C and absorbance recorded on UV–VIS spectrophotometer at 765 nm. TPC was presented in mg gallic acid equivalent (GAE) g^{-1}dry weight (DW). About 100 μL of muffin extract mixed with 3.9 mL of DPPH solution was incubated for 30 min at 25 °C and absorbance recorded at 515 nm for the estimation of RSC in μmoles Trolox equivalent (TE) g^{-1}DW.

Muffin characteristics

Colour (a*, b* and L*) values of muffin crust and crumb were measured using Hunter Lab (Hunter Associates, USA) according to Kaur *et al.* (2022). Browning index (BI) of muffin crust and crumb was estimated using the formula given below:

$$\mathrm{BI} = \frac{(100(x - 0.31))}{0.17}$$

where $x = \frac{(a^{*} + 1.75\ L^{*})}{(5.645L^{*} + a^{*} - 3.012b^{*})}.$

The height (mm) of muffin was measured by calliper and muffin volume (mL) was estimated using millet-seed displacement method. The specific volume (mL g^{-1}) of muffin was calculated by dividing the muffin volume (mL) by its weight (g). The water activity (a_w) of crumb was measured using water activity metre (Aqua Lab, Decogon Devices, USA). Bake loss (g 100 g^{-1}) was estimated using the below equation given by Heo *et al.* (2019).

$$\text{Back loss} = \frac{\text{Batter weight} - \text{Muffin weight}}{\text{Batter weight}} \times 100$$

Texture of muffins

Texture parameters of the crumb (12.5 mm^3 cubes from muffin centre) were studied using texture analyser equipped with a 5 kg load cell (TA/TX2-plus, Stable Micro systems, UK) as described by Shevkani & Singh (2014). The crumb cubes placed on a heavy duty platform (HD P/90) were subjected to 50% compression at a speed of 1 mm s^{-1} using a 75-mm flat aluminium probe (P/75). Textural parameters (hardness [N], cohesiveness [ratio], gumminess [N] and springiness [ratio]) were calculated.

Sensory analysis and shelf life of muffins

Sensory attributes of muffins were evaluated by 25 trained and semi-trained participants including faculty members, research fellows and postgraduate students. The acceptance of muffins was assessed by applying 9-point structured hedonic scale (score 9 = extremely liked; score 1 = extremely disliked). The sensory attributes evaluated by randomly serving of muffins include colour, appearance, taste, texture, odour and overall acceptability (OA). Muffins packed in polypropylene sheets and stored at room temperature were evaluated daily on the basis of appearance of microbial growth and willingness to consume with a ‘positive or negative’ response from participants. The number of days before microbial growth with positive response from participants was noted as sensory shelf life (in days) of OCF-incorporated muffins (Baixauli *et al.*, 2008).

Statistical analysis

The results presented in tables are mean ± standard deviation of experimental replicates (n = 3) except for sensory properties (analytical replicates, n = 25). For statistical analysis, Minitab version 14.12.0 (USA) was employed. The means were compared using one-way ANOVA and relationship among different variables of muffins was established using principal component analysis.

Results and discussion

Batter rheology of muffins

The loss modulus (G") and storage modulus (G’) *versus* angular frequency (at 1 rad s^{-1}) for OCF-incorporated and wheat flour alone (control) muffin batters are shown in Table 1 and illustrated in Fig. S1 and S2. G" indicate viscous behaviour of muffin batter. It measures deformation energy used up and lost or viscous dissipation per cycle of deformation. G’ indicate elastic behaviour of muffin batter. It measures batter’s ability to store energy or recoverable cycle of deformation. The G’ and G" values for batters varied from 308.04 to 4747.80 Pa and 179.51 to 2322.79 Pa, respectively. The highest and lowest values were observed for 30%MCF and 10%SCF-incorporated batters, respectively. The changes in G’ and G" by increasing OCF incorporation could be attributed to changes in protein content and water absorption capacity of flour blends and difference in moisture content of muffin batters (Tables S1 and S3). Increase in angular frequency increases G "and G’ of muffin batters. All muffin batters exhibited distinctive visco-elasticity with the lower G" than the G’ at all values of angular frequency, indicating their good ability to retain air bubbles within the batter system. Similarly, the lower G″ than G′ was recorded for muffin batters incorporated with wheatgrass and mung bean micro-greens powder (Kaur *et al.*, 2022), jambolan fruit pulp

Table 1 Batter rheology (at 1 rad s^{-1}) of OCF-incorporated muffin batters

Muffin batter	Storage modulus (G′)	Loss modulus (G″)	Loss tangent (tan δ)
Control	425.17 ± 2.44[a]	249.27 ± 1.20[a]	0.59 ± 0.01[b]
10%FCF	762.13 ± 3.80[a]	474.34 ± 1.92[a]	0.62 ± 0.01[c]
20%FCF	1063.34 ± 5.04[b]	558.58 ± 2.81[b]	0.53 ± 0.00[b]
30%FCF	996.04 ± 3.63[a]	487.51 ± 2.14[a]	0.49 ± 0.00[a]
10%SCF	308.04 ± 1.00[a]	179.51 ± 1.15[a]	0.58 ± 0.00[b]
20%SCF	318.00 ± 1.51[a]	206.71 ± 0.89[a]	0.65 ± 0.00[c]
30%SCF	507.12 ± 1.96[a]	365.74 ± 1.87[a]	0.72 ± 0.00[d]
10%MCF	2368.83 ± 9.45[c]	1736.00 ± 4.11[d]	0.73 ± 0.00[d]
20%MCF	3197.27 ± 9.92[d]	1762.34 ± 1.87[d]	0.55 ± 0.00[b]
30%MCF	4747.80 ± 12.24[e]	2322.79 ± 4.81[e]	0.49 ± 0.00[a]
10%NCF	1072.23 ± 5.30[b]	599.78 ± 1.19[b]	0.56 ± 0.00[b]
20%NCF	2391.95 ± 8.19[c]	1219.12 ± 1.48[c]	0.51 ± 0.00[b]
30%NCF	4549.80 ± 10.53[e]	1899.45 ± 4.17[d]	0.42 ± 0.00[a]
10%GCF	1993.03 ± 2.05[b]	1118.30 ± 1.16[c]	0.56 ± 0.00[b]
20%GCF	3060.13 ± 4.80[d]	1497.30 ± 2.79[c]	0.49 ± 0.00[a]
30%GCF	3535.30 ± 9.25[d]	1544.62 ± 4.55[d]	0.44 ± 0.00[a]

Values (mean ± SD, $n = 3$) with similar superscripts in a column do not differ significantly ($P < 0.05$).
FCF, Flaxseed cake flour; GCF, Groundnut cake flour; MCF, Mustard cake flour; NCF, Nigella cake flour; OCF, Oilseed cake flour; SCF, Sesame cake flour.

(Singh *et al.*, 2015) and protein isolates (Shevkani & Singh, 2014).

The tan δ of muffin batters ranged from 0.42 to 0.73, with the highest and lowest values observed for 10%MCF- and 30%NCF-incorporated batters, respectively (Table 1). The lowest tan δ of 30%NCF batter indicate higher water retention capacity and highest contribution to the elastic properties of batter (Kaur *et al.*, 2022). OCF incorporation had affected the ratio of viscous to elastic portion in batter. An increase in G' and G" values and decrease in tan δ with OCF incorporation are related with supplementation of dietary fibre from OCF (as indicated by changes in TDF content, Table 2), which have limited the availability of water for the flow of particles in muffin batters. The higher water absorption capacity and lower moisture content of wheat flour OCF blends (Table S3) might have affected the viscoelasticity of the OCF-incorporated muffin batters. Similarly, the incorporation of jambolan fruit pulp (Singh *et al.*, 2015), protein isolates (Shevkani & Singh, 2014) and wheatgrass powder (Kaur *et al.*, 2022) had also affected the viscoelasticity of the batters. The higher batter viscosity may decelerate the rate of gas diffusion while mixing and restrict the expansion of air bubbles during baking of muffins (Singh *et al.*, 2015).

Proximate composition of muffins

The control muffins had TDF content of 2.87% and it increased by OCF incorporation and was highest for 30%FCF (8.29%) muffins. Incorporation of OCF at 10%, 20% and 30% levels had significantly influenced the proximate composition of muffins. The ash, moisture, protein, fat and TDF contents of muffins varied from 1.48%–2.14%, 19.40%–31.69%, 11.55%–16.65%, 3.15%–4.63% and 2.87%–8.29%, respectively (Table 2). The control muffins exhibited highest

Table 2 Proximate composition and antioxidant properties of OCF-incorporated muffins

Muffins	MC (%)	AC (%)	FC (%)	PC (%)	TDF (%)	TPC (mg GAE g^{-1})	RSC (μmoles TE g^{-1})
Control	31.69 ± 0.75[e]	1.48 ± 0.01[a]	3.15 ± 0.03[a]	11.55 ± 0.04[a]	2.87 ± 0.04[a]	0.50 ± 0.01[a]	1.94 ± 0.02[a]
10%FCF	29.99 ± 0.49[d]	1.59 ± 0.03[a]	3.86 ± 0.03[c]	13.28 ± 0.06[b]	3.76 ± 0.06[b]	0.56 ± 0.01[a]	2.19 ± 0.01[a]
20%FCF	26.61 ± 0.26[c]	1.79 ± 0.03[b]	3.91 ± 0.02[c]	13.52 ± 0.18[c]	6.01 ± 0.06[d]	0.61 ± 0.01[b]	2.38 ± 0.04[a]
30%FCF	19.40 ± 0.05[a]	2.13 ± 0.03[d]	4.05 ± 0.03[d]	13.69 ± 0.29[c]	8.29 ± 0.10[e]	0.64 ± 0.01[b]	2.51 ± 0.01[b]
10%SCF	28.35 ± 0.59[d]	1.59 ± 0.02[a]	4.41 ± 0.04[e]	14.27 ± 0.07[c]	3.12 ± 0.03[b]	0.53 ± 0.01[a]	2.12 ± 0.02[a]
20%SCF	29.94 ± 0.09[d]	1.94 ± 0.03[c]	4.56 ± 0.03[e]	14.54 ± 0.06[c]	4.73 ± 0.06[c]	0.58 ± 0.01[a]	2.20 ± 0.01[a]
30%SCF	25.26 ± 0.03[c]	2.14 ± 0.04[d]	4.63 ± 0.04[e]	14.85 ± 0.09[c]	6.45 ± 0.11[d]	0.66 ± 0.20[b]	2.34 ± 0.02[a]
10%MCF	19.94 ± 0.01[a]	1.67 ± 0.03[b]	3.88 ± 0.04[c]	14.87 ± 0.11[c]	2.89 ± 0.06[a]	0.99 ± 0.20[c]	2.65 ± 0.05[b]
20%MCF	21.89 ± 0.02[b]	1.77 ± 0.02[b]	4.05 ± 0.03[d]	14.92 ± 0.54[c]	3.06 ± 0.10[b]	1.30 ± 0.13[d]	3.40 ± 0.04[c]
30%MCF	21.95 ± 0.42[b]	2.05 ± 0.02[d]	4.12 ± 0.03[d]	15.69 ± 0.19[d]	3.85 ± 0.08[b]	1.49 ± 0.03[d]	4.07 ± 0.03[d]
10%NCF	22.27 ± 0.06[b]	1.58 ± 0.03[a]	4.15 ± 0.04[d]	12.34 ± 0.12[b]	2.90 ± 0.08[a]	0.64 ± 0.01[b]	2.07 ± 0.02[a]
20%NCF	25.16 ± 0.14[c]	1.84 ± 0.04[c]	4.24 ± 0.03[d]	12.49 ± 0.09[b]	2.98 ± 0.10[a]	0.57 ± 0.01[a]	2.24 ± 0.04[a]
30%NCF	21.85 ± 0.14[b]	2.05 ± 0.02[d]	4.31 ± 0.03[d]	12.58 ± 0.04[b]	3.50 ± 0.08[b]	0.92 ± 0.01[c]	2.62 ± 0.03[b]
10%GCF	21.06 ± 0.57[b]	1.84 ± 0.04[c]	3.24 ± 0.03[b]	16.23 ± 0.06[d]	3.23 ± 0.06[b]	0.58 ± 0.01[a]	2.01 ± 0.07[a]
20%GCF	23.90 ± 0.04[b]	1.75 ± 0.03[b]	3.48 ± 0.03[b]	16.35 ± 0.04[d]	5.08 ± 0.08[c]	0.80 ± 0.01[b]	2.11 ± 0.01[a]
30%GCF	21.09 ± 0.07[b]	1.78 ± 0.01[b]	3.78 ± 0.03[c]	16.65 ± 0.10[e]	6.88 ± 0.10[d]	0.96 ± 0.02[c]	2.28 ± 0.01[a]

Values (mean ± SD, $n = 3$)with similar superscripts in a column do not differ significantly ($P < 0.05$).
AC, Ash content; FC, Fat content; FCF, Flaxseed cake flour; GCF, Groundnut cake flour; MC, Moisture content; MCF, Mustard cake flour; NCF, Nigella cake flour; OCF, Oilseed cake flour; PC, Protein content; RSC, Radical scavenging capacity; SCF, Sesame cake flour; TDF, Total dietary fibre; TPC, Total phenolic content.

moisture (31.69%) and lowest ash (1.48%), fat (3.15%) and protein (11.55%) contents than the OCF fortified muffins. Moisture content decreased by increasing the level of OCF incorporation with the lowest (19.40%) observed for 30%FCF-incorporated muffins. The dietary fibres present in FCF (Table S1) might have reduced the moisture content of 30%FCF-incorporated muffins. Similar decrease in moisture content of muffins by increasing sunflower seed flour incorporation (from 15% to 30%) was noted by Grasso *et al.* (2020). The fat and ash content increased with OCF incorporation and highest (4.63% and 2.14%, respectively) was observed for 30%SCF-incorporated muffins. The results are related with higher ash and fat content in SCF (Table S1). Protein and TDF content increased with OCF incorporation and highest was observed for 30%GCF (16.65%) and 30%FCF (8.29%) muffins, respectively. These values are related with high protein and TDF content of GCF and FCF, respectively (Table S1). Kaur *et al.* (2021) also reported higher protein and TDF content in groundnut and flaxseed cakes, respectively. Similar increase in ash, protein and fat content of fortified muffins was reported by increasing defatted sunflower seed flour level from 15% to 30% (Grasso *et al.*, 2020).

Antioxidant properties of muffins

The control muffins exhibited TPC of 0.50 mg GAE g^{-1} and radical scavenging capacity (RSC) of 1.94 μmol TE g^{-1} (Table 2). Increase in level of OCF had increased the TPC and RSC of muffins. The highest TPC (1.49 mg GAE g^{-1}) and RSC (4.07 μmol TE g^{-1}) were noted for 30%MCF-incorporated muffins. Similar increase in TPC and antioxidant properties of bread enriched with walnut oil cake was reported by Pycia *et al.* (2020). TPC and RSC of muffins are related with the contents of phenolic compounds reported in oilseed cakes by Kaur *et al.* (2021). The higher TPC (5.12 mg GAE g^{-1}) reported in mustard seed cake (Kaur *et al.*, 2021) might be responsible for higher TPC and RSC of 30%MCF fortified muffins. The muffins fortified with partially deoiled chia meal (Aranibar *et al.*, 2019), wheatgrass powder (Kaur *et al.*, 2022) and jambolan fruit pulp (Singh *et al.*, 2015) also exhibited higher TPC and antioxidant activity than the control muffins. The RSC was positively correlated with TPC of muffins by Soong *et al.* (2014).

Muffin characteristics

The colour values and browning index (BI) of muffins are shown in Table 3. The crust of wheat-alone muffins exhibited L*, b*and a* values of 60.54, 23.40 and

Table 3 Colour values, bake loss, specific volume, water activity and height of OCF-incorporated muffins

Muffins	Crust L*	Crust a*	Crust b*	Crust BI	Crumb L*	Crumb a*	Crumb b*	Crumb BI	Bake loss (g 100 g^{-1})	Specific volume (mL g^{-1})	Height (mm)	Water activity (a_w)
Control	60.54 ± 0.38^{d}	6.42 ± 0.38^{b}	23.40 ± 0.31	55.69 ± 0.24^{d}	47.37 ± 0.12^{c}	1.18 ± 0.01^{d}	8.42 ± 0.04^{c}	20.98 ± 0.03^{d}	5.91 ± 0.01^{d}	2.83 ± 0.01^{c}	42.30 ± 0.04^{e}	0.89 ± 0.00^{b}
10%FCF	49.91 ± 0.09^{c}	12.42 ± 0.21^{d}	16.91 ± 0.45	58.91 ± 1.51^{d}	44.88 ± 0.08^{b}	1.17 ± 0.02^{d}	6.32 ± 0.08^{c}	16.76 ± 0.20^{c}	4.14 ± 0.03^{a}	2.75 ± 0.04^{bc}	40.10 ± 0.07^{d}	0.91 ± 0.00^{c}
20%FCF	45.78 ± 0.06^{b}	10.70 ± 0.09^{d}	10.95 ± 0.31^{c}	43.86 ± 1.08^{c}	42.87 ± 0.67^{b}	1.19 ± 0.06^{d}	5.12 ± 0.30^{b}	14.47 ± 0.61^{c}	4.30 ± 0.02^{b}	2.49 ± 0.02^{a}	39.12 ± 0.02^{d}	0.91 ± 0.01^{c}
30%FCF	43.64 ± 0.29^{b}	8.58 ± 0.31^{c}	10.18 ± 0.09^{c}	40.46 ± 0.76^{c}	40.55 ± 0.36^{b}	2.06 ± 0.06^{e}	5.38 ± 0.42^{b}	17.66 ± 1.14^{c}	4.44 ± 0.03^{b}	2.40 ± 0.03^{a}	37.20 ± 0.10^{c}	0.93 ± 0.00^{d}
10%SCF	42.62 ± 0.30^{b}	9.52 ± 0.18^{c}	8.62 ± 0.29^{c}	38.39 ± 1.12^{c}	52.95 ± 0.05^{d}	1.02 ± 0.02^{d}	8.99 ± 0.02^{c}	19.62 ± 0.03^{c}	4.89 ± 0.61^{c}	2.98 ± 0.03^{c}	41.11 ± 0.03^{d}	0.90 ± 0.01^{bc}
20%SCF	44.36 ± 0.22^{b}	7.96 ± 0.07^{c}	12.21 ± 0.38^{c}	44.84 ± 0.80^{c}	52.03 ± 0.19^{d}	1.03 ± 0.04^{d}	10.07 ± 0.06^{d}	22.49 ± 0.09^{d}	4.95 ± 0.03^{c}	2.64 ± 0.02^{b}	31.21 ± 0.06^{a}	0.90 ± 0.01^{bc}
30%SCF	49.52 ± 0.34^{c}	3.76 ± 0.32^{b}	14.62 ± 0.14^{d}	39.93 ± 1.05^{c}	46.15 ± 0.17^{c}	0.84 ± 0.01^{c}	7.58 ± 0.06^{c}	18.88 ± 0.08^{d}	5.05 ± 0.03^{c}	2.58 ± 0.01^{b}	29.60 ± 0.06^{a}	0.87 ± 0.01^{a}
10%MCF	45.80 ± 0.13^{b}	8.33 ± 0.30^{c}	14.54 ± 0.33^{d}	50.97 ± 1.08^{d}	43.99 ± 0.08^{b}	-0.82 ± 0.01^{b}	6.51 ± 0.02^{c}	14.23 ± 0.02^{c}	5.41 ± 0.06^{d}	3.35 ± 0.02^{d}	29.40 ± 0.20^{a}	0.91 ± 0.00^{c}
20%MCF	43.68 ± 0.31^{b}	7.43 ± 0.37^{c}	8.46 ± 0.29^{c}	33.53 ± 1.43^{b}	42.04 ± 0.65^{b}	-1.12 ± 0.03^{a}	5.58 ± 0.37^{b}	11.89 ± 0.72^{b}	5.65 ± 0.05^{d}	2.80 ± 0.02^{c}	34.22 ± 0.05^{b}	0.88 ± 0.00^{ab}
30%MCF	41.15 ± 0.37^{a}	5.83 ± 0.41^{b}	5.07 ± 0.49^{b}	23.10 ± 1.83^{a}	39.16 ± 0.01^{a}	-1.21 ± 0.01^{a}	4.39 ± 0.01^{b}	9.30 ± 0.02^{b}	5.75 ± 0.04^{d}	2.91 ± 0.01^{c}	31.89 ± 0.02^{b}	0.90 ± 0.00^{bc}
10%NCF	38.86 ± 0.21^{a}	4.82 ± 0.10^{b}	4.73 ± 0.06^{b}	21.70 ± 0.11^{a}	39.73 ± 0.16^{a}	0.12 ± 0.01^{c}	2.73 ± 0.12^{a}	7.17 ± 0.28^{b}	5.34 ± 0.03^{c}	2.67 ± 0.05^{b}	37.81 ± 0.08^{c}	0.90 ± 0.00^{bc}
20%NCF	37.62 ± 0.34^{a}	3.29 ± 0.30^{a}	4.10 ± 0.34^{b}	17.66 ± 1.31^{a}	37.71 ± 0.24^{a}	0.04 ± 0.01^{c}	1.41 ± 0.09^{a}	3.79 ± 0.23^{a}	4.55 ± 0.04^{b}	2.62 ± 0.01^{b}	32.50 ± 0.10^{b}	0.90 ± 0.00^{bc}
30%NCF	35.33 ± 0.20^{a}	3.10 ± 0.03^{a}	3.81 ± 0.08^{a}	17.53 ± 0.30^{a}	35.26 ± 0.08^{a}	-0.09 ± 0.02^{b}	0.24 ± 0.03^{a}	0.48 ± 0.11^{a}	5.49 ± 0.09^{d}	2.60 ± 0.02^{b}	29.62 ± 0.06^{a}	0.89 ± 0.00^{b}
10%GCF	47.37 ± 0.54^{b}	11.50 ± 0.34^{d}	15.57 ± 0.21^{d}	56.97 ± 0.88^{d}	47.36 ± 0.47^{b}	1.17 ± 0.04^{d}	8.35 ± 0.12^{c}	20.79 ± 0.54^{d}	4.92 ± 0.06^{c}	2.92 ± 0.02^{c}	37.73 ± 0.08^{c}	0.90 ± 0.00^{bc}
20%GCF	44.77 ± 0.16^{b}	9.44 ± 0.33^{c}	10.65 ± 0.18^{c}	42.08 ± 0.63^{c}	46.80 ± 0.73^{c}	1.19 ± 0.10^{d}	8.07 ± 0.61^{c}	20.37 ± 1.37^{d}	5.45 ± 0.03^{d}	2.92 ± 0.02^{c}	37.55 ± 0.11^{c}	0.88 ± 0.00^{ab}
30%GCF	42.65 ± 0.33^{b}	9.10 ± 0.29^{c}	11.20 ± 0.58^{c}	45.57 ± 1.02^{c}	46.55 ± 0.11^{c}	1.24 ± 0.03^{d}	7.18 ± 0.13^{c}	18.35 ± 0.32^{d}	4.95 ± 0.04^{c}	2.89 ± 0.01^{c}	37.19 ± 0.09^{c}	0.90 ± 0.00^{bc}

Values (mean ± SD, $n = 3$) with similar superscripts in a column do not differ significantly ($P < 0.05$).

BI, Browning index; FCF, Flaxseed cake flour; GCF, Groundnut cake flour; MCF, Mustard cake flour; NCF, Nigella cake flour; OCF, Oilseed cake flour; SCF, Sesame cake flour.

6.42, while crumb had L*, b* and a* values of 47.37, 8.42 and 1.18, respectively. OCF incorporation had lowered the colour values of crust, indicating a darkening effect on crust colour. The lowest colour values of crumb (L* and b*) and crust (L*, b* and a*) were noted for 30%NCF-incorporated muffins. The high concentration of pigments and phenolics present in NCF might have changed the colour of NCF-incorporated muffins (Fig. S3). The differences observed in the colour of muffins are related with protein content and colour of cake ingredients (Beegum *et al.*, 2017). Moreover, the colour of muffins also depends on sugar caramelisation and Maillard reaction during baking (Singh *et al.*, 2015). Similar changes in colour values for muffins fortified with partially deoiled chia meal (Aranibar *et al.*, 2019), virgin coconut oil cake (Beegum *et al.*, 2017), protein isolates (Shevkani & Singh, 2014) and jambolan fruit pulp (Singh *et al.*, 2015) were reported. BI of crumb and crust ranged between 0.48 and 22.49 and 17.53 and 58.91, respectively. The lowest BI was observed for crumb and crust of 30%NCF-incorporated muffins, while the highest BI of crumb and crust was observed for 20%SCF- and 10%FCF-incorporated muffins, respectively. BI of crumb and crust is mainly influenced by colour of ingredients used for incorporation in muffins (Heo *et al.*, 2019; Shevkani & Singh, 2014).

Bake loss varied from 4.14 to 5.91 g 100 g^{-1} with the lowest and highest observed for 10%FCF-incorporated and control muffins, respectively. The low bake loss of 10%FCF-incorporated muffins indicated that the dietary fibre and other ingredients were more capable of holding water during baking. The height and specific volume (SV) of muffins ranged between 29.40 and 42.30 mm and 2.40 and 3.35 mL g^{-1}, respectively (Table 3). The control and 10%MCF-incorporated muffins exhibited highest and lowest height, respectively. The highest and lowest SV was observed for 10% MCF- and 30%FCF-incorporated muffins, respectively. The low height and high SV of 10%MCF muffins might be attributed to low elasticity (high tan δ) of the batter (Table 1). The optimum viscoelasticity favours diffusion and migration of air bubbles during mixing and baking thus increases SV of the muffins. Incorporation of air in batters exhibiting high-elastic behaviour is often difficult, whereas predominance of viscous behaviour in batters can also reduce air incorporation and retention during batter mixing and baking (Bhinder *et al.*, 2022). SV and height of baked product is important quality criterion for quantitative measurements of baking performance. The changes in air retention capacity and rheological properties due to addition of dietary fibre and dilution of gluten might be attributed for decrease in SV and height of the final baked product (Aranibar *et al.*, 2019; Shevkani & Singh, 2014). The reduction in SV and height was reported for bread fortified with walnut oil cake (Pycia *et al.*, 2020) and muffins incorporated with virgin coconut oil cake (Beegum *et al.*, 2017), respectively. Similar changes in SV and height were reported for muffins incorporated with partially deoiled chia meal (Aranibar *et al.*, 2019), mung bean flours (Jeong & Chung, 2019), wheatgrass powder (Kaur *et al.*, 2022) and jambolan fruit pulp (Singh *et al.*, 2015). The a_w determines the availability of free/unbound water in muffins (Singh *et al.*, 2015). It is important for the shelf life of muffins. The higher a_w increases the rate of oxidation and promotes the growth of microorganisms. OCF incorporation had slightly changed the a_w of muffins, and it ranged between 0.87 and 0.93, with the highest and lowest exhibited by 30% FCF- and 30%SCF-incorporated muffins, respectively (Table 3). Similar changes in a_w were reported for muffins containing defatted sunflower seed flour (Grasso *et al.*, 2020), cold-pressed aniseed flour (Gökşen & Ekiz, 2021), wheatgrass powder (Kaur *et al.*, 2022) and jambolan fruit pulp (Singh *et al.*, 2015).

Texture profile of muffins

The control muffins exhibited hardness, cohesiveness, springiness and gumminess of 3.14, 0.74, 0.65 and 2.49 N, respectively (Table 4). OCF incorporation had significantly influenced the textural properties of muffins. The highest hardness (9.92 N) and gumminess (7.56 N) were noted for 20%MCF-incorporated muffins. The decrease in moisture content and SV (Tables 2 and 3) with OCF incorporation is related with increased hardness of the muffins. The 10%FCF- and 20%SCF-incorporated muffins exhibited highest cohesiveness (0.75) and springiness (0.99), respectively. The poor gas retention, low water availability, compact crumb, tiny air cells and low SV might be responsible for higher hardness and gumminess of 20%MCF-incorporated muffins. The hardness was related with water availability and protein content of muffins fortified with different protein isolates (Shevkani & Singh, 2014). Similar changes in hardness and gumminess were reported for mung bean microgreens and wheatgrass fortified muffins (Kaur *et al.*, 2022). The lowest hardness (2.68 N), cohesiveness (0.51) and gumminess (1.64 N) were recorded for 20%NCF-incorporated muffins, while the lowest springiness (0.65) was noted for control muffins. The lower hardness and cohesiveness indicate a tender and crumbly texture of 20%NCF-incorporated muffins. Beegum *et al.* (2017) reported significant decrease in springiness, chewiness, resilience and hardness of muffins by increasing level (10%–50%) of virgin coconut oil cake. Springiness determines the extent of recovery between compressions and is related with elasticity, aeration and freshness of the baked product. Cohesiveness is negatively associated with food disintegration rate

Table 4 Textural, sensory properties and shelf life of OCF-incorporated muffins

Muffins	Hardness (N)	Cohesiveness (ratio)	Springiness (ratio)	Gumminess (N)	Colour	Appearance	Taste	Odour	Texture	OA	Shelf life (Days)
Control	3.14 ± 0.08^{a}	0.74 ± 0.04^{c}	0.65 ± 0.03^{a}	2.49 ± 0.01^{b}	7.83 ± 0.29^{c}	8.33 ± 0.29^{c}	7.67 ± 0.29^{d}	8.00 ± 0.50^{d}	8.17 ± 0.29^{d}	8.00 ± 0.50^{cd}	6 ± 0^{a}
10%FCF	3.23 ± 0.01^{a}	0.75 ± 0.06^{c}	0.70 ± 0.02^{a}	2.62 ± 0.19^{b}	8.00 ± 0.50^{cd}	7.83 ± 0.29^{b}	7.50 ± 0.50^{d}	7.83 ± 0.29^{d}	8.00 ± 0.87^{cd}	7.83 ± 0.29^{c}	8 ± 0^{c}
20%FCF	7.31 ± 0.39^{c}	0.68 ± 0.07^{b}	0.93 ± 0.03	5.40 ± 0.12^{c}	7.83 ± 0.29^{c}	7.00 ± 1.00^{a}	7.17 ± 0.29^{d}	7.50 ± 0.50^{cd}	7.83 ± 0.29^{c}	7.33 ± 0.29^{c}	7 ± 0^{b}
30%FCF	6.43 ± 0.70^{c}	0.63 ± 0.07^{b}	0.85 ± 0.04^{b}	4.38 ± 0.71^{c}	7.50 ± 0.50^{c}	6.83 ± 0.76^{a}	7.00 ± 0.50^{d}	6.50 ± 0.50^{c}	7.00 ± 0.50^{b}	7.17 ± 0.29^{c}	7 ± 0^{b}
10%SCF	3.32 ± 0.06^{a}	0.71 ± 0.04^{b}	0.95 ± 0.03^{c}	2.48 ± 0.31^{b}	8.33 ± 0.29^{d}	7.17 ± 1.04^{a}	7.33 ± 0.58^{d}	7.33 ± 0.58^{c}	7.83 ± 0.29^{c}	7.67 ± 0.76^{c}	8 ± 0^{c}
20%SCF	6.07 ± 0.24^{c}	0.70 ± 0.10^{b}	0.99 ± 0.01^{c}	4.58 ± 0.37^{c}	7.83 ± 0.58^{c}	7.17 ± 0.58^{a}	6.33 ± 1.04^{d}	7.00 ± 0.87^{c}	7.17 ± 0.29^{b}	7.00 ± 0.50^{c}	8 ± 0^{c}
30%SCF	5.26 ± 0.28^{b}	0.63 ± 0.10^{b}	0.89 ± 0.04^{b}	3.68 ± 0.71^{b}	7.17 ± 0.76^{c}	7.17 ± 0.58^{a}	5.67 ± 1.04^{c}	6.17 ± 1.15^{c}	7.00 ± 0.50^{b}	6.67 ± 0.76^{c}	9 ± 0^{d}
10%MCF	6.59 ± 0.36^{c}	0.65 ± 0.09^{b}	0.98 ± 0.01^{c}	4.76 ± 0.84^{c}	7.17 ± 0.29^{c}	7.17 ± 0.58^{a}	4.83 ± 1.26^{c}	5.67 ± 0.29^{b}	6.83 ± 0.29^{b}	5.33 ± 0.76^{b}	7 ± 0^{b}
20%MCF	9.92 ± 0.25^{d}	0.70 ± 0.06^{b}	0.89 ± 0.03^{b}	7.56 ± 0.61^{d}	7.00 ± 0.50^{bc}	6.67 ± 0.29^{a}	3.50 ± 1.32^{b}	5.00 ± 0.50^{b}	6.67 ± 0.29^{b}	3.83 ± 1.04^{a}	8 ± 0^{c}
30%MCF	3.24 ± 0.53^{a}	0.63 ± 0.05^{b}	0.81 ± 0.02^{b}	2.32 ± 0.57^{b}	7.33 ± 0.29^{c}	7.67 ± 0.29^{b}	2.33 ± 0.58^{b}	4.50 ± 0.87^{ab}	6.67 ± 0.29^{b}	2.83 ± 1.04^{a}	8 ± 0^{c}
10%NCF	4.09 ± 0.21^{b}	0.61 ± 0.09^{b}	0.92 ± 0.01^{c}	2.78 ± 0.49^{b}	7.17 ± 0.58^{c}	7.67 ± 0.58^{b}	4.83 ± 0.29^{c}	6.00 ± 0.87^{bc}	6.83 ± 0.29^{b}	5.00 ± 0.50^{b}	6 ± 0^{a}
20%NCF	2.68 ± 0.06^{a}	0.51 ± 0.12^{a}	0.91 ± 0.02^{c}	1.64 ± 0.38^{a}	6.33 ± 0.29^{b}	7.17 ± 0.29^{a}	3.33 ± 1.04^{b}	4.67 ± 0.29^{b}	6.83 ± 0.29^{b}	3.67 ± 0.76^{a}	6 ± 0^{a}
30%NCF	6.48 ± 0.36^{c}	0.56 ± 0.10^{a}	0.81 ± 0.01^{b}	4.24 ± 0.84^{c}	5.67 ± 0.76^{a}	7.33 ± 0.29^{b}	2.00 ± 0.87^{ab}	4.00 ± 0.50^{a}	6.33 ± 0.58^{a}	2.50 ± 0.87^{a}	10 ± 0^{e}
10%GCF	3.99 ± 0.01^{a}	0.62 ± 0.08^{b}	0.80 ± 0.03^{b}	2.78 ± 0.31^{b}	7.83 ± 0.29^{c}	7.83 ± 0.58^{b}	6.83 ± 0.58^{d}	6.33 ± 0.29^{c}	7.33 ± 0.29^{c}	6.67 ± 0.29^{c}	6 ± 0^{a}
20%GCF	3.38 ± 0.09^{a}	0.51 ± 0.01^{a}	0.90 ± 0.01^{bc}	1.94 ± 0.05^{a}	7.67 ± 0.29^{c}	7.67 ± 0.29^{b}	6.67 ± 0.29^{d}	6.17 ± 0.29^{c}	7.17 ± 0.29^{b}	6.67 ± 0.29^{c}	6 ± 0^{a}
30%GCF	5.53 ± 0.36^{b}	0.58 ± 0.09^{a}	0.87 ± 0.01^{b}	3.67 ± 0.76^{b}	8.00 ± 0.50^{cd}	7.50 ± 0.50^{b}	7.00 ± 0.87^{d}	6.33 ± 0.58^{c}	7.00 ± 0.50^{b}	7.00 ± 0.87^{c}	9 ± 0^{d}

Values (mean ± SD) with similar superscripts in a column do not differ significantly ($P < 0.05$) $n = 3$ for textural properties and shelf life while $n = 25$ for sensory properties.
FCF, Flaxseed cake flour; GCF, Groundnut cake flour; MCF, Mustard cake flour; NCF, Nigella cake flour; OA, Overall Acceptability; OCF, Oilseed cake flour; SCF, Sesame cake flour.

while mastication as it determines tensile and compression strength of the food (Shevkani & Singh, 2014).

Sensory evaluation and shelf life of muffins

The mean sensory scores for colour, appearance, taste, texture, overall acceptability (OA) and odour of OCF-incorporated muffins are presented in Table 4. The sensory attractiveness along with nutritional value and health benefits is important for a viable food product. The control muffins had the highest sensory scores for appearance, taste, odour, texture and OA (8.33, 7.67, 8.00, 8.17 and 8.00, respectively). The 10%SCF muffins had higher rating for colour (8.33) than the control (7.83) muffins (Fig. S3). The addition of OCF at higher level (30%) had lowered the rating of muffins. The lowest score for colour, taste, odour, texture and OA (5.67, 2.00, 4.00, 6.33 and 2.50, respectively) was observed for 30%NCF-incorporated muffins, while 20%MCF-incorporated muffins had lowest score (6.67) for appearance (Fig. S3). The shelf life of OCF-incorporated muffins ranged between 6 and 10 days with the highest observed for 30%NCF-incorporated muffins. The sensory analysis results indicated that the 10%FCF- and 10%SCF-incorporated muffins had better texture and were acceptable based on OA and shelf life, while 30% MCF- and 30%NCF-incorporated muffins were unacceptable in terms of taste and odour. Beegum *et al.* (2017) reported higher sensory scores for odour, texture, flavour, taste and OA of 40% virgin coconut oil cake–incorporated muffins compared to wheat flour muffins. Another study by Arshad *et al.* (2007) reported acceptable sensory scores for wheat flour cookies supplemented with 15% wheat germ flour.

Principal component analysis (PCA)

The relationship among variables of OCF-incorporated muffins was established with PCA (Fig. S4). The three principal components (PC1-3) were found to be significant and explained 67.6% variability (eigenvalues >1) among the studied variables (Table S4). PC1, PC2 and PC3 contributed variability of 42.4%, 13.3% and 11.9%, respectively. The PC1 was mainly contributed by G’ (0.262), odour (−0.307), OA (−0.297), taste (−0.293), texture (−0.292) and colour (−0.250). FC (0.365), SV (−0.434), PC (−0.368), TPC (−0.279), G"(−0.277) and BI crust (−0.250) mainly contributed to PC2, while gumminess (−0.467) and hardness (−0.450) contributed to PC3 construction. The score plot (Figure S4a) shows a gradual shift in positioning of OCF-incorporated muffins from control to 30%MCF and 30%NCF with the progression of PC1 from negative to positive. It provides visualisation of muffins having similar properties. The control muffins present close to y-axis on left-hand side of the score plot had highest height, moisture content, crust L* and b* values, bake loss, sensory scores (appearance, taste, odour, texture and OA) and lowest ash, protein, fat and TPC. While 30%NCF-incorporated muffins positioned on extreme right-side of score plot had lowest crust and crumb colour (L* and a*) values, tan δ and sensory scores (taste, odour, texture and OA). The 10%FCF- and 10%SCF-incorporated muffins were placed close to control muffins in score plot and have acceptable sensory scores for taste, colour, odour, OA and texture. In loading plot (Figure S4b), G' and G" correlated positively with gumminess, hardness and springiness, while cohesiveness and height were positioned close to tan δ suggesting a close positive correlation among these variables. Furthermore, TPC was positioned close to RSC, indicating role of phenolic compounds in augmenting the RSC of OCF-incorporated muffins.

Conclusion

Incorporation of OCF in wheat flour had increased batter viscoelasticity (G' and G" increased), hardness, cohesiveness, springiness, gumminess and antioxidant properties of muffins. The 30%MCF- and 10%SCF-incorporated muffin batter showed higher and lower G′ and G″ values, respectively. The 30%NCF-incorporated muffins were unacceptable and rated lower for taste, odour, texture and overall acceptability and had lowest tan δ, L* and a* values for crust and crumb. The 10%FCF- and 10%SCF-incorporated muffins were acceptable based on texture, nutritional properties, sensory scores and shelf life. Thus, 10%FCF and 10%SCF can be incorporated without significantly affecting the quality and sensory attributes of wheat flour muffins.

Acknowledgments

Authors gratefully acknowledge DST-PURSE for providing financial assistance in the form of fellowship and SERB for Science and Technology Award for Research (STR/2021/000019) and research project (EEQ/2020/000565).

Conflict of interest

Authors have no conflict of interest to declare.

Ethical approval

Ethics approval was not required for this research.

Peer review

The peer review history for this article is available at https://publons.com/publon/10.1111/ijfs.16050.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

AACC (2000). *Approved Methods of American Association of Cereal Chemists*. St. Paul, MN: The American Association of Cereal Chemists.

Aranibar, C., Aguirre, A. & Borneo, R. (2019). Utilization of a by-product of chia oil extraction as a potential source for value addition in wheat muffins. *Journal of Food Science and Technology*, **56**, 4189–4197.

This work was compared for changes in colour, TPC, antioxidant properties, specific volume and height of muffins.

Arshad, M.U., Anjum, F.M. & Zahoor, T. (2007). Nutritional assessment of cookies supplemented with defatted wheat germ. *Food Chemistry*, **102**, 123–128.

Baixauli, R., Salvador, A. & Fiszman, S.M. (2008). Textural and colour changes during storage and sensory shelf life of muffins containing resistant starch. *European Food Research and Technology*, **226**, 523–530.

Beegum, S., Sharma, M., Manikantan, M.R. & Gupta, R.K. (2017). Effect of virgin coconut oil cake on physical, textural, microbial and sensory attributes of muffins. *International Journal of Food Science & Technology*, **52**, 540–549.

Bhinder, S., Singh, N. & Kaur, A. (2022). Impact of germination on nutraceutical, functional and gluten free muffin making properties of Tartary buckwheat (*Fagopyrum tataricum*). *Food Hydrocolloids*, **124**, 107268.

Gökşen, G. & Ekiz, H.İ. (2021). Use of aniseed cold-pressed by-product as a food ingredient in muffin formulation. *LWT*, **148**, 111722.

Grasso, S., Liu, S. & Methven, L. (2020). Quality of muffins enriched with upcycled defatted sunflower seed flour. *LWT*, **119**, 108893.

Heo, Y., Kim, M.J., Lee, J.W. & Moon, B. (2019). Muffins enriched with dietary fibre from kimchi by-product: baking properties, physical–chemical properties, and consumer acceptance. *Food Science & Nutrition*, **7**, 1778–1785.

Jeong, D. & Chung, H.J. (2019). Physical, textural and sensory characteristics of legume-based gluten-free muffin enriched with waxy rice flour. *Food Science and Biotechnology*, **28**, 87–97.

Kaur, M., Singh, B., Kaur, A. & Singh, N. (2021). Proximate, mineral, amino acid composition, phenolic profile, antioxidant and functional properties of oilseed cakes. *International Journal of Food Science & Technology*, **56**, 6732–6741.

The methods followed and results of proximate composition and antioxidant properties were compared.

Kaur, N., Singh, B. & Kaur, A. (2022). Influence of wheatgrass and mung bean microgreens incorporation on physicochemical, textural, sensory, antioxidant properties and phenolic profile of gluten-free eggless rice muffins. *International Journal of Food Science & Technology*, **57**, 3012–3020.

The methods followed and results of batter rheology, muffin characteristics and textural properties were compared.

Kotecka-Majchrzak, K., Sumara, A., Fornal, E. & Montowska, M. (2020). Oilseed proteins–properties and application as a food ingredient. *Trends in Food Science & Technology*, **106**, 160–170.

Marchetti, L., Califano, A.N. & Andrés, S.C. (2018). Partial replacement of wheat flour by pecan nut expeller meal on bakery products. Effect on muffins quality. *LWT*, **95**, 85–91.

Pojić, M., Mišan, A. & Tiwari, B. (2018). Eco-innovative technologies for extraction of proteins for human consumption from renewable protein sources of plant origin. *Trends in Food Science & Technology*, **75**, 93–104.

Pycia, K., Kapusta, I. & Jaworska, G. (2020). Walnut oil and oilcake affect selected the physicochemical and antioxidant properties of wheat bread enriched with them. *Journal of Food Processing and Preservation*, **44**, e14573.

Shevkani, K. & Singh, N. (2014). Influence of kidney bean, field pea and amaranth protein isolates on the characteristics of starch-based gluten-free muffins. *International Journal of Food Science & Technology*, **49**, 2237–2244.

Singh, J.P., Kaur, A., Shevkani, K. & Singh, N. (2015). Influence of jambolan (S yzygium cumini) and xanthan gum incorporation on the physicochemical, antioxidant and sensory properties of gluten-free eggless rice muffins. *International Journal of Food Science & Technology*, **50**, 1190–1197.

The methods followed and results of batter rheology and muffin characteristics were compared.

Soong, Y.Y., Tan, S.P., Leong, L.P. & Henry, J.K. (2014). Total antioxidant capacity and starch digestibility of muffins baked with rice, wheat, oat, corn and barley flour. *Food Chemistry*, **164**, 462–469.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1 Chemical composition of WF and OCF used in preparation of muffins.

Table S2. Formulation of different OCF-incorporated muffins.

Table S3. Moisture content and water absorption capacity of wheat flour OCF blends and moisture content of muffin batters.

Table S4. Principal components for illustrating the interpretation in Figure S4.

Figure S1. (a) Storage modulus (G’) of FCF-incorporated muffin batters. (b) Storage modulus (G’) of SCF-incorporated muffin batters. (c) Storage modulus (G’) of MCF-incorporated muffin batters. (d) Storage modulus (G’) of NCF-incorporated muffin batters. (e) Storage modulus (G’) of GCF-incorporated muffin batters.

Figure S2. (a) Loss modulus (G") of FCF-incorporated muffin batters. (b) Loss modulus (G") of SCF-incorporated muffin batters. (c) Loss modulus (G") of MCF-incorporated muffin batters. (d) Loss modulus (G") of NCF-incorporated muffin batters. (e) Loss modulus (G") of GCF-incorporated muffin batters.

Figure S3. Appearance of different OCF (control, 10%, 20% and 30%)-incorporated muffins (FCF: Flaxseed cake flour; SCF: Sesame cake flour; MCF: Mustard cake flour; NCF: Nigella cake flour; GCF: Groundnut cake flour).

Figure S4. Principal component analysis score plot (a) and loading plot (b) describing relationship among different properties of control and OCF (10%, 20% and 30%)-incorporated muffins. AC, Ash content; a_w, Water activity; BI, Browning index; FC, Fat content; FCF, Flaxseed cake flour; G", Loss modulus; G’, Storage modulus; GCF, Groundnut cake flour; MC, Moisture content; MCF, Mustard cake flour; NCF, Nigella cake flour; OA, Overall acceptability; PC, Protein content; RSC, Radical scavenging capacity; SCF, Sesame cake flour; SV, Specific volume; Tan δ, Loss tangent; TPC, Total phenolic content.