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Research Article

Quality and technological characteristics of cookies enriched with microfluidized hull-less barley flour

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Abstract

The present study aimed to investigate the effects of microfluidization on the functional properties of hull-less barley flour (HLBF) and to evaluate its technological performance in cookie production. Hull-less barley (cv. Yalın) was microfluidized at 20,000 psi, freeze-dried, milled, and incorporated into wheat flour at substitution levels ranging from 0% to 100%. Microfluidization significantly enhanced β-glucan, total dietary fiber, total phenolic content, and antioxidant activity, while reducing phytic acid by nearly 80% compared with untreated HLBF. In cookie formulations, increasing HLBF levels decreased diameter and spread ratio, but increased thickness, and these effects were more pronounced with microfluidized HLBF due to its higher water-binding ability. Color measurements showed a marked decrease in L and increases in a, b*, and ΔE, indicating darker and more intense coloration at higher substitution levels. Although functional properties improved substantially, sensory scores declined above 50% microfluidized HLBF, mainly due to excessive darkening and a firmer texture. Overall, microfluidization effectively enhanced the nutritional quality of HLBF, and moderate incorporation levels (≤50%) provided the best balance between functional enhancement and acceptable technological and sensory properties.

Keywords

β-glucan; hull-less barley; microfluidization; phenolics; phytic acid

Abbreviations

AACCI – American Association of Cereal Chemists International; DPPH – 2,2-diphenyl-1-picrylhydrazyl; GAE – Gallic acid equivalent; HFCS – High-fructose corn syrup; HLBF – Hull-less barley flour; L*, a*, b* – CIE Lab color coordinates; SD – Standard deviation; SEM – Standard error of the mean; SWF – Soft wheat flour; TE – Trolox equivalent; TPC – Total phenolic content; TDF – Total dietary fiber

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Introduction

Functional foods have gained increasing attention due to their potential roles in improving human health through physiologically active components such as dietary fiber, phenolic compounds and antioxidants (Aguiar et al. 2019). Cereal grains represent an essential group of functional ingredients because they are rich in fiber, bioactive compounds and micronutrients. Studies have shown that phenolic compounds contribute not only to sensory attributes but also to antioxidant, anticancer and anti-inflammatory effects (Han et al. 2007). Cereal antioxidants play a key role in eliminating reactive oxygen species and chelating pro-oxidant metal ions, thereby contributing to the prevention of chronic diseases (Fox and Eberl 2002). Hull-less barley is of particular interest due to its high β-glucan content, balanced protein structure, soluble and insoluble dietary fibres, and phenolics with antioxidant capacity (Li et al. 2019; Zhao et al. 2008).

In addition to valuable bioactive constituents, cereals contain phytic acid, an antinutritional factor that forms insoluble complexes with essential minerals, thereby reducing their bioavailability (Zhou and Erdman 1995). Reducing phytic acid while enhancing functional components is therefore a desirable goal in developing functional cereal-based products. Microfluidization, a high-pressure homogenization technique, has emerged as an effective method for modifying the structural and functional properties of cereal materials. It reduces particle size, increases surface area, and promotes the release of bound phenolics and dietary fibers (Ciron et al. 2011; Wang et al. 2012; Zhu et al. 2010).

Previous studies have examined microfluidization in wheat bran, bulgur bran and chickpea bran, demonstrating improved hydration properties, increased phenolic content and reduced phytic acid (Baumgartner et al. 2023). Comprehensive reviews have also highlighted the technological and functional significance of barley-based ingredients in bakery applications (Stamatovska et al. 2023). However, despite the nutritional potential of hull-less barley, no published study has investigated the direct effect of microfluidization on hull-less barley flour or its incorporation into cookie formulations.

The present study aimed to enhance the functional properties of hull-less barley flour through microfluidization and to evaluate its chemical, functional and technological performance in cookie production at varying substitution levels. The goal was to develop cookies with reduced phytic acid and improved nutritional attributes - particularly β-glucan, dietary fiber, phenolic content and antioxidant activity - while maintaining acceptable physical and sensory quality.

Materials and Methods

Materials. Soft wheat flour (cv. Bayraktar 2000) and hull-less barley (cv. Yalın) were obtained from the Central Research Institute for Field Crops (Ankara, Türkiye).

All chemicals and reagents used in analytical procedures were of analytical or spectrophotometric grade: Folin-Ciocalteu reagent (Merck, Germany), DPPH radical (Sigma-Aldrich, USA), glucose oxidase–peroxidase (GOPOD) reagent and β-glucan assay kit (Megazyme, Ireland), total dietary fibres kit (Megazyme, Ireland), ammonium bicarbonate (Merck, Germany), sodium bicarbonate (Merck, Germany), vanadomolybdophosphoric acid reagent (Sigma-Aldrich, USA), and iron(III) solution for phytic acid precipitation (Merck, Germany). High-fructose corn syrup (HFCS) (food-grade) and other cookie ingredients (shortening, powdered sugar, non-fat dry milk, salt) were purchased from local markets in Ankara.

Preparation of flours. The Wheat samples were conditioned to 15% moisture and milled using a Bühler MLU 202 laboratory mill (Uzwil, Switzerland) according to AACCI Approved Method 26-50 (AACCI 2010) to obtain soft wheat flour suitable for cookie production.

Hull-less barley grains were milled using an ultra-centrifugal mill (Retsch ZM 200, Germany) equipped with a 500 µm sieve. The resulting flour was divided into two fractions. For microfluidization, an aqueous dispersion containing 7.5% (w/w) HLBF was prepared and processed using a microfluidizer (Microfluidics M-110P, Newton, MA, USA) at 20,000 psi, with the sample passing through a 100 µm "Z-type" interaction chamber (IC_{100}) twice. The processed HLB dispersions were freeze-dried, not the flours

themselves, and then milled with a disc mill (Bühler DLFU W22050, Beilngries, Germany).

Particle size distribution (D10, D50, D90) of the microfluidized flour was determined using a Bluewave Particle Size Analyzer (Microtrac, USA) following Wang et al. (2012).

Cookie preparation. Cookies were prepared according to a modified AACCI Method 10-54 (AACCI 2010). The base recipe included: 40.0 g flour (13% moisture basis), 16.8 g powdered sugar, 16.0 g shortening, 0.5 g salt, 0.4 g sodium bicarbonate, 0.2 g ammonium bicarbonate, 0.6 g HFCS (high-fructose corn syrup), 0.4 g non-fat dry milk, 8.8 mL water.

Dry ingredients were combined with shortening and mixed with a KitchenAid Mixer (St. Joseph, MI, USA). HFCS and ammonium bicarbonate were dissolved in water and added to form a cream. Wheat flour or blends containing 0%, 25%, 50%, 75% or 100% HLBF (both microfluidized and non-microfluidized) were incorporated to form dough. Doughs were sheeted to 6 mm thickness and cut into 60 mm diameter discs. Cookies were baked at 205°C for 11 min and cooled at room temperature.

Analytical methods. Total dietary fibres content was determined using the AOAC 991.43 enzymatic-gravimetric procedure (Megazyme kit) (AOAC 2012). Measurements were performed in triplicate (n = 3) and expressed on a dry basis.

Total phenolic content (TPC) was measured using the Folin-Ciocalteu method (Gao et al. 2002). Results were expressed as mg garlic acid equivalent per kg dry sample (mg GAE.kg^{-1}).

DPPH radical scavenging activity was determined according to Brand-Williams et al. (1995) and expressed as µmol Trolox equivalent per 100 g (µmol TE.100 g^{-1}).

β-glucan content was quantified enzymatically using the Megazyme assay kit based on lichenase and β-glucosidase hydrolysis, followed by GOPOD measurement at 510 nm.

Phytic acid content was analysed using the Haug and Lantzsch (1983) method, based on Fe(III) precipitation and spectrophotometric detection at 519 nm. Phytate phosphorus was calculated stoichiometrically.

Total phosphorus was determined spectrophotometrically using the vanadomolybdophosphoric yellow complex method (Ozkaya and Ozkaya 2005).

Diameter (W, mm) and thickness (T, mm) were measured following AACCI Method 10-54. Spread ratio was calculated as W/T. All measurements were conducted in triplicate (n = 3).

The color values of the cookies were measured using a colorimeter (Hunterlab MiniScan XE Plus, USA) and expressed as L* value [(0) black – (100) white], a* value [(+) red – (-) green], and b* value [(+) yellow – (-) blue]. The L*, a*, and b* values of barley flour-enriched cookies were subtracted from the values of the control cookies to calculate the total color difference (ΔE*), using the equation provided below (Peressini and Sensidoni 2009).

$$\Delta E^{*} = \sqrt{(L^{*} - L^{*}control)^2 + (a^{*} - a^{*}control)^2 + (b^{*} - b^{*}control)^2}$$

The sensory analysis of the cookie samples was conducted in a well-lit sensory analysis laboratory with 10 panellists, aged between 26 and 56, consisting of researchers from the Field Crops Central Research Institute and faculty members from the Department of Food Engineering at Ankara University. Before the sensory evaluation, the panellists underwent a brief training on the evaluation process. Each sample was assigned a random three-digit code, and the panellists were asked to score the samples based on appearance, color, aroma, texture, taste, and overall acceptability. A 9-point hedonic scale, ranging from 9 (extremely liked) to 1 (extremely disliked), was used for evaluation (Hooda and Jood 2005). The average score for each criterion was calculated, and the results were presented as a polar coordinate graph created using Microsoft Excel (Microsoft, USA).

All analyses were performed in triplicate (n = 3) unless otherwise stated. Results were expressed as mean ± standard deviation (SD). One-way ANOVA was conducted using SPSS v.20 (IBM, Armonk, NY, USA). Mean differences were compared using Duncan's multiple range test at $P < 0.05$.

Results and Discussion

Functional properties of flours. The chemical characteristics of wheat flour, hull-less barley flour

(HLBF) and microfluidized HLBF are presented in Table 1. As expected, HLBF showed significantly higher levels of total dietary fiber, phenolics, antioxidant activity and β-glucan compared to wheat flour. Microfluidization further enhanced these components by reducing particle size and exposing previously encapsulated cell-wall–bound constituents.

Table 1. Chemical characteristics of wheat flour and hull-less barley flour

Analysis	Wheat flour	HLB flour	Microfluidized HLB flour
Total dietary fiber*, g.100 g^{-1}	3.48 ±0.07	18.05±0.09	19.29±0.13
Total phenolic content*, mg GAE.kg^{-1}	719.30±1.2	2413.51±23.4	2886.01±30.6
Total antioxidant activity*, µmol TE.100 g^{-1}	86.93±3.9	979.20±17.5	997.15±16.9
β-glucan content ,%	0.28±0.01	5.11±0.08	5.54±0.06
Phytic acid*, mg.100 g^{-1}	159.50±3.7	1012.25±16.8	214.05±1.5
Phytate phosphorus*, mg.100 g^{-1}	44.98±1.7	285.46±2.5	60.36±2.3
Total phosphorus*, mg.100 g^{-1}	97.52±4.2	420.94±9.6	419.59±11.8

*GAE: Gallic acid equivalent HLB: Hull-less barley TE: Trolox equivalent *dry basis

An increase in β-glucan content from 5.11% (HLBF) to 5.54% (microfluidized HLBF) was observed. Similar improvements were reported in barley and wheat bran subjected to high-energy milling techniques, which promote the release of soluble fibres fractions (Nakov et al. 2019; Mariotti et al. 2014). Microfluidization increased total phenolic content from 2413.51 to 2886.01 mg GAE.kg^{-1}. This enhancement is attributed to high-pressure disruption of the fiber matrix, which increases surface area and facilitates the release of bound phenolics. This mechanistic effect has been widely documented in microfluidized cereal fractions (Wang et al. 2012; Zhu et al. 2010).

Phytic acid decreased from 1012.25 mg.100 g^{-1} to 214.05 mg.100 g^{-1} (≈ 78.6% reduction). The substantial decline likely results from the hydrolytic cleavage of phytate complexes under high shear and cavitation, which enables the destabilization of Fe(III)-phytate. Such reductions were similarly noted in microfluidized chickpea and bulgur brans (Baumgartner et al. 2023).

Overall, microfluidized HLBF exhibited superior nutritional functionality compared to untreated HLBF, confirming the effectiveness of microfluidization as a pre-processing method for enhancing the nutritional value of barley-based ingredients.

Physical properties of cookies. The physical characteristics of cookies produced with HLBF and microfluidized HLBF are shown in Table 2. Substitution of wheat flour with HLBF significantly decreased cookie diameter while increasing thickness ($P < 0.05$). Consequently, the spread ratio declined as the level of HLBF increased.

This trend can be explained by the high water-binding capacity of β-glucan and dietary fiber, which restricts dough spread during baking. The results align with previous research, which reports reduced spread in fiber-enriched cookies due to limited dough flow and increased viscosity (Narwal et al. 2017).

Cookies containing microfluidized HLBF exhibited greater reductions in diameter compared to non-microfluidized counterparts at equivalent substitution levels. Higher specific surface area and hydration capacity of microfluidized HLBF produce a firmer dough structure, reducing flowability and decreasing spread.

At 100% substitution, cookies with microfluidized HLBF maintained a spread ratio of 6.38 compared to 5.27 in the non-microfluidized sample, indicating that microfluidization altered the water–solids interactions and dough matrix behavior differently across addition levels.

Color characteristics of cookies. The color characteristics of cookie products are given in Table 3, and the cookies' photographs are shown in Fig. 1. As seen in Table 3, the control sample's L*, a*, and b* values were 71.95, 3.67, and 18.86, respectively. The highest L* (lightness) and b* (yellowness) values were observed in the control sample, while

Table 2. Physical properties of cookies

Cookie samples	Supplementation level, g. 100 g^{-1}	Diameter (W), mm	Thickness (T), mm	Spread factor, W/T
HLB flour	0	70.70^{eA}	10.87^{aA}	6.50^{eA}
	25	68.85^{dA}	11.24^{bA}	6.13^{dA}
	50	67.47^{cA}	12.24^{cA}	5.51^{cA}
	75	65.78^{bA}	12.31^{cdA}	5.35^{bA}
	100	65.18^{aA}	12.38^{dA}	5.27^{aA}
Microfluidized HLB flour	0	70.70^{eA}	10.87^{cA}	6.50^{eA}
	25	64.34^{dB}	12.39^{eB}	5.20^{aB}
	50	61.72^{cB}	11.25^{dB}	5.48^{bA}
	75	60.47^{bB}	10.31^{bB}	5.87^{cB}
	100	58.44^{aB}	9.16^{aB}	6.38^{dB}

*HLB: Hull-less barley, *dry basis; Different small superscripts 'a-e' within the same column indicate significant differences between the means of different incorporation levels of the same barley flour (P<0.05). Different capital superscripts 'A-B' within the same column indicate significant differences between the means of the same incorporation level of the same barley flour with different treatments (P <0.05).

the highest a* (redness) value was obtained from the cookie made with 100% HLBF (4.34). The lowest L* and b* values were found in the cookie made with 100% microfluidized HLBF, while the lowest a* value was reported in the cookie with 25% microfluidized HLBF (3.27).

The decreases in L* and b* values were statistically significant for all addition levels in cookies enriched with HLBF and microfluidized HLBF (p<0.05). For a* value, it was found that HLBF had an increasing effect at the 50% and 75% Addition levels compared to the 25% level (p<0.05).

When examining the color values (L*, a*, and b*) of cookies made with HLBF and microfluidized HLBF at the same addition levels, the differences in L*, a*, and b* values were found to be statistically significant across all addition levels (p<0.05). It was observed that adding microfluidized HLBF reduced the cookies' L*, a*, and b* values. In the literature, it has been reported that the color of bread made with barley flours of different particle sizes darkened, and this darkening increased as particle size decreased (Prasopsunwattana et al. 2009). In all samples, as the amount of both microfluidized and non-microfluidized HLBF increased, the ΔE* value (indicating color difference) also increased, meaning the color difference between the control and the enriched samples became more pronounced. The largest increase in color change was observed in the cookies made with microfluidized HLBF, where the ΔE* value reached 40.93 for the cookies made with 100% microfluidized HLBF.

These findings agree with reports showing that baked goods produced with finely milled barley fractions become progressively darker as particle size decreases (Prasopsunwattana et al. 2009; Frost et al. 2011).

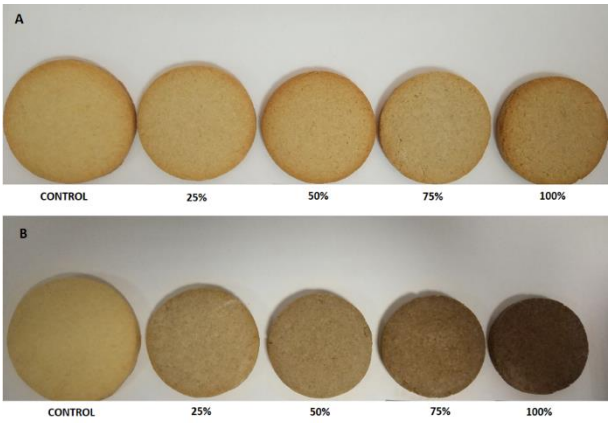


Figure 1. Cookie samples
A. Cookies Produced with HLBF
B. Cookies Produced with Microfluidized HLB

Table 3. Color characteristics of cookies

Cookie samples	Supplementation Level, g.100 g^{-1}	Diameter (W), mm	Thickness (T), mm	Spread factor, W/T
HLB flour	0	70.70^{eA}	10.87^{aA}	6.50^{eA}
	25	68.85^{dA}	11.24^{bA}	6.13^{dA}
	50	67.47^{cA}	12.24^{cA}	5.51^{cA}
	75	65.78^{bA}	12.31^{cdA}	5.35^{bA}
	100	65.18^{aA}	12.38^{dA}	5.27^{aA}
Microfluidized HLB flour	0	70.70^{eA}	10.87^{cA}	6.50^{eA}
	25	64.34^{dB}	12.39^{eB}	5.20^{aB}
	50	61.72^{cB}	11.25^{dB}	5.48^{bA}
	75	60.47^{bB}	10.31^{bB}	5.87^{cB}
	100	58.44^{aB}	9.16^{aB}	6.38^{dB}

*HLB: Hull-less barley; Different small superscripts 'a-e' within the same column indicate significant differences between the means of different incorporation levels of the same barley flour ($P<0.05$). Different capital superscripts 'A-B' within the same column indicate significant differences between the means of the same incorporation level of the same barley flour with different treatments ($P<0.05$).

Functional properties of cookies. The functional properties of cookie samples are given in Table 4. In cookies, adding barley flour increased the β-glucan and total dietary fibres content depending on the addition ratio. This increase was found to be statistically significant ($p<0.05$). The lowest values for β-glucan and total dietary fibres were found in the control samples, while the highest values were observed in cookies made with 100% microfluidized HLBF.

The β-glucan content in the control sample was 0.11%, whereas it reached 2.91% in the cookies made with 100% microfluidized HLBF. Similarly, the total dietary fibres content increased from 2.09% in the control sample to 13.21% in the cookies made with 100% microfluidized HLBF. It was observed that the microfluidization process enhanced both the β-glucan and total dietary fibres content. This increase is attributed to the microfluidization process, which breaks down cell wall components (hemicellulose, cellulose, and lignin) into smaller particles, converting them into a more soluble form (Zhu et al. 2010). As a result, there is an increase in the soluble fibres fraction, specifically β-glucan, which subsequently leads to a rise in the total dietary fibres content.

When comparing the values of cookies with barley flour and microfluidized HLBF at the same addition levels, the differences between the incorporation ratios were also statistically significant ($p<0.05$). In a study conducted by Skrbic and Cvejanov (2011), the total β-glucan content of cookies made by adding different proportions (30%, 50%) of hull-less barley flour to refined and whole wheat flours was found to range between 1.30% and 2.06%. The highest β-glucan content was reported to be achieved by incorporating 50% hull-less barley flour into the refined wheat flour.

The total phenolic content of the cookies made by adding HLBF to the wheat flour samples ranged from 498.68 to 1594.97 mg GAE.kg^{-1}, while the total antioxidant activity values varied between 74.97 and 457.40 μmol TE.100 g^{-1} (Table 4).

The highest phenolic content was found in the cookies made with 100% microfluidized HLBF, which contained approximately 2.2 times more total phenolic compounds than the control sample. These cookies also exhibited the highest antioxidant activity among all samples, with a value of 457.40 μmol TE.100 g^{-1}. The addition of barley flour, depending on the addition level, increased both the total phenolic content and total antioxidant activity, and this increase was statistically significant across all levels ($p<0.05$). This is attributed to the higher antioxidant activity of the HLBF as compared to wheat flour. This increase is thought to result from the high pressure applied during the microfluidization process, which releases phenolic compounds bound within the fibres matrix of the product (Wang et al. 2012). In a study by Gupta et al. (2011), it was reported that as the proportion of barley flour (0%, 10%, 20%, 30%, 40%) replaced wheat flour in flour blends, the total phenolic

Table 4. Functional properties of cookies

Cookie samples	Supplementation level, g. 100 g^{-1}	β-glucan content*, %	Total dietary fibers*, %	Total phenolic content*, mgGAE.kg^{-1}	Total antioxidant activity*, µmol TE.100 g^{-1}	Phytic acid*, mg.100 g^{-1}	Phytate phosphorus amount*, mg.100 g^{-1}	Total phosphorus*, mg.100 g^{-1}
HLB flour	0	0.11^{aA}	2.09^{aA}	498.68^{aA}	74.97^{aA}	86.45^{aA}	24.38^{aA}	49.04^{aA}
	25	0.75^{bA}	4.31^{bA}	687.02^{bA}	186.20^{bA}	202.10^{bA}	56.99^{bA}	97.56^{bA}
	50	1.42^{cA}	6.46^{cA}	965.60^{cA}	261.75^{cA}	356.20^{cA}	100.45^{cA}	138.71^{cA}
	75	1.94^{dA}	8.78^{dA}	1129.86^{dA}	387.70^{dA}	504.65^{dA}	142.32^{dA}	182.26^{dA}
	100	2.45^{eA}	12.68^{eA}	1303.43^{eA}	447.50^{eA}	703.75^{eA}	198.46^{eA}	233.41^{eA}
Microfluidized HLB flour	0	0.11^{aA}	2.09^{aA}	498.68^{aA}	74.97^{aA}	86.45^{aA}	24.38^{aA}	49.04^{aA}
	25	0.87^{bB}	5.20^{bB}	753.63^{bB}	208.43^{bB}	106.70^{bB}	30.09^{bB}	99.15^{bB}
	50	1.60^{cB}	7.15^{cB}	1060.35^{cB}	279.46^{cB}	115.30^{cB}	32.52^{cB}	131.81^{cB}
	75	2.15^{dB}	9.35^{dB}	1272.39^{dB}	412.40^{dB}	132.70^{eB}	37.42^{eB}	150.55^{dB}
	100	2.91^{eB}	13.21^{eB}	1594.97^{eB}	457.40^{eB}	120.55^{dB}	34.00^{dB}	238.74^{eB}

*HLB: Hull-less barley, GAE: Gallic acid equivalent, TE: Trolox equivalent, *dry basis
Different small superscripts 'a-e' within the same column indicate significant differences between the means of different incorporation levels of the same barley flour (P<0.05). Different capital superscripts 'A-B' within the same column indicate significant differences between the means of the same incorporation level of the same barley flour with different treatments (P <0.05).

content in both the cookie dough and cookies increased. In cookies, the addition of barley flour increased the phytic acid and total phosphorus content in a manner dependent on the addition level, and this increase was found to be statistically significant ($p<0.05$). The control samples obtained the lowest values, with phytic acid, phytate phosphorus, and total phosphorus contents of 86.45 mg.100 g^{-1}, 24.38 mg.100 g^{-1}, and 49.04 mg.100 g^{-1}, respectively. The highest phytic acid content, 703.75 mg.100 g^{-1}, was found in cookies with 100% HLBF (Table 4).

The differences were statistically significant when comparing the phytic acid and total phosphorus contents of cookies made with HLBF and microfluidized HLBF at the same addition levels ($p<0.05$). The microfluidization process significantly reduced the phytic acid content while increasing the total phosphorus content. The reduction in phytic acid is attributed to the high pressure applied during the microfluidization process, which breaks down phytic acid compounds.

Sensory evaluation. Sensory evaluation has studied the parameters of appearance, color, aroma, texture, taste, and overall acceptability. Fig. 2 and Fig. 3 present the polar coordinate charts for the cookie sensory evaluation scores.

In the context of the sensory analysis results, the averages of the scores provided by the panelists for each cookie sample were considered. Upon reviewing the results, it was observed that the highest acceptability scores were obtained from the control sample. When the cookies were evaluated regarding appearance, texture, and taste, the preference scores generally decreased as the proportion of barley flour increased. However, except for the texture score of the cookie made with 100% barley flour (5.8), all cookies received scores above 6 ("slightly liked").

In cookies made with micro fluidized HLBF, the color darkened as the addition level increased, negatively impacting the preference for color and appearance. Therefore, it is recommended that microfluidized HLBF not be added at levels higher than 50% in cookie formulations.

Literature studies on the sensory properties of cookies with barley flour have reported that adding 5-30% barley flour significantly improves the sensory quality of the cookies, and cookies with 30% barley flour were preferred over the control sample (Hassan et al. 2012).

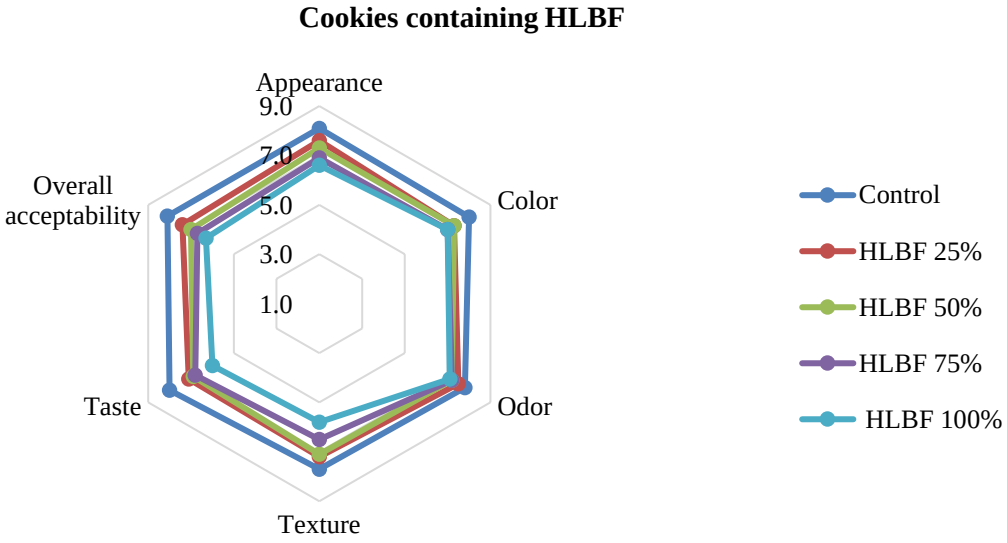


Figure 2. Polar coordinate graphics of the sensory properties of cookies with HLBF (Cookies containing HLBF)

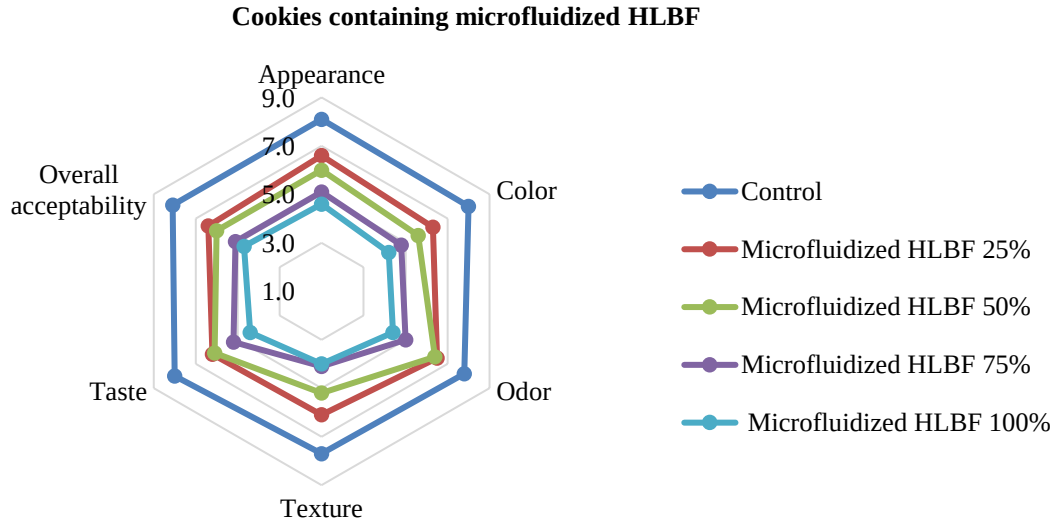


Figure 3. Polar coordinate graphics of the sensory properties of cookies with HLBF (Cookies containing microfluidized HLBF)

Conclusions

The present study demonstrated that microfluidization is an effective pre-treatment for enhancing the nutritional functionality of hull-less barley flour and improving its applicability in cookie formulations. Microfluidization significantly increased β-glucan, total dietary fibres, phenolic content and antioxidant activity while reducing phytic acid by nearly 80%. When incorporated into cookies, microfluidized HLBF improved the functional composition more effectively than untreated HLBF, although higher substitution levels intensified darkening and reduced sensory acceptability. Moderate incorporation levels (≤50%) offered the best balance between functional enhancement and acceptable technological and sensory properties. Overall, microfluidized hull-less barley flour

represents a promising ingredient for developing fibres and phenolic-rich functional bakery products and its use in other soft-textured cereal products such as cakes or muffins warrants further investigation.

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Author Contributions

Conceptualization, Ozer A., Ozkaya. B.; methodology, Ozer A., Ozkaya. B.; formal analysis Ozer A.; investigation, Ozer A.; resources Ozer A., Ozkaya. B.; data curation, Ozer A., Ozkaya. B.; writing - original draft preparation, Ozer A.; writing Ozer A., Ozkaya. B.; review and editing, Ozer A., Ozkaya. B.; visualization, Ozer A., Ozkaya. B.; supervision, Ozkaya. B.; project administration Ozkaya. B.; funding acquisition Ozer A., Ozkaya. B. All authors have read and agreed to the published version of the manuscript.

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Ethical Statement

The sensory evaluation conducted in this study was performed in accordance with the principles of the Declaration of Helsinki. All panellists were informed about the purpose of the study and provided verbal informed consent prior to participation. The sensory analysis involved no invasive procedures and posed no risk to the participants. Participation was voluntary, and all data were evaluated anonymously.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding authors.

Conflicts of Interest

The authors declare no conflicts of interest

References

AACC International. Approved Methods of Analysis. 11th Edition, The Global Gold Standard in Grain Science Laboratory Methods. 2010, St. Paul, MNq USA. Available at: https://www.cerealsgrains.org/resources/methods/Pages/default.aspx

Aguiar L.M., Geraldi M.V., Betim Cazarin C.B., Maróstica Junior M.R. Chapter 11. Functional Food Consumption and Its Physiological Effects. In: *Bioactive Compounds. Health Benefits and Potential Applications* (M.R.S. Campos Ed.). https://doi.org/10.1016/B978-0-12-814774-0.00011-6, Woodhead Publishing. 2019, pp. 205-225. e-ISBN: 978-0-12-814774-0, https://doi.org/10.1016/C2017-0-02265-6

AOAC Official Method of Analysis: Association of Analytical Chemists. 19th Edition, 2012. pp. 121-130, Washington, DC, USA.

Baumgartner B., Özkaya B., Saka İ., Özkaya H. Functional and physicochemical properties of milled and microfluidized bulgur and chickpea brans. *Journal of Agricultural Sciences* (Tarim Bilimleri Dergisi), 2023, 29(1): 200-208. https://doi.org/10.15832/ankutbd.1001981

Brand-Williams W., Cuvelier M.E., Berset C. Use of a free radical method to evaluate antioxidant activity. *LWT Food Science and Technology*, 1995, 28(1): 25-30. https://doi.org/10.1016/S0023-6438(95)80008-5

Ciron C.I.E., Gee V.L., Kelly A.L., Auty M.A.E. Effect of microfluidization of heat-treated milk on rheology and sensory properties of reduced fat yogurt. *Food Hydrocolloids*, 2011, 26(2): 412-420. https://doi.org/10.1016/j.foodhyd.2011.02.014

Fox C.H., Eberl M. Phytic acid (IP6), novel broad spectrum anti-neoplastic agent: a systematic review. *Complementary Therapies in Medicine*, 2002, 10(4): 229-234. https://doi.org/10.1016/S0965-2299(02)00092-4

Frost D.J., Adhikari K., Lewis D.S. Effect of barley flour on the physical and sensory characteristics of chocolate chip cookies. *Journal of Food Science and Technology - Mysore*, 2011, 48(5): 569-576. https://doi.org/10.1007/s13197-010-0179-x

Gao L., Wang S., Oomah B.D., Mazza G. Wheat Quality: Antioxidant Activity of Wheat Millstreams. İn: *Wheat Quality Education* (P. Ng, C.W. Wrigley Eds.). First Edition, AACC International. 2002, pp. 219-233, 219-233.

Gupta M., Bawa A.S., Abu-Ghannam N. Effect of barley flour and freeze-thaw cycles on textural

nutritional and functional properties of cookies. *Food and Bioproducts Processing*, 2011, 89(4): 520-527. https://doi.org/10.1016/j.fbp.2010.07.005

Han X., Shen T., Lou H. Dietary polyphenols and their biological significance. *International Journal of Molecular Sciences*, 2007, 8(9): 950-988. https://doi.org/10.3390/i8090950

Hassan A.A., Rasmy N.M., Foda M.I., Bahgaat W.K. Production of functional biscuits for lowering blood lipids. *World Journal of Dairy & Food Sciences*, 2012, 7(1): 1-20. Available at: https://idosi.org/wjdfs/wjdfs7(1)/1.pdf

Haug W., Lantzsch H.J. Sensitive method for the rapid determination of phytate in cereals and cereal products. *Journal of the Science of Food and Agriculture*, 1983, 34(12): 1423-1426. https://doi.org/10.1002/jsfa.2740341217

Hooda S., Jood S. Organoleptic and nutritional evaluation of wheat biscuits supplemented with untreated and treated fenugreek flour. *Food Chemistry*, 2005, 90(3): 445-452. https://doi.org/10.1016/j.foodchem.2004.05.006

Li Q., Yang S., Li Y., Huang Y. Zhang J. Antioxidant activity of free and hydrolyzed phenolic compounds in soluble and insoluble dietary fibers derived from hull-less barley *LWT*, 2019, 111(8): 534-540. https://doi.org/10.1016/j.lwt.2019.05.086

Mariotti M., Garofalo C., Aquilanti L., Osimani A., Fongaro L., Tavoletti, S. Hager, A.-S. Clementi F. Barley flour exploitation in sourdough bread-making: A technological, nutritional and sensory evaluation. *LWT – Food Science and Technology*, 2014, 59(12): 973-980. https://doi.org/10.1016/j.lwt.2014.06.052

Nakov G., Stamatovska V., Jukić M., Necinova L., Ivanova N., Šušak A., Komlenić D.K. Beta-glucans in biscuits enriched with barley flour made with different sweeteners. *Journal of Hygienic Engineering and Design*, 2019, 26(1): 88-92. Available at: https://keypublishing.org/jhed/wp-content/uploads/2020/07/04.-Full-paper-Gjore-Nakov.pdf

Narwal S., Kumar D., Sheoran S., Verma R.P.S., Gupta R.K. Hulless barley as a promising source to improve the nutritional quality of wheat products. *Journal of Food Science and Technology*, 2017, 54(9): 2638-2644. https://doi.org/10.1007/s13197-017-2669-6

Ozkaya H., Ozkaya B. Tahıl ve ürünleri analiz yöntemleri. (Fifth Edition). Sim Publications, Ankara. 2005, 157 pages.

Peressini D., Sensidoni A. Effect of soluble dietary fibre addition on rheological and breadmaking properties of wheat doughs. *Journal of Cereal Science*, 2009, 49(2): 190-201. https://doi.org/10.1016/j.jcs.2008.09.007

Prasopsunwattana N., Omary M.B., Arndt E.A., Cooke P.H., Flores R.A., Yokoyama W., Toma A., Chongcham S., Lee S.P. Particle size effects on the quality of flour tortillas enriched with whole-grain waxy barley. *Cereal Chemistry*, 2009, 86(4): 439-451. https://doi.org/10.1094/CCHEM-86-4-0439

Skrbic B., Cvejanov J. The enrichment of wheat cookies with high-oleic sunflower seed and hull-less barley flour: Impact on nutritional composition, content of heavy elements and physical properties. *Food Chemistry*, 2011, 124(4): 1416-1422. https://doi.org/10.1016/j.foodchem.2010.07.101

Stamatovska V., Nakov G., Dimov I., Traneva I., Kalevska T., Uzunoska Z. The changes in colour of biscuits during baking depending on time and different proportion of barley flour.. In: *Proceedings of UBT International Conference* (E. Hajrizi Ed). Proceedings of the UBT International Conference; 2017 Durres, Albania. UBT Knowledge Center – Making Local Knowled Visible. Durres, Albania, 2017, pp. 93-101. ISBN 978-9951-437-63-9 https://doi.org/10.33107/ubt-ic.2017.165

Wang T., Sun X.H., Zhou Z.X., Chen G.B. Effects of microfluidization process on physicochemical properties of wheat bran. *Food Research International*, 2012, 48(2): 742-747. https://doi.org/10.1016/j.foodres.2012.06.015

Zhao H., Fan W., Dong J., Lu J., Chen J., Shan L., Lin Y., Kong W. *Food Chemistry*, 2008, 107(1): 296-304. https://doi.org/10.1016/j.foodchem.2007.08.018

Zhou J.R., Erdman J.W. Phytic acid in health and disease. *Critical Reviews in Food Science and Nutrition*, 1995, 35(6): 495-508. https://doi.org/10.1080/10408399509527712

Zhu K., Huang S., Peng W., Qian H., Zhou H. Effect of ultrafine grinding on hydration and antioxidant properties of wheat bran dietary fiber. *Food Research International*, 2010, 43(4): 943-948. https://doi.org/10.1016/j.foodres.2010.01.005