



Development of functional muffin products made from sorghum and sea buckthorn

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Abstract. In modern nutrition, functional food products could have a significant role amending chronic diseases and reducing inflammation. In this study, a gluten-free bakery product was developed using a sorghum-based flour enriched with sea buckthorn berry flour. Total phenol and flavonoid content and antioxidant capacities of flours and products were analysed together with their rheological properties such as water and oil absorption capacity, swelling index, and texture analysis. We found that sorghum flour enriched with 5% sea buckthorn flour is an excellent source of total phenols and flavonoids with significant amounts present. They showed high antioxidant potential, with DPPH value of 4.30 μmol Trolox equivalent/g. These bioactive properties were preserved during the baking process, with a 1-1.5-fold increase in phenol content and antioxidant activities compared to the dough. Overall, the developed flour mixture is a promising base ingredient for functional and gluten-free bakery products.

Keywords and phrases: gluten-free, phenols, modern nutrition, superfood

1. Introduction

Non-communicable and chronic diseases, such as type 2 diabetes, cardiovascular diseases, cancer, allergies, etc., are present at an alarming rate in modern society. This leads to the emergence of a more health-conscious generation, and simply fulfilling food security is no longer sufficient to meet customer demands (Baker *et al.*, 2022; Bigliardi & Galati, 2013). Attention has shifted towards functional and medical foods, which are products capable of tackling these diseases thanks to their enhanced bioactive composition. However, the production of high-quality functional foods requires new types of ingredients in food development. Among these, the demand for bioactive compounds with high antioxidant capacity is important to consumers (Adefegha, 2018; Fekete *et al.*, 2025; Vignesh *et al.*, 2024). Sorghum (*Sorghum bicolor* L. Moench) and sea buckthorn (*Hippophae rhamnoides* L.) are living their renaissance in home kitchens as a novel, nutrition-rich food raw material and have gained significant scientific interest in recent years (Aguilar *et al.*, 2023; McGinnis & Webster, 2024; Vilas-Franquesa *et al.*, 2020; Zhu *et al.*, 2025). Their nutritional value is mainly stemming from their high polyphenol and flavonoid content compared to conventional ingredients, which also contributes to their potent antioxidant effects as well.

Sea buckthorn is a shrub commonly found in Eurasia and is considered to be a superfood due to its rich composition and numerous health benefits. The berries have especially high content of vitamin C and polyphenols, such as cinnamic, quinic, and ferulic acid, as well as quercetin derivatives, providing strong antioxidant and anti-inflammatory effects. The extracted oil contains important omega fatty acids (omega 7 and omega 3), which play an important role in combatting cardiovascular problems and regulating cholesterol levels. Due to the presence of palmitoleic acid, the oil also has important skin care and wound-healing properties. Furthermore, research also suggests anti-cancer, neuroprotective, and gastrointestinal improving effects as well (Dubey *et al.*, 2024; Gâtlan & Gutt, 2021). The plant also shows high tolerance against droughts and high temperature; thus, it can be grown in marginalized areas (Ji *et al.*, 2020; Wang *et al.*, 2022).

Sorghum is a gluten-free cereal originating from the North-East African region, cultivated mainly in drought-stricken, arid areas, but it has gained popularity in developed areas as well due to its advantageous bioactive composition. These compounds mainly consist of phenolic acids and flavonoids with strong antioxidant properties. Among them, condensed tannins (CT), mainly procyanidin B and C type dimers and trimers, are especially important due to their anti-nutritive, protein chelating effects. In addition, sorghum flour contains high amounts of dietary fibres, minerals, and, depending on the variety, large amounts of resistant starch as well (Cervini *et al.*, 2021; Kang *et al.*, 2016; Khoddami *et al.*, 2023; Rao *et al.*, 2018; Teixeira *et al.*, 2016). The aim of our study was to develop a novel bakery product enriched

with bioactive compounds, embracing sorghum and sea buckthorn as novel functional ingredients, and provide the population with a healthier alternative in their diet. Psyllium husk (*Plantago ovata*) was also included as a significant dietary fibre source and boosting the organoleptic properties of our product. Such fibre content not only has an important role regulating healthy bowel movements and microbiota, but its soluble dietary fibre content proved to have cholesterol- and blood-sugar-lowering effects as well. Furthermore, some antioxidant properties were also reported for their arabinoxylan content, which could be relevant during product development (Geremew Kassa *et al.*, 2024; Jalanka *et al.*, 2019; Waleed *et al.*, 2022). Muffin was chosen as a final bakery product, as it is a popular and well-known breakfast or dinner snack across all age groups. There is also great variability among different brands and products due to differences between additives and flavouring agents used in production, which results in higher tolerance towards unusual organoleptic properties among customers. As both sorghum and sea buckthorn are a rich source of bioactive components, with potential health benefits, our aim was to produce a novel snack product with higher bioactive values compared to commercially available products, without compromising on the rheological properties.

2. Materials and methods

Materials

Commercial whole sorghum flour (SF) of Ukrainian origin “Éden Prémium” was sourced from a domestic market (Naturtrade Hungary Kft., Szeged, Hungary), and sea buckthorn flour “Biofrutti” (SBF) was obtained from a local producer (Homoktövis Farm, Berettyóújfalu, Hungary). The other ingredients (olive oil, egg, milk, sugar, vanillin sugar, psyllium husk, starch) were sourced from a local market. Commercial refined wheat flour (BL55) and whole wheat flour (WWF) were used as controls.

Preparation of flour mixture

A sorghum–sea buckthorn flour mixture (SF-5SBF) was prepared, using sorghum flour as a base, and supplemented with sea buckthorn in 5 w/w% ratios. The mixture was later used to make muffins.

Preparation of muffins

The muffins were made by hand according to the recipe described in *Table 1*. Wheat muffin (WM), whole wheat muffin (WWM), sorghum muffin (SM), and

sorghum–sea buckthorn muffin (SBM) were prepared. The solid ingredients were mixed with egg, milk, and olive oil until a homogenous slurry was obtained. The mixture was poured into a plastic muffin pan and baked in an oven at 180 °C for 30 minutes. After baking, the final products were stored in plastic containers at 4 °C until further analysis.

Table 1. Product formulas

Product name	WM	WWM	SM	SBM
Wheat flour (g)	42.4	0	0	0
Whole wheat flour (g)	0	42.4	0	0
Sorghum flour (g)	0	0	42.4	0
Sorghum–sea buckthorn mixture (g)	0	0	0	42.4
Starch (g)	16.6	16.6	16.6	16.6
Psyllium husk (g)	4	4	4	4
Lingonberry jam(g)	6	6	6	6
Egg (g)	25.5	25.5	25.5	25.5
Olive oil (g)	20.5	20.5	20.5	20.5
Sugar (g)	30	30	30	30
Vanilla sugar (g)	1	1	1	1
Milk (ml)	50	50	50	50
End weight (g)	196	196	196	196

Measurement of total polyphenol and flavonoid content

The total polyphenol content was measured using the Folin–Ciocalteu assay with some modification (*Singleton & Rossi*, 1965). 1 g of sample was weighted on an analytical scale, and then 10 ml methanol-distilled water (80:20 v/v%) was added. The samples were vortexed for 30 seconds and then placed on a rotary mixer (LABINCO L28 Test-Tube Rotator) for 1 hour at constant speed (10 RPM). After extraction, the samples were centrifuged at 13 000 rpm for 20 minutes (Eppendorf 5453 MiniSpin), and the supernatant was decanted for further analysis. A gallic acid stock solution with a concentration of 100 mg/l was used as a standard. 0.5 ml of sample was pipetted into glass test tubes, and 2.5 ml (0.2N) of Folin–Ciocalteu reagent was added into each tube. After 5 minutes of incubation, we added another 2 ml of sodium-carbonate (75 g/l) and incubated the solutions at room temperature for 2 hours. The measurement was done at 760 nm, 25 °C, using a two-channel spectrophotometer (Ultrospec 2100 pro) with quartz cuvettes.

The total flavonoid content was measured using the aluminium-chloride colorimetric method according to *Zhishen et al.* (1999), with some modifications. The previously prepared extract was used for the analysis. 1 ml of sample was added to 4 ml of distilled water, and then 0.3-0.3 ml of sodium-nitrite (5 w/v%) and aluminium-chloride (10 w/v%) were added at 5-minute intervals. After 1 minute of incubation, 2 ml of sodium-hydroxide (1M) was added, and the solutions were supplemented to 10 ml by adding 2.4 ml of distilled water. The absorbance values were immediately measured at 510 nm, 25 °C. Catechin-hydrate prepared from a 100 mg/l stock solution was used as standard. All values were given as gallic acid (GAE) and catechin (CE) equivalents, and relative to fresh weight.

Measurement of antioxidant capacity by DPPH assay

The DPPH test was done according to the method of *Brand-Williams et al.* (1995), with some modifications. A methanol extract was prepared from 1 g sample mixed with 10 ml of methanol. The samples were vortexed for 30 s and extracted for 1 hour. After extraction, they were centrifuged at 13,000 rpm for 20 minutes, and supernatants were used for analysis. A 9 w/v% of DPPH reagent was prepared beforehand and stored in the dark until the measurement. During analysis, 1.4 ml of methanol, 0.1 ml of sample, and 1.5 ml of DPPH reagent were mixed. Trolox was used as a standard, which was prepared from a 1 mg/ml stock solution. Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) is a water-soluble vitamin E analogue often used in *in vitro* assays to measure antioxidant capacity based on H⁺/ electron donation. Absorbance values were measured after 20 minutes of incubation at 517 nm, 25 °C. All values were given as Trolox equivalent (TE), relative to fresh weight.

Measurement of functional properties of flours

Water absorption capacity (WAC), oil absorption capacity (OAC), and swelling index (SI) were measured according to the method of *Klunkin & Savage* (2018), with some modifications. 10 ml of distilled water (WAC) or sunflower oil (OAC) were added to 1 g sample weighted on an analytical scale, and it was stirred on a vortex for 30 s. The suspension was centrifuged (Hettich EBA 21) at 6,000 rpm for 15 minutes. The supernatant was removed, and the remaining wet solids were weighted again. In the case of SI, 2 g samples were weighted, and 20 ml of distilled water was added to each. The suspension was heated in a shaking water bath at 80 °C for 30 min. The tubes were cooled to room temperature and centrifuged at 3,000 rpm for 15 min. After the removal of supernatant, the paste was weighted again.

Organoleptic analysis of bakery products

A texture profile analysis was done using a TA–XT2 texture analyser (Stable Micro System, Godalming, United Kingdom). The muffins were tested as a whole piece. Firmness and springiness were measured using a 36 mm diameter cylinder probe attached to a 5 kg load cell. Test speed was set as follows: 2 mm/s pre-test speed, 1 mm/s test speed, and 10 mm/s post-test speed respectively. The analysis was performed until a maximum distance of 8 mm was reached, and the probe was held for 30 s. During the test, the data acquisition rate was set at 200 pps (points per second). Springiness was calculated by dividing the end force by the maximum force exerted on the slices. Springiness values were given as a percentage, while firmness was given as force expressed (g). A sensory test was applied with 5 parameters (appearance, colour, taste, odour, and general impression) using a 9-point hedonistic scale. Tasters were chosen randomly, and a blind testing design was applied to evaluate the muffin products.

Statistical analysis

All data was analysed using IBM SPSS Statistics 26 software. One-way analysis of variance with Tukey's post-hoc test was applied to all data, and statistically significant differences were marked using superscript letters (a–f). All experiments had at least three replicates.

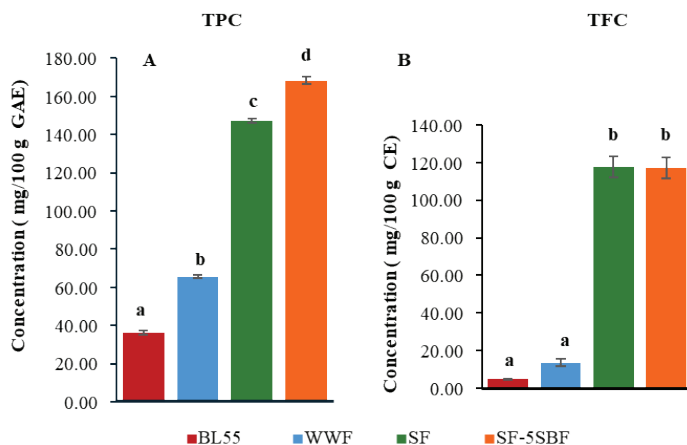
3. Results and discussions

Aside from being gluten-free, alternative cereals and plants have a significant role in the bakery industry due to their prominent bioactive composition and relating physiological effects. Among them, polyphenols and flavonoids are significant as anti-inflammatory and antioxidant agents. Their higher antioxidant content is also linked to aiding celiac patients due to their oxidative stress-relieving effects (Stojiljković *et al.*, 2009; Stojiljković *et al.*, 2012). In this study, different flours and flour mixtures were evaluated for their biochemical value and possible utilization to produce functional food products for the market.

Comparative analysis of the bioactive composition of flours and flour mixtures

We determined the total phenol, flavonoid content, and antioxidant capacities of sorghum (SF) flour and sorghum flour supplemented with 5 w/w% sea buckthorn

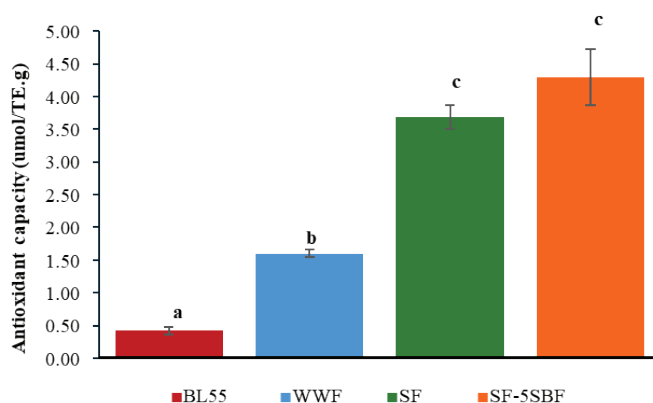
flour (SF-5SBF). Refined wheat flour (BL55) and whole wheat flour (WWF) were also measured as controls. Total phenol and flavonoid values can be seen in *Figure 1*.



Note: Values with different letters (a–d) within one measurement are statistically different at $p < 0.05$, according to Tukey's test.

Figure 1. Total phenol (A) and flavonoid (B) content of evaluated flours and flour mixtures

Among the evaluated flours, both SF and SF-5SBF had significantly higher content of phenols and flavonoids compared to control BL55 and even WWF flours. The SF-5SBF flour mixture had the highest values with 168.36 mg GAE/100 g phenol and 117 mg CE/100 g flavonoid content. There was also a significant ($p < 0.05$) difference in phenol content between SF and SF-5SBF flours, attributed to the SBF's high content of phenols, with a measured concentration of 1,120 mg GAE/100 g. However, despite the SBF's high flavonoid content of 366 mg CE/100 g, there was no significant difference between the flavonoid content of SF and SF-5SBF flours. Control wheat flours showed significantly lower phenol and flavonoid concentration; thus, we can conclude, that SF and SBF is an appropriate alternative to increase antioxidant intake during meals. The antioxidant properties of flours were also evaluated using the DPPH assay method, as it can be seen in *Figure 2*. Among them, SF and SF-5SBF flours had the highest antioxidant capacities with values of 3.68 and 4.30 $\mu\text{mol TE/g}$ respectively. However, there was no significant difference between SF and SF-5SBF despite the high antioxidant capacity of SBF with 58 $\mu\text{mol TE/g}$. The BL55 and WWF samples showed much lower antioxidant properties compared to SF and SF-5SBF. However, WWF contained a significantly ($p < 0.05$) higher amount of antioxidants, which could be attributed to the bran fraction of the flour containing fibre-bound polyphenols and flavonoids.



Note: Values with different letters (a–c) are statistically different at $p < 0.05$, according to Tukey's test.

Figure 2. Antioxidant capacity of evaluated flours and flour mixtures measured by DPPH assay

Our results indicate that SBF could indeed be a valuable natural ingredient with high bioactive properties to produce healthier snack and bakery product alternatives for the consumers. In this research, only one ratio was experimented with due to the expected strong sour taste of sea buckthorn, but further enrichment is advised. In a study conducted by *Stanciu et al.*, breads supplemented with sea-buckthorn-powdered pomace were developed with 6, 8, and 10% addition. All products exceeded the control sample by their bioactive content and antioxidant properties but showed slightly decreased rheological values (*Stanciu et al.*, 2023). In another study, sea buckthorn flour produced from berries with phenol and flavonoid content similar to the values presented here was used in bread development with 1, 3, and 5% addition. The study reported a significant increase in antioxidant properties as well as in shelf life due to the inhibition of oxidative processes. However, SBF addition higher than 1% resulted in detrimental effects on organoleptic properties (*Ghendov-Mosanu et al.*, 2020). *Keyata* and his co-workers produced weaning flour mixture from malted sorghum flour, soybean, and karkade, which also showed significant bioactive activity. The amount of total phenols and flavonoids was especially high due to the malting process in sorghum flour. Our flour mixture also contained a significant content of polyphenols, which could be further increased by malting process (*Keyata et al.*, 2023). A study conducted by *Guo et al.* reported sea buckthorn pulp, a residue of oil production that could be an important source of bioactive compounds due to its high content of total phenols (14 mg/g DW) and strong antioxidant potential (1307 $\mu\text{mol/g TE DW}$). In comparison, our study showed a more modest bioactive composition, which could be traced back to differences in variety and processing technology (*Guo et al.*, 2019). Overall, the mixture of sorghum and sea buckthorn as gluten-free ingredients

shows great potential and may help the often-present inadequate nutritional value of gluten-free products present on the market (*El Khoury et al.*, 2018).

Evaluation of the functional properties of the flours

To determine the suitability of the sorghum flour and the developed supplemented flour mixture, the functional properties of flours were also evaluated, as it can be seen in *Table 2*.

Table 2. Functional properties of evaluated flours

Name	Water absorption capacity (%)	Oil absorption capacity (%)	Swelling power (g/g)
BL55	103.06 ± 3.69 ^a	116.18 ± 6.57 ^a	5.44 ± 0.06 ^a
WWF	92.68 ± 6.81 ^a	126.65 ± 5.97 ^a	4.88 ± 0.06 ^b
SF	131.59 ± 1.2 ^b	118.05 ± 4.54 ^a	5.79 ± 0.38 ^a
SF-5SBF	142.85 ± 3.7 ^b	127.03 ± 3.83 ^a	5.44 ± 0.12 ^a

Note: Values with different letters (a–b) within one column are statistically different at $p < 0.05$, according to Tukey's test.

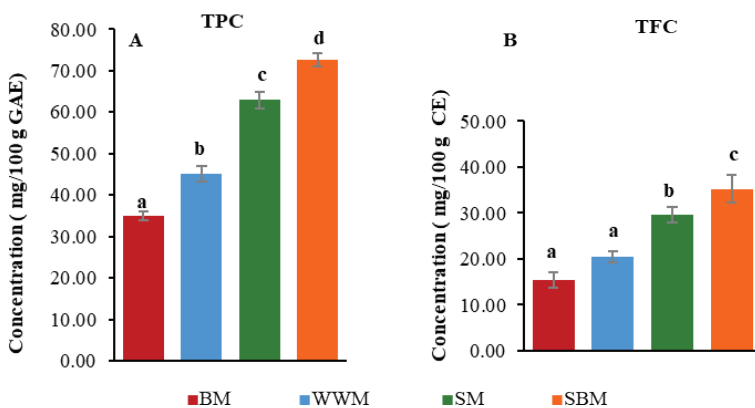
Water and oil absorption capacity as well as swelling power are key factors determining the rheological properties of dough such as elasticity, softness, and the starch readiness to gelatinize during baking. Overall, SF had a significantly higher WAC value compared to BL55 and WWF samples, indicating superior water holding ability. This ability could be connected to the higher fibre content and its different composition in whole sorghum flour. In the case of OAC, there were no significant differences between the samples, and the applied SBF supplementation did not result in significantly different WAC and OAC values either. Swelling power showed similar results in all samples, except WWF flour, whose swelling power was significantly lower compared to other samples. Ibrahim and his co-workers reported similar results when producing flour blends for pasta making, with an increase of 5% in WAC values due to the presence of the higher amount of amylopectin compared to normal wheat flour (*Ibrahim & Ani*, 2018). Another study described similar results with sorghum–bean flour mixtures, where functional properties were significantly improved compared to the wheat-based counterpart (*Isaac et al.*, 2025).

Evaluation of the preservation of bioactive compounds in the final product

Polyphenols include several chemicals with varying chemical structure, many of which considered thermally degradable during food processing. However, this

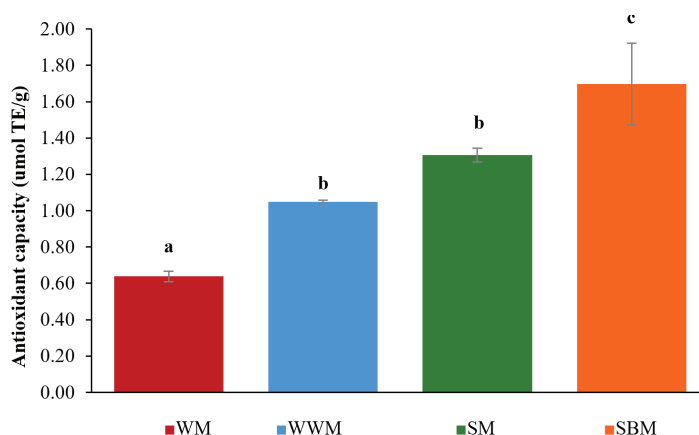
is influenced by many factors such as temperature, time, matrices, and the type of polyphenol. Anthocyanins and procyanidins are especially heat sensitive, and most phenols or flavonoids are hydrolysed at prolonged high ($> 180\text{ }^{\circ}\text{C}$) temperature (Arfaoui, 2021; Blanch & Ruiz del Castillo, 2021; Ross *et al.*, 2011). Thus, it is extremely important to know how the bioactive composition of the dough changed during baking, which can be seen in *Figure 3* and *Figure 4*. Among the samples, SM and SBM contained significantly higher amounts of polyphenols with concentrations of 62 and 72 mg/100 g GAE, compared to WM and WWM. The difference between SM and SBM was also statistically significant, with SBM being a richer source of phenols. The muffins contained lingonberry jam, which accounted for the total phenol and flavonoid content of the final products. The jam had an average of 61 and 18 mg/100 g phenol (GAE) and flavonoid (CE) content respectively.

Flavonoid content showed in *Figure 3* expressed similar tendencies to total phenol values by SM and SBM, providing the highest source of flavonoids with values of 29 and 35 mg CE/100 g concentrations compared to wheat alternatives. Sea buckthorn addition also significantly improved the flavonoid content of sorghum-based muffins. In both cases, phenol and flavonoid content increased significantly in the baked product compared to the ratio of flours in the product. This phenomenon could be explained by either the release of bound phenolics fraction from the matrix or the Maillard reaction products (MRPs) generated during the baking process. These MRPs could have significant antioxidant activities depending on their structure, and also, they are measured by the Folin–Ciocalteu assay, thus compromising the evaluated phenolic content of the samples (Kitchen & Williamson, 2024).



Note: Values with different letters (a–d) within one measurement are statistically different at $p < 0.05$, according to Tukey's test.

Figure 3. Total phenol (A) and flavonoid (B) content of different muffin products



Note: Values with different letters (a–c) are statistically different at $p < 0.05$, according to Tukey's test.

Figure 4. Antioxidant capacities of different muffin products evaluated by DPPH assay

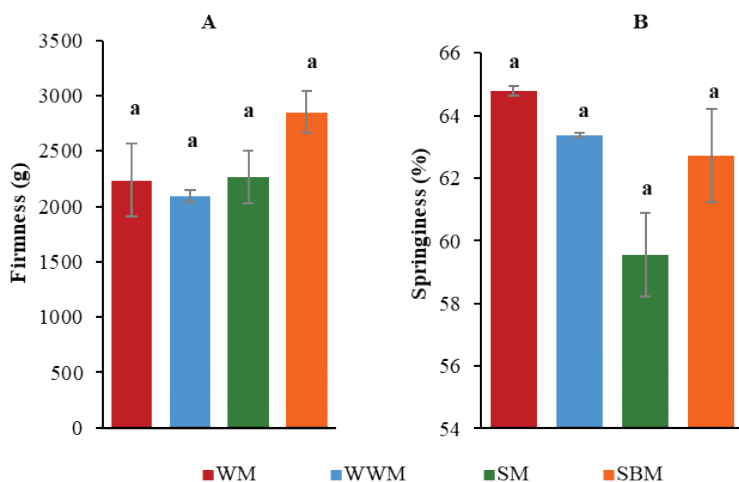
In another study, muffins enriched with lupine flour showed also significantly increased phenol content after baking. The authors connected this increase to thermal degradation and release of bound phenols from cell wall (*Rumiyati et al.*, 2015). Other studies also reported an increase in smaller-sized phenol esters and flavanol dimer and trimer compounds after the heat treatment process (*Rodriguez-Mateos et al.*, 2014). Evidence also suggests that baking and other heat treatments have a significant role in regulating the bioaccessibility of polyphenols due to depolymerization and enzymatic hydrolysis of fibres and polyphenols (*Collar et al.*, 2014; *Vogrinčič et al.*, 2010). Altogether, this increase in phenol and flavonoid content may suggest that the combination of physical processes and the utilization of ingredients rich in bioactive compounds could lead together to novel food products with high nutrition scores among customers, but further qualitative analysis is needed. The antioxidant activities measured by DPPH assay in the final products seem to be diminished compared to raw flours.

Furthermore, it seems that a significant part of this antioxidant effect comes from the lingonberry jam bioactive composition, especially in the case of WM and WWM. Similar to the earlier measurements, SM and SBM had the highest antioxidant capacities with values of 1.31 and 1.70 $\mu\text{mol TE/g}$ concentrations. This antioxidant capacity is partially originating from the lingonberry jam used in the recipe, which had 1.71 $\mu\text{mol TE/g}$ antioxidant capacity. Interestingly, the measured antioxidant capacities followed similar tendencies to the phenol and flavonoid content of different muffins. Baked muffins expressed much higher antioxidant capacities compared to expected values by ingredient ratios. This finding suggests that the newly formed secondary metabolites also have significant

antioxidant properties. *Collins et al.* evaluated five different sorghum varieties for their change in phenol content and antioxidant properties after a combination of fermentation and cooking process, and they found a highly significant increase in antioxidant capacities compared to raw materials (*Collins et al.*, 2024).

Organoleptic properties of developed muffin bakery products

One of the main differences between doughs with or without gluten is the lack of protein network providing structural stability and improved gas-holding ability to the dough. Because of this, gluten-free products tend to score worse on organoleptic sensory tests due to their poor or crumbly texture. In our product, psyllium husk was used as a fibre source and thickener to improve the texture. Wheat control muffin products were also supplemented with psyllium husk. The results are shown in *Figure 5*.



Note: Values with different letters (a–c) within one measurement are statistically different at $p < 0.05$, according to Tukey's test.

Figure 5. Texture analysis of firmness (A) and springiness (B) on muffin products

There were no statistically significant differences between the muffin samples despite the different flours used in their production. A slight decrease could be observed in terms of springiness in the case of sorghum containing muffins. These results can most possibly be attributed to the psyllium husk and egg fibre and protein content, but further analysis is required to identify the effects of the different components. Interestingly, the firmness of muffins was quite high, as a fluffier, lighter texture is usually expected from the muffin-type bakery products.

This discrepancy may originate from the psyllium husk's high fibre content and its extremely good water-absorbing ability.

Psyllium husk is an effective gluten substitute with excellent rheological properties. According to other studies, it helps forming more elastic, resilient doughs, but it can also increase crumb hardness and gumminess (Filipčev *et al.*, 2021; Torres-Pérez *et al.*, 2024). This also backed our findings in this study as well. According to our results, SF and SBF did not influence the final texture profile of the muffin products.

An organoleptic analysis was also performed, as shown in Figure 6. A 9-point hedonistic scale was applied to evaluate the customer acceptance of muffin products.

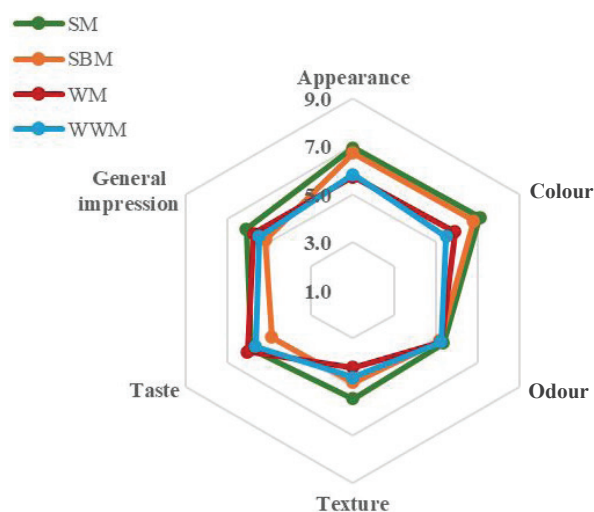


Figure 6. Organoleptic analysis of developed muffin products

Among the developed products, SM and SBM muffins got the highest acceptance scores compared to control wheat products. There was a significant difference ($p < 0.05$) in colour between SM, SBM and WM, WWM muffins. However, there were no significant differences in terms of texture, odour, taste, or overall impression.

4. Conclusions

In this study, a gluten-free flour mixture with sorghum and sea buckthorn flour was developed and evaluated for its bioactive value in a functional bakery product. Our results reveal that sea buckthorn berry flour is an excellent source of phenols and flavonoids with high antioxidant capacity, and it could be used as a functional ingredient alongside sorghum flour, which is also known as a good source of

polyphenols. SF and SF-5SBF showed superior bioactive composition in terms of phenol and flavonoid content and antioxidant capacity compared to refined and whole grain wheat flours. However, aside from the nutritional value, some techno-functional properties are also relevant during dough preparation. Among them, water binding and holding ability is especially important, as it influences viscosity, elasticity, and gas retention ability as well. Sorghum-based flours proved to be superior compared to wheat flours – supposedly due to their higher fibre content compared to the latter. Furthermore, a gluten-free bakery product, namely muffin, was developed using the flour samples evaluated in this study to achieve a novel bakery product with functional properties. The final products preserved their bioactive value during baking, with high phenol and flavonoid content and potent antioxidant properties. However, the measured values could partially originate from Maillard reaction by-products. Overall, SF and SF-5SBF are flours suitable for novel gluten-free food development with high biological and functional value and good techno-functional properties. Further research with higher SBF addition and further analytical evaluation is still needed for a clearer picture.

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