European Food Science and Engineering

Eur Food Sci Eng 2024, 5 (1), 1-7
doi: 10.55147/efse.1443464
https://dergipark.org.tr/tr/pub/efse

Potential use of hazelnut (*Corylus avellana* L.) shell in muffin production by substitution of wheat flour: Color, bioactive, textural, and sensory properties

Esma Nur Demirkan[1], Seyma Nur Akyurek[1], Deniz Bayraktar[1], Gozde Kutlu[2*] and Fatih Tornuk[1,3]

[1] Department of Food Engineering, Faculty of Chemical and Metallurgical Engineering, Yildiz Technical University, İstanbul, Türkiye
[2] Department of Gastronomy and Culinary Arts, Faculty of Fine Arts, Design and Architecture, Ankara Medipol University, Ankara, Türkiye
[3] Department of Nutrition and Dietetics, Faculty of Health Sciences, Sivas Cumhuriyet University, Sivas, Türkiye

ARTICLE INFO

Research Article
Article History:
Received: 27 February 2024
Accepted: 10 May 2024
Available Online: 30 June 2024
Keywords:
Muffin
Hazelnut Shell
Functional ingredient
By-products
Textural changes
Sensory evaluation

ABSTRACT

Herein, three muffin samples were produced by substituting 0, 5, and 10% (w:w) hazelnut shell (HS) into wheat flour (WF) and their color, bioactive, textural and sensory properties were determined. The results showed that both total phenolic content and DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity were not significantly affected by the addition of HS to the muffin formulation (P>0.05). Upon enrichment of muffins with HS, L^* (70.00-44.79 for crumb, 51.53-44.00 for crust) and b^* values of muffins (27.39-12.49 for crumb, 30.65-17.17 for crust) significantly decreased in both crumb and crust, while a^* values significantly increased in crumb (-0.26-6.97) and decreased in crust (8.39-14.30) (P<0.05). Textural analysis revealed that hardness (9.74-32.14 N), gumminess (7.17-14.83 N), and chewiness (6.40-12.55 N) significantly decreased (P<0.05) while the springiness (0.85-0.89%) and resilience insignificantly increased as the amount of HS increased in the muffin formulation (P>0.05). The substitution of WF with 5% (w:w) HS significantly received the highest crust (5.6), crumb (5.1), chewiness (6.0), taste/aroma (6.0) and overall acceptability scores (5.9) by the panelists (P<0.05). Overall, HSs, which are a waste and by-product of hazelnut processing, can be successfully used in functional muffin production, both expanding their potential areas of use and contributing to their economic value.

1. Introduction

According to Food and Agriculture Organization (FAO) statistical data in 2007, ⅓ of the edible food in the world is wasted and/or lost, amounting to 1.3 billion tons (Salihoglu et al., 2018). In undeveloped countries, food waste reveals at the initial stages of food production, while in developed countries it occurs mostly at the final stages. In Europe, 42% of total food waste comes from households, 39% from food production and processing facilities, 14% from the service and catering sector and 5% from the wholesale and retail sector. In Europe, consumers throw away 30-68% of the food they buy and the annual amount of food waste per capita reaches 280-300 kg (European Commission 2010; Gustavson et al., 2011; Gustavson et al., 2013). The amount of organic waste generated in the food industry as a result of physical processes such as sorting and peeling applied to fruits and vegetables is quite high. These wastes are remain as waste and usually use as animal feed. However, latest studies revealed that these wastes are very rich in terms of nutritional value (Mirabella et al., 2014; Galanakis, 2012). For this reason, it has become a valuable, functional ingredient to reuse organic wastes such as fruit peels and seeds and to investigate ways of using them in different ways. It is extremely important to investigate the potential use of valuable and functional components for the reuse of organic waste such as fruit peels and seeds (Goel et al., 2020).

Hazelnut (*Corylus avellana* L.) has an important place in the economy of the Eastern Black Sea Region, which has a monoculture agricultural structure, especially in Trabzon, Giresun and Ordu, Türkiye (Gönenc et al., 2006). Türkiye, a significant producer, accounted for approximately 63% of global hazelnut production from 2016 to 2020, with Italy, Azerbaijan, and other countries following suit (Öztürk, 2023). Hazelnuts can be consumed fresh or roasted as a snack, but are also used in the food, pharmaceutical, and cosmetic industries for the preparation of chocolate, biscuits, confectionery, cakes,

*Corresponding author
E-mail address: gozcelk@gmail.com

ice cream, refined edible oil, cleaning agents, moisturizers and pharmaceuticals (Topkafa, et al., 2015). Hazelnut shell, a waste and by-product of the hazelnut processing industry, accounts for 50% of the total hazelnut weight. Due to the burning of crop residues, their disposal poses an economic threat to producers as well as a significant environmental threat (Esposito et al., 2017). Hazelnut shells mostly consist of lignin (40-50%), hemicellulose (13-32%), and cellulose (16-27%) (Zhao et al., 2023). These lignocelluloses shells were rich in bioactive ingredients such as phenolic acids, flavonoids, tannins, diaryleptanoids, and lignans (Esposito et al., 2017; Di Michele et al., 2021; Zhao et al., 2023).

A worldwide known wheat-based snack, muffins are widely accepted and recognized as a convenient food in today's eating habits and food choices due to their ready-to-eat form (Olawuyi et al., 2019). It has been reported that many food additives are used in industrial cake production to improve cake properties, extend shelf life and prevent differences. Raw material properties and processing conditions used in muffin production have a significant impact on the product quality (Difonzo et al., 2022). Their quality properties are determined by physical and sensory characteristics such as crust and crumb color, height, weight, texture, volume, symmetry (Xu et al., 2020; Difonzo et al., 2022). Thus far, different functional muffin formulations were developed in the literature using different by-products or wastes such as mango pulp fibre waste (Sudha et al., 2015), tomato processing by-product (Mehta et al., 2018), *Rosa damascena* Mill. by-products and cocoa pod husks (Chochkov et al., 2022), and cocoa bean shell powder (Souza et al., 2022). However, to the best of our knowledge, no studies have been conducted so far on the use of hazelnut shell (HS) in muffin production through substitution of wheat flour and its potential for conversion from food waste to a functional food ingredient. In this context, the objectives of this study were (i) to prepare functional muffin samples containing different proportions of HS (0, 5 and 10%, w:w) to evaluate their crumb and crust color, bioactive, textural, and sensory characteristics.

2. Materials and methods

2.1. Materials

Hazelnut shells (HS) were obtained from Union of Hazelnut Sales Cooperative (FISKOBIRLIK). Other ingredients used in the preparation of the muffins such as sugar (Altınküp, Ankara, Türkiye), ultrahigh temperature (UHT) whole fat milk (Pinar Süt, Izmir, Türkiye), sunflower oil (Yudum oils, Balıkesir, Turkiye) and baking powder (Dr. Oetker, Izmir, Türkiye) were purchased from local markets. As well, all-purpose wheat flour (additive-free, 11.9% protein content, Eris Flour, Samsun, Türkiye) suitable for bread, cake, pie making *etc.* was purchased. Sodium carbonate (Na_2CO_3) (Sigma-Aldrich, Steinheim, Germany), DPPH (Sigma-Aldrich, Germany), methanol (Merck, Germany), Folin-Ciocalteu phenol reagent (Sigma-Aldrich, Steinheim, Germany) were obtained.

2.2. Preparation of HS

The shells underwent a thorough cleaning process using distilled water and scrubbing to remove any potential contaminants, and then subsequently dried using an oven (Memmert UF-110, Germany) at 110 °C for 2 h. Then, HSs were ground with a grinder (Tefal 8100.31 coffee grinder, France). The samples were then sealed and stored at room temperature until used in the muffin production and analysis.

2.3. Muffin production

Muffin production was carried out with some modifications of Topkaya & Işık (2019). The proportions of HS to be incorporated into the muffin samples were determined as a result of preliminary experiments and sensory analysis. Moreover, the flowchart given in Figure 1 was followed for the preparation of muffins. HS was substituted into wheat flour at 0%, 5% and 10% (w:w) ratios and 3 different muffins were produced using the ingredients given in Table 1. For this purpose, eggs and sugar were mixed at high speed for 2 min using a mixer with dough hook (Bosch, MFQ 3030, 350 W). Then, milk and sunflower oil were added and mixed for another 2 min. After that, wheat flour, baking powder, and various proportions of HS were added. It was mixed for another 2 min. Then, muffin batter (12 g each) was transferred into pre-greased muffin cups. They were baked in a preheated oven at 180 °C for 30 min and left at room temperature for 1 h to cool down. Finally, they were named as HS-0, HS-5, and HS-10 at HS ratio of 0, 5, and 10%, respectively.

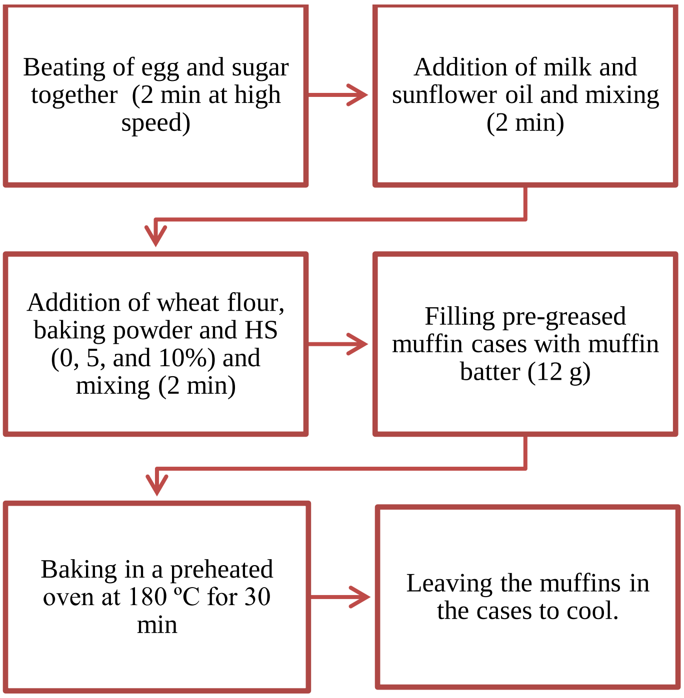

Figure 1. Flowcharts of muffin production.

Table 1. The used recipes for the production of HS-0, HS-5 and HS-10 muffins.

Ingredients (%, w/w)	Muffin Samples		
	HS-0	HS-5	HS-10
Flour	32.00	30.40	28.80
Hazelnut shell powder	0.00	1.60	3.20
Egg	19.20	19.20	19.20
Sugar	16.00	16.00	16.00
Oil	16.00	16.00	16.00
Milk	16.00	16.00	16.00
Baking powder	0.80	0.80	0.80

HS-0: The muffin samples without hazelnut shell; HS-5: The muffin samples including 5% substitution of hazelnut shell; HS-10: The muffin samples including 10% substitution of hazelnut shell.

2.4. Color assessment

Both crumb and crust color characteristics of muffins were determined by the method previously reported by Yavuz et al. (2022). $L*$ ($L*$=0, black; $L*$=100, white), $a*$ ($-a*$ = greenness; $+a*$ = redness) and $b*$ values ($-b*$=blueness; $+b*$=yellowness) of muffins for their crumb and crust were quantitatively measured employing a portable colorimeter (CR-400, Minolta Camera Co., Osaka, Japan). For this purpose, crust color values were measured from the tops of the muffins as a whole, while crumb colors were determined by cutting the muffins into two equal parts parallel to the ground using a knife. Total color difference *($\Delta E*$)* was calculated as follows:

$$\Delta E^* = \sqrt{(\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta L^*)^2} \quad (1)$$

2.5. Bioactive properties

Preparation of muffin extract

Initially, muffin samples were mixed with 70% methanol in the ratio of 1:10 (w/v) using an Ultra-Turrax dispenser (Daihan, HG-15D, Gang-Won-Do, South Korea) for 1 min and then kept in ultrasonic water bath (Daihan, WUC-D10H, Seoul, South Korea) for 10 min at 40 °C. The mixture was mixed using a magnetic stirrer (IKA C-MAG HS 7, Germany) at 250 rpm for 15 min and then centrifuged (Centrifuge Multifuge X3 FR, Thermo Scientific, Heraeus, Germany) at 4 °C for 20 min at 6000 rpm. Afterwards, the clear supernatant was taken into a beaker, and then 70% methanol was added to the remaining precipitate and centrifuged once more under the same conditions. The collected supernatants were stored at -18 ºC until measured on a spectrophotometer (UV-1800, Shimadzu, Kyoto, Japan).

Total phenolic content (TPC)

TPC of muffin samples as well as the extract of HS (HS-E) were determined based on the study previously reported by Bakkalbası et al. (2015) with minor modifications. To begin with, 0.5 mL of muffin extract were mixed with 2.5 mL Folin Ciocalteu reagent (1:10 diluted with distilled water) and 2 mL of 7.5% Na_2CO_3 solution. Subsequently, the samples were kept in the dark at room temperature for half an hour. The calibration curve was generated using gallic acid solutions in the concentration range of 5-100 mg/L. Absorbance values were then read at 760 nm. The results were calculated as mg gallic acid equivalent per gram (mg GAE/g).

DPPH antioxidant activity

Modified version of DPPH antioxidant activity assay from the study of Bakkalbası et al. (2015) was applied to muffin extracts. Firstly, 0.1 mL of muffin extract and 4.9 mL of DPPH solution were mixed. After the samples were kept in the dark for half an hour, absorbance values were measured at 515 nm wavelength. Antioxidant activity values were calculated as µmol Trolox equivalent (TE)/g sample on dry matter basis.

2.6. Texture profile analysis

The procedure previously reported by Pauter et al. (2018) were applied to determine the textural properties (hardness, springiness, cohesiveness, gumminess, chewiness, resilience) of the muffins using a texture analyser (TPA, Micro Stable Systems TA.XDplus Texture Analyzer, England). For this aim, fresh muffin samples with 25 mm thickness were placed on to the instrument with a 5 kg load cell using a 35 mm diameter of a cylindrical plunger probe. The analysis were performed under following conditions: strain 40%, test speed: 1.7 mm/s and pre-test speed: 1.0 mm/s.

2.7. Sensorial attributes

After the cakes had cooled for 2 h, they were cut into two equal pieces. Eight semi-trained students from Yıldız Technical University, Faculty of Chemistry Metallurgy, Department of Food Engineering participated in the sensory analysis as panelists. Panelists rated the muffins on a scale of 1 (extremely poor) to 7 (excellent) for crust color, crumb color, pore structure, structure/texture, odor, chewiness, taste/aroma and overall acceptability. During the sensory evaluation, panelists were also offered water to neutralize the taste after each sample tasting (Topkaya & Işık, 2019).

2.8. Statistical evaluation

The findings were given as mean ± standard deviation of at least three replicates. Statistical analyses were conducted using JMP Statistical Software version 6 (SAS Institute, Cary, NC) by one-way analysis of variance (ANOVA) (Student's *t* test; $P<0.05$).

3. Results and Discussion

3.1. Crumb and crust color properties

Crumb and crust color properties, namely $L*$, $a*$, $b*$, and $\Delta E*$ values were presented in Table 2. HS-0 (70.00±1.13) possessed significantly the highest $L*$ values for crumb color than that of HS-5 (48.56±0.46) and HS-10 (44.79±0.79) ($P<0.05$). As the proportion of HS in the formulation increased, the color darkness of the crumb of the muffin samples increased significantly compared to the control samples due to the brown color of HS ($P<0.05$). When fiber with a different sugar content was used in place of wheat flour, the non-enzymatic browning can become more apparent, which can cause this effect (Jeddou et al., 2017). Several studies, for instance Karp et al., 2017, Hassan et al., 2019, Heo et al., 2019, Marchetti et al., 2018, Marchetti et al., 2021, and Vo et al., 2023 had been reported similar findings in accordance with our findings. Moreover, when $a*$ values of crumb color were compared within each other, it was determined that HS-10 significantly showed highest $a*$ value of 6.97±0.09, followed by HS-5 (5.68±0.08) and lastly HS-0 with $a*$ value of -0.26±0.04 ($P<0.05$). $a*$ value measured for HS-0 showed the greenness of the samples, however, $a*$ value belonging to the HS-5 and HS-10 indicated that crumb color of muffins shifted towards red. These results were in line with previous research examining muffins fortified with coffee ground residual water extracts and powder (Kim et al., 2016).

Regarding the $b*$ values of crumb color, the HS-0 significantly had the highest $b*$ value (27.30±1.78), followed by HS-5 (14.85±0.27), and HS-10 (12.49±0.40), respectively ($P<0.05$). The highest yellowness was observed in the crumb of reference samples, however incorporation of HS led to decrease of the yellowness in muffin samples, which was in line with the findings of Karp et al. (2017) and Marchetti et al. (2021). Furthermore, $\Delta E*$ values for HS-5, and HS-10 regarding to crust color were determined as 25.49 and 30.12, respectively compared to the HS-0, showing that the differences can be detectable by human eyes due to *ΔE*>3 when compared to HS-0 as previously reported by Yavuz et al. (2022), Akman et al. (2023) and Atlar et al. (2024).

Table 2. Crumb and crust color properties of HS-0, HS-5 and HS-10 muffins

Coded samples	*L**	*a**	*b**	*ΔE**
	Crumb color properties of muffins			
HS-0	70.00±1.13[a]	-0.26±0.04[c]	27.30±1.78[a]	0.00
HS-5	48.56±0.46[b]	5.68±0.08[b]	14.85±0.27[b]	25.49
HS-10	44.79±0.79[c]	6.97±0.09[a]	12.49±0.40[c]	30.12
	Crust color properties of muffins			
HS-0	51.53±0.38[a]	14.30±0.31[a]	30.65±1.18[a]	0.00
HS-5	46.07±1.08[b]	8.39±0.24[c]	20.68±0.86[b]	12.81
HS-10	44.00±0.67[c]	8.59±0.09[b]	17.17±0.52[c]	16.46

[a,b,c]: Means with different letters in the same column are significantly different (P<0.05). HS-0: The muffin samples without hazelnut shell; HS-5: The muffin samples including 5% substitution of hazelnut shell; HS-10: The muffin samples including 10% substitution of hazelnut shell.

The following order was observed from low to high in terms of *L** values of crust color among muffin samples: HS-10 (44.00±0.67) <HS-5 (46.07±1.08) <HS-0 (51.53±0.38), indicating that enrichment of the muffins with HS led to a significant decrease in crust lightness (P<0.05). Additionally, the *a** values of crust color showed the following trend: HS-5 (8.39±0.24) < HS-10 (8.59±0.09) < HS-0 (14.30±0.31). Moreover, as the level of HS addition increased from 0% to 10%, the *b** value of the crust color decreased significantly from 30.65±1.18 to 17.17±0.52, indicating that incorporation of HS in the muffins led to a reduction in the measured degree of yellowness (P<0.05). Likewise, kimchi by-product powder replacement into the muffins led to the reduction in *L**, *a** and *b** values compared to the control samples (Heo et al., 2019). Similar observations were also made by Marchetti et al. (2018) who reported that fortification of muffin samples with pecan nut expeller meal resulted a higher darkness and redness and less yellowness compared to the control samples. In addition, the Δ*E** value compared to the reference sample was 12.81 for HS-5 and 16.46 for HS-10. The results showed that color differences can be obtained by eye, similar to the Δ*E** findings for crumb color. Considering all the results, we can conclude that both the resulting crumb and crust color characteristics of the muffins depended on the HS/wheat flour ratio in the formulation used.

3.2. TPC and DPPH radical scavenging activity

Hazelnut shells are good source of bioactive compounds such as coumaroyl acid, feruloylquinic acid, galloylquinic acid, methyl gallat, myricetin, naringin, quinic acid, quercetin 3-rhamnoside, taxifolin, vanillin, and veratric acid (Zhao et al., 2023). The analysis results demonstrated that TPC was not significantly different (P>0.05) in HS-0 (0.22 mg GAE/g), HS-5 (0.23 mg GAE/g) and HS-10 (0.22 mg GAE/g) muffin samples (Table 3), but significantly higher TPC findings were determined in HS-E (0.40 mg GAE/g) (P<0.05). Di Michele et al. (2021) reported the TPC of hazelnut shell extracts in the range of 1.34-4.66 mg/GAE g depending on different extraction method and parameters. Souza et al. (2022) reported the addition of cocoa shell powder decreased TPC values in cakes from 124 to 92 mg GAE/100 g up to 75% level, while 100% replacement caused an increase in TPC (96 mg GAE/100 g).

HS-E (0.08 mg TEAC/g) possessed the greatest DPPH antioxidant activity than that of HS-0 (0.03 mg TEAC/g), HS-5 (0.04 mg TEAC/g), and HS-10 (0.02 mg TEAC/g). The results showed that the DPPH radical scavenging activities of hazelnut shell extracts were lower than Di Michele et al. (2021) who noted the DPPH radical scavenging activities of hazelnut shell extracts in the range of 1.22-4.37 mg TEAC/g depending on different extraction method and parameters. The analysis results revealed that incorporation of HS into the muffin samples had no significant effect on the DPPH antioxidant activity (P>0.05). Souza et al. (2022) reported a decrease in DPPH antioxidant activity of muffins from 484 to 62 g sample/g DPPH with incorporation of cocoa shell powder level rose from 0 to 100%. However, Marchetti et al. (2021) reported 4 or 5 times higher DPPH antioxidant activity in enriched muffins compared to the reference muffins. Not all phenolic compounds exhibit identical antioxidant activity; some demonstrate strong antioxidative properties while others are comparatively weaker. Additionally, these compounds can interact in either antagonistic or synergistic ways with each other or with other constituents present in extracts (Zieliński & Kozłowska, 2000). Moreover, diverse extraction solvents, temperatures, and durations can lead to differing outcomes regarding the TPC and antioxidant activity (Addai et al., 2013).

Table 3. Some bioactive properties of HS-0, HS-5 and HS-10 muffins as well as HS-E.

Coded Samples	TPC (mg GAE/g)	DPPH radical scavenging activity (mg TEAC/g)
HS-0	0.22±0.01[a]	0.03±0.02[a]
HS-5	0.23±0.00[a]	0.04±0.01[a]
HS-10	0.22±0.00[a]	0.02±0.01[a]
HS-E	0.40±0.00[b]	0.08±0.01[a]

Control: The muffin samples without hazelnut shell; HS-5: The muffin samples including 5% substitution of hazelnut shell; HS-10: The muffin samples including 10% substitution of hazelnut shell; HS-E: the extract of hazelnut shell powder; TE: Trolox Equivalents; GAE: Gallic Acid Equivalents.

3.3. Textural properties

Internal structure properties of the muffin samples were evaluated using the hardness, springiness, cohesiveness, gumminess, chewiness, and resilience given in Table 4. The findings showed that HS-0 had the greatest hardness values (32.14 N). This was followed by HS-5 (21.69 N) and HS-10 (9.79 N), respectively, indicating that the higher the proportion of HS in the muffin formulation, the softer the texture in the fortificated specimens. Moreover, this decrease in hardness values can be related to the higher specific volume or fiber content of the supplemented muffin samples compared to the reference samples (Dhen et al., 2016). The results obtained in terms of hardness were similar to those reported by Marchetti et al. (2018), Jia et al. (2008), Bakkalbası et al. (2015) and Marchetti et al. (2021). Conversely, Heo et al. (2019) reported an increase in the hardness values with the incorporation of kimchi by-product powder into the muffins in comparison to the reference samples.

HS-0, HS-5, and HS-10 did not exhibit any significant differences in their springiness values (P>0.05), which ranged between 0.85-0.89 g. Similar trend was also observed by Huang & Jang (2019). However, adverse trends in terms of springiness and resilience had been reported by Heo et al. (2019) with the addition of kimchi by-product powder to muffin samples.

Table 4. Textural properties of HS-0, HS-5 and HS-10 muffins

Coded Samples	Hardness (N)	Springiness (%)	Cohesiveness	Gumminess (N)	Chewiness (N)	Resilience
HS-0	32.14±0.19^{a}	0.85±0.03^{a}	0.46±0.03^{b}	14.83±1.20^{a}	12.55±1.14^{a}	0.19±0.00^{a}
HS-5	21.69±0.17^{b}	0.87±0.03^{a}	0.54±0.01^{b}	11.34±0.90^{b}	9.90±0.83^{b}	0.24±0.00^{a}
HS-10	9.74±0.19^{c}	0.89±0.01^{a}	0.74±0.02^{a}	7.17±1.12^{c}	6.40±0.92^{c}	0.38±0.00^{a}

^{a,b,c}: Means with different letters in the same column are significantly different (P<0.05). HS-0: The muffin samples without hazelnut shell; HS-5: The muffin samples including 5% substitution of hazelnut shell; HS-10: The muffin samples including 10% substitution of hazelnut shell.

Table 5. Sensory properties of HS-0, HS-5 and HS-10 muffins

Coded Samples	Crust color	Crumb color	Structure/ Texture	Odor	Chewiness	Taste/ Aroma	Overall acceptability	Crust color
HS-0	5.0±0.93^{a}	4.8±0.71^{b}	4.4±0.52^{c}	5.1±0.35^{c}	5.0±0.76^{c}	4.4±0.52^{c}	4.9 ± 0.83^{c}	5.0±0.93^{a}
HS-5	5.6±0.74^{a}	5.1±0.99^{a}	5.5±0.93^{b}	5.4±0.74^{b}	6.0±0.76^{a}	6.0±0.76^{a}	5.9 ± 0.64^{a}	5.6±0.74^{a}
HS-10	5.4±0.74^{a}	5.1±0.83^{a}	6.1±0.64^{a}	5.8±0.46^{a}	5.8±0.71^{b}	5.9±0.64^{b}	5.8 ± 0.46^{b}	5.4±0.74^{a}

^{a,b,c}: Means with different letters in the same column are significantly different (P<0.05). HS-0: The muffin samples without hazelnut shell; HS-5: The muffin samples including 5% substitution of hazelnut shell; HS-10: The muffin samples including 10% substitution of hazelnut shell.

HS-10 (0.74) possessed significantly the highest cohesiveness than that of HS-0 (0.46) and HS-5 (0.54) (P<0.05), showing that HS makes muffins less tended to the disintegration (Souza et al., 2022). Such decrease in chewiness and hardness values with the incorporation of HS can probably be a result of the oil content of HS as in reported by Goswami et al. (2015). Demirbaş & Akdeniz (2001) reported the fat content of hazelnut shell as 1.4% and 3.2% on wet and dry basis, respectively. This probably resulted in more cohesive and softer muffin samples as previously reported by Marchetti et al. (2018).

In the TPC instrument, 14.83, 11.34 and 7.17 N gumminess values were determined for muffins containing 0%, 5% and 10% HS, respectively. There were statistical differences between gumminess results (P<0.05). In a related work, tomato processing residues supplementation into the muffin samples resulted in a decrease in hardness, gumminess and an increase in springiness, cohesiveness (Mehta et al., 2018).

The chewiness values of the muffin samples ranged from 6.40 to 12.55 N, with the highest chewiness value measured in the HS-0, probably due to water absorption with increasing fiber concentration as a result of increasing HS content in the muffin formulation (Heo et al., 2019). Furthermore, chewiness values also followed similar trend in line with the hardness values. Previously, hardness and chewiness were reported to be inversely related to cake quality (Huang & Yang, 2019). Therefore, in terms of the hardness and chewiness values, we can say that the addition of HS in the formulation at 5% and 10% (w:w) ratios positively affected the cake quality.

The resilience value was positively related with the consumer acceptance of a new product. The highest resilience value was measured in muffin formulation containing 10% HS (0.38), while the lowest value was in the reference muffin samples (0.19). The muffins containing 5% HS had an average resilience value (0.24), however, there was no statistical differences between resilience findings (P>0.05). Overall, the increase in HS content in the formulation exhibited positive effect on texture properties and led to a softer texture.

3.4. Sensory evaluation

Sensory evaluation of cake quality is largely based on subjective qualitative assessment and personal judgment. The results are not always accurate, but they can be taken into account for customer preferences (Jeddou et al., 2017). The photograph images of muffin samples from different angles were given in Figure 2.

Figure 2. Photograph images of muffin samples from different angles (HS-0: The muffin samples without hazelnut shell; HS-5: The muffin samples including 5% substitution of hazelnut shell; HS-10: The muffin samples including 10% substitution of hazelnut shell).

The sensory evaluation parameter scores given by panelists for HS-0, HS-5 and HS-10 including the crust color, crumb color, structure/texture, odor, chewiness, taste/aroma, and overall acceptability were presented in Table 5. The crust color scores of muffin samples indicated a random variation between 5.0 and 5.6, which were statistically non-significant (P>0.05). Regarding to crumb color findings, the panelists gave scores in the range of 4.8-5.1. Interestingly, the panelists did not identify crumb color differences between HS-5 and HS-10. Both crumb and crust color scores showed that darker samples were more desirable, but there was no statistically significant differences between crust colors (P>0.05). Moreover, for the parameter of structure/texture, there were significant differences between the three different muffin specimens: HS-0 = 4.4, HS-5 = 5.5 and HS-10 = 6.1 (P<0.05). The increase in chewiness and structure/texture parameter scores in muffins was thought to result from a decrease in hardness values obtained from TPA analysis. This suggested that panelists gave higher scores to softer muffin samples, as reported by Marchetti et al. (2018). Therefore, to obtain higher scores for control samples, more milk and sunflower oil can be added to the formulation (Goswami et al., 2015). Similar findings were also reported in muffins incorporated with pecan nut expeller meal by Marchetti et al. (2018), and they noted that darker crumb and softer texture were the most preferred by panelists. Additionally, the odor scores of muffins were between 5.1 and 5.8, which improved in both HS-5 and HS-10 samples. The HS-5 and HS-10 formulation was rated at almost the same level of acceptance by the panelists, but the reference muffins were the least accepted samples. Following the above-mentioned conclusions, we can say that the incorporation of HS in muffins resulted in uniform appearance, better odor, chewiness and taste/flavor, and improved the overall acceptability by the panelists.

4. Conclusions

Incorporation of hazelnut shell, a by-product in the food industry, into the food formulations allows it to be transformed into a value-added product, increasing the possibilities of its use as a functional ingredient and contributing to the sustainability of the production chain. In the present study, hazelnut shell (0, 5, and 10, w:w) were substituted with wheat flour in order to produce functional muffin samples and their color, some bioactive, textural, and sensory properties were evaluated. The results showed that the reference muffin samples had lighter crust and crumb color compared to the muffins with added hazelnut shell, as the higher pigment content in the enriched muffins reduced the lightness of the composite flour. Furthermore, incorporation of different ratio of hazelnut shell (0, 5, and 10, w:w) had no statistically significant effect on DPPH radical scavenging activity and total phenolic content. Moreover, the increase of hazelnut shell in the formulation resulted in a softer texture. Both satisfactory textural and sensorial scores were provided with the incorporation of hazelnut shell into the muffins. However, further researches also require to investigate the effects of hazelnut shell on the starch retrogradation properties during the storage and whether people with hazelnut allergies can consume hazelnut shells. Also, new symbiotic recipe can be generated with the use of hazelnut shell as a prebiotic source in the future studies.

References

Addai, Z. R., Abdullah, A., & Mutalib, S. A. (2013). Effect of extraction solvents on the phenolic content and antioxidant properties of two papaya cultivars. *Journal of Medicinal Plants Research*, *7*(47), 3354-3359. doi:10.5897/JMPR2013.5116

Akman, P. K., Kutlu, G., & Tornuk, F. (2023). Development and characterization of a novel sodium alginate based active film supplemented with Lactiplantibacillus plantarum postbiotic. *International Journal of Biological Macromolecules*, 244, 125240. doi:10.1016/j.ijbiomac.2023.125240

Atlar, G. C., Kutlu, G., & Tornuk, F. (2024). Design and characterization of chitosan-based films incorporated with summer savory (Satureja hortensis L.) essential oil for active packaging. *International Journal of Biological Macromolecules*, 254, 127732. doi:10.1016/j.ijbiomac.2023.127732

Bakkalbasi, E., Meral, R., & Dogan, I. S. (2015). Bioactive compounds, physical and sensory properties of cake made with walnut press-cake. *Journal of Food Quality*, *38*(6), 422-430. doi:10.1111/jfq.12169

Chochkov, R., Denkova, R., Denkova, Z., Denev, P., Vasileva, I., Dessev, T., Simitchiev, A., Nenov, V., & Slavov, A. (2022). Utilization of industrial Rosa damascena Mill. by-products and cocoa pod husks as natural preservatives in muffins. *Periodica Polytechnica Chemical Engineering, 66*(1), 157-166. doi:10.3311/PPch.18122

Demirbaş, A., & Akdeniz, F. (2001). Supercritical fluid extraction of hazelnut shell. *Energy Sources*, *23*(1), 55-62. doi:10.1080/00908310151092155

Dhen, N., Román, L., Ben Rejeb, I., Martínez, M. M., Garogouri, M., & Gómez, M. (2016). Particle size distribution of soy flour affecting the quality of enriched gluten-free cakes. *LWT - Food Science and Technology*, *66*, 179-185. doi:10.1016/j.lwt.2015.10.032

Di Michele, A., Pagano, C., Allegrini, A., Blasi, F., Cossignani, L., Raimo, E. D., Faieta, M., Oliva, E., Pittia, P, Primavilla, S., Sergi, M., Vicino, C., Ricci, M., Schirone, B., & Perioli, L. (2021). Hazelnut shells as source of active ingredients: Extracts preparation and characterization. *Molecules*, *26*(21), 6607. doi:10.3390/molecules26216607

Difonzo, G., de Gennaro, G., Pasqualone, A., & Caponio, F. (2022). Potential use of plant-based by-products and waste to improve the quality of gluten-free foods. *Journal of the Science of Food and Agriculture*, *102*(6), 2199-2211. doi:10.1002/jsfa.11702

Esposito, T., Sansone, F., Franceschelli, S., Del Gaudio, P., Picerno, P., Aquino, R. P., & Mencherini, T. (2017). Hazelnut (Corylus avellana L.) shells extract: phenolic composition, antioxidant effect and cytotoxic activity on human cancer cell lines. *International Journal of Molecular Sciences*, *18*(2), 392. doi:10.3390/ijms18020392

European Commission (2010). Preparatory study on food waste across EU 27. Final report. Bio Intelligence Service, Paris.

Galanakis, C. M. (2012). Recovery of high added-value components from food wastes: Conventional, emerging technologies and commercialized applications. *Trends in Food Science & Technology*, *26*(2), 68-87. doi:10.1016/j.tifs.2012.03.003

Goel, S., Bansal, M., Pal, P., & Prajapati, P. (2020). Fruit waste: Potential as a functional ingredient in foods. *Emerging Technologies in Food Science: Focus on the Developing World*, 95-116.

Goswami, D., Gupta, R. K., Mridula, D., Sharma, M., & Tyagi, S. K. (2015). Barnyard millet based muffins: Physical, textural and sensory properties. *LWT-Food Science and Technology*, *64*(1), 374-380. doi:10.1016/j.lwt.2015.05.060

Gönenc, S., Tanrıvermis, H., & Bülbül, M. (2006). Economic assessment of hazelnut production and the importance of supply management approaches in Turkey. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, *107*(1), 19-32.

Gustavsson J, Cederberg C, Sonesson U, Otterdijk RV, Meybeck A (2011) Global food losses and food waste. Extent, causes and prevention. Food and Agriculture Organization of the United Nations, Rome.

Gustavsson J, Cederberg C, Sonesson U, Emanuelsson A (2013) The methodology of the FAO study: ''Global Food Losses and Food Waste—extent, causes and prevention'' - FAO, 2011. SIK report No. 857. The Swedish Institute for Food and Biotechnology, Goteborg, Sweden.

Hassan, N. H. A., Zulkifli, N. A., & Ho, L. H. (2019). Physical and sensory evaluation of muffin incorporated with rubber seed (Hevea brasiliensis) flour, pumpkin (Cucurbita moschata) flour and cassava (Manihot esculenta crantz) flour. *Journal of Agrobiotechnology*, *10*(1S), 1-12.

Heo, Y., Kim, M. J., Lee, J. W., & Moon, B. (2019). Muffins enriched with dietary fiber from kimchi by-product: Baking properties, physical–chemical properties, and consumer acceptance. *Food Science & Nutrition*, *7*(5), 1778-1785. doi:10.1002/fsn3.1020

Huang, M., & Yang, H. (2019). Eucheuma powder as a partial flour replacement and its effect on the properties of sponge cake. *LWT - Food Science and Technology*, *110*, 262-268. doi:10.1016/j.lwt.2019.04.087

Jeddou, K. B., Bouaziz, F., Zouari-Ellouzi, S., Chaari, F., Ellouz-Chaabouni, S., Ellouz-Ghorbel, R., & Nouri-Ellouz, O. (2017). Improvement of texture and sensory properties of cakes by addition of potato peel powder with high level of dietary fiber and protein. *Food chemistry*, *217*, 668-677. doi:10.1016/j.foodchem.2016.08.081

Jia, C., Kim, Y. S., Huang, W., & Huang, G. (2008). Sensory and instrumental assessment of Chinese moon cake: Influences of almond flour, maltitol syrup, fat, and gums. *Food Research International*, *41*(9), 930-936. doi:10.1016/j.foodres.2007.10.006

Karp, S., Wyrwisz, J., Kurek, M. A., & Wierzbicka, A. (2017). Combined use of cocoa dietary fibre and steviol glycosides in low-calorie muffins production. *International Journal of Food Science & Technology*, *52*(4), 944-953. doi:10.1111/ijfs.13358

Kim, B. G., Park, N. Y., & Lee, S. H. (2016). Quality characteristics and antioxidative activity of muffins added with coffee ground residue water extract and powder. *Journal of the Korean Society of Food Science and Nutrition*, *45*(1), 76-83. doi:10.3746/jkfn.2016.45.1.076

Marchetti, L., Califano, A. N., & Andres, S. C. (2018). Partial replacement of wheat flour by pecan nut expeller meal on bakery products. Effect on muffins quality. *LWT - Food Science and Technology*, *95*, 85-91. doi:10.1016/j.lwt.2018.04.050

Marchetti, L., Acuña, M. S., & Andres, S. C. (2021). Effect of pecan nut expeller meal on quality characteristics of gluten-free muffins. *LWT - Food Science and Technology*, *146*, 111426. doi:10.1016/j.lwt.2021.111426

Mehta, D., Prasad, P., Sangwan, R. S., & Yadav, S. K. (2018). Tomato processing byproduct valorization in bread and muffin: Improvement in physicochemical properties and shelf life stability. *Journal of Food Science and Technology*, *55*(7), 2560-2568. doi:10.1007/s13197-018-3176-0

Mirabella, N., Castellani, V., & Sala, S. (2014). Current options for the valorization of food manufacturing waste: a review. *Journal of Cleaner Production*, 65, 28-41. doi:10.1016/j.jclepro.2013.10.051

Öztürk, G. (2023). A waste material rich in bioactive compounds: Hazelnut waste. *European Food Science and Engineering*, *4*(1), 15-25. doi:10.55147/efse.1289656

Pauter, P., Różańska, M., Wiza, P., Dworczak, S., Grobelna, N., Sarbak, P., & Kowalczewski, P. (2018). Effects of the replacement of wheat flour with cricket powder on the characteristics of muffins. *Acta Scientiarum Polonorum Technologia Alimentaria*, *17*(3), 227-233. doi:10.17306/J.AFS.2018.0570

Salihoglu, G., Salihoglu, N. K., Ucaroglu, S., & Banar, M. (2018). Food loss and waste management in Turkey. *Bioresource Technology*, 248, 88-99. doi:10.1016/j.biortech.2017.06.083

Souza, F. N. S., Vieira, S. R., Campidelli, M. L. L., Rocha, R. A. R., Rodrigues, L. M. A., Santos, P. H., Carneiro, J.D.S., Tavares, I.M.C. & de Oliveira, C. P. (2022). Impact of using cocoa bean shell powder as a substitute for wheat flour on some of chocolate cake properties. *Food Chemistry*, *381*, 132215. doi:10.1016/j.foodchem.2022.132215

Sudha, M. L., Indumathi, K., Sumanth, M. S., Rajarathnam, S., & Shashirekha, M. N. (2015). Mango pulp fibre waste: characterization and utilization as a bakery product ingredient. *Journal of Food Measurement and Characterization*, *9(3)*, 382-388. doi:10.1007/s11694-015-9246-3

Topkafa, M., Ayyildiz, H. F., & Kara, H. (2019). Hazelnut (Corylus avellana) oil. *Fruit Oils: Chemistry and Functionality*, 223-241.

Topkaya, C., & Isik, F. (2019). Effects of pomegranate peel supplementation on chemical, physical, and nutritional properties of muffin cakes. *Journal of Food Processing and Preservation*, *43*(6), e13868. doi:10.1111/jfpp.13868

Olawuyi, I. F., & Lee, W. Y. (2019). Quality and antioxidant properties of functional rice muffins enriched with shiitake mushroom and carrot pomace. *International Journal of Food Science & Technology*, *54*, 2321-2328. doi:10.1111/ijfs.14155

Xu, J., Zhang, Y., Wang, W., & Li, Y. (2020). Advanced properties of gluten-free cookies, cakes, and crackers: A review. *Trends in Food Science & Technology*, *103*, 200-213. doi:10.1016/j.tifs.2020.07.017

Vo, T. P., Tran, H. K. L., Pham, N. T., Tran, T. N., Nguyen, T. H. N., Phan, T. H., Lee, H. & Nguyen, D. Q. (2023). Application of bacterial cellulose in dietary fiber-enriched castella cake production. *CyTA-Journal of Food*, *21*(1), 321-327. doi:10.1080/19476337.2023.2199048

Yavuz, Z., Kutlu, G., & Tornuk, F. (2022). Incorporation of oleaster (Elaeagnus angustifolia L.) flour into white bread as a source of dietary fibers. *Journal of Food Processing and Preservation*, *46*(11), e17050. doi:10.1111/jfpp.17050

Zhao, J., Wang, X., Lin, H., & Lin, Z. (2023). Hazelnut and its by-products: a comprehensive review of nutrition, phytochemical profile, extraction, bioactivities and applications. *Food Chemistry*, 135576. doi:10.1016/j.foodchem.2023.135576

Zieliński, H., & Kozłowska, H. (2000). Antioxidant activity and total phenolics in selected cereal grains and their different morphological fractions. *Journal of Agricultural and Food Chemistry*, *48*(6), 2008-2016. doi:10.1021/jf990619o