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Effect of different forms of buckwheat addition on the physicochemical and sensory properties of bread

Erdi Eren[1], Murat Reis Akkaya[2]*

[1]*Gastronomy and Culinary Arts, Faculty of Art and Design, Alanya University, Antalya, Türkiye*
[2]*Food Engineering, Faculty of Engineering, Adana Alparslan Türkeş Science and Technology University, Adana, Türkiye*

**Corresponding author: erdi.eren@alanyauniversity.edu.tr*

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Abstract: This study aimed to obtain buckwheat bread by adding whole buckwheat to the white bread formulation in groat and flour form. The addition was made in different proportions (0, 10, 20, and 30%) according to the principle of substitution. Buckwheat addition, as groat, increased the bread's hardness to a great extent. Moisture analysis results indicated that the buckwheat additive can increase the water-holding capacity and may extend the shelf life, especially in flour form. The samples' antioxidant activities and phenolic content significantly increased when the addition was made as flour. All buckwheat-added samples had lower volume values than control samples. Buckwheat addition caused an increase in volatile components such as phenylethanol and benzylalcohol. As a result of sensory analysis, using buckwheat as flour and groat positively affected breadmaking. Considering the samples' nutritional and sensory properties, the combination in which 20% buckwheat flour is added to the white bread formulation is the most appropriate use.

Keywords: pseudocereals; bakery products; volatile compounds; fortified bread

Bread is made with flour, water, salt, and yeast. It is prepared by fermenting and cooking the dough after proper kneading. Bread and bread-making research is essential and quite complex in food research. The recent increase in artisan bread-making due to the pandemic has made bread research even more attractive. Consumers worldwide are increasingly aware of the relationship between food and health and are adopting more nutritious diets. Rapid developments in science and technology worldwide have caused an increase in interest in maintaining a healthy life through diet and consumption of beneficial foods for the body beyond essential nutrition (Salmeron et al. 2015). Buckwheat is an annual pseudocereal belonging to the *Polygonaceae* family and the *Fagopyrum* genus. It is mainly grown in the northern hemisphere and is a widely consumed food item worldwide (Zhu 2016). Two types of buckwheat are of agricultural importance. The first of these is *Fagopyrum esculentum* Moench, which is widely cultivated. The other is *Fagopyrum tataricum* Gaertn, also known as Tatarstan buckwheat or bitter buckwheat (Luthar et al. 2021). 62.1% of world buckwheat production is made in Europe and 29.4% in Asia (FAO 2022). Buckwheat has high ecological adaptability. It can quickly grow in harsh climates and soil conditions (Zhu 2016). Buckwheat is a relatively inexpensive plant resistant to pathological damage. Today, buckwheat is considered a pseudocereal with high nutritional value due to its high vitamin B1 and B2 content, high protein, lysine, balanced amino acid composition, flavonoids, phytosterols, and soluble carbohydrates. In addition to being a rich source of starch, polyphenols, and dietary fibre, buckwheat is taken more and more in various products every day thanks to its glu-

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ten-free structure and health benefits (Yu et al. 2018). Consumption of gluten-free products is increasing daily, and buckwheat has been recognised as a potential functional food with nutritionally valuable protein, lipids, dietary fibre, and minerals. Buckwheat also contains other components that positively impact health, such as phenolic compounds and sterols, and also presents antioxidants such as rutin, quercetin, orientin, isoorientin, vitexin, and isovitexin. While the quercetin-3-O-rutinoside (rutin) compound is not found in other pseudocereals, buckwheat contains this compound in high amounts (Lee et al. 2016). Buckwheat is also rich in resistant starch and dietary fibre. Foods containing high amounts of starch generally have a low glycemic index. Foods with low glycemic index are essential in diabetes control and blood sugar regulation (Cui et al. 2023). Glutathione, phytic acid, and melatonin were detected in buckwheat seeds, bran, and vitamins. These components positively affect buckwheat's antioxidant activity (Giménez-Bastida and Zielinski 2015). Studies on buckwheat bread have increased in recent years. Although Tartary buckwheat is chosen in nutritional studies, it is not often preferred in sensory tests due to its bitter taste.

Adding cereal-pseudocereal ingredients of different particle sizes or shapes to bakery products is a crucial way to add variety and nutritional and textural richness to products. This variety provides a richer experience for the consumer and enhances the overall gustatory value of the products. In addition, different grain shapes and sizes add nutritional value to bakery products. This method encourages product innovation in the bakery sector while providing consumers with more diverse and nutritious products. Advances in the technology of fortified foods have led to the need for more research on this topic. No comprehensive study exists in the literature in which buckwheat is added to the bread formulation in different proportions in groat and flour form. This study focuses on obtaining buckwheat-enriched bread and detecting possible changes in bread properties.

MATERIAL AND METHODS

Material

Latvian-origin commercial white wheat flour and pressed fresh yeast form of *Saccharomyces cerevisiae* were used for bread production. Common buckwheat (*F. esculentum* Moench) was used as the material obtained from a Latvian brand in Dagda. The granulated sugar and salt are taken from a chain market's branded products. An average of 25 °C tap water of drinkable quality was used. For the buckwheat bread experiments, whole buckwheat groats were ground (< 500 µm) in a laboratory-type mill (Queen 1; Hawos, Germany) to obtain a 100% yield of whole buckwheat flour.

Methods

Bread production. Bread production was made based on three different formulations: buckwheat groat (BWG), buckwheat flour (BWF), and control bread samples (C) made from 100% white bread wheat without buckwheat. The American Association of Cereal Chemists (AACC) direct bread baking method 10-10.03 (1999) was partially adapted to enriched bread making (bread formulations are shown in Table 1). The dough components were mixed in a kneader (Varimixer Bear, Denmark) for 6 min. The obtained doughs were left to pre-fermentation at 25 °C for 10 min; then, the dough was divided and shaped. Doughs placed in baking trays (13 × 25 × 6.5 cm; $w \times h \times d$) were left to proof for 45 min at 35 °C and 75% humidity using

Table 1. Bread formulations

Bread types	Bread formulation	Wheat flour (g)	Buckwheat flour (g)	Buckwheat groats (g)	Water (mL)	Yeast (g)	Salt (g)	Sugar (g)
Buckwheat flour	10% BWF	90	10	0	60	3	1.5	2
	20% BWF	80	20	0	60	3	1.5	2
	30% BWF	70	30	0	60	3	1.5	2
Buckwheat groats	10% BWG	90	0	10	10* + 50	3	1.5	2
	20% BWG	80	0	20	20* + 40	3	1.5	2
	30% BWG	70	0	30	30* + 30	3	1.5	2
Control		100	0	0	60	3	1.5	2

* Amounts of water added beforehand

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the fermentation cabinet (Sveba Dahlen, Sweden). Fermented doughs were baked in the convection oven at 200 °C for 18 min. To obtain a more uniform endosperm texture, buckwheat groats were soaked in water the night before, according to the groat ratio of the formulations. To prevent microbial contamination, groats were kept in the refrigerator at +4 °C.

Three parallels were produced for different formulations of bread types. Twenty-one loaves were obtained for a total of seven types of bread. Processes, temperatures, and equipment were kept stable for all the samples to minimise the environmental effects.

Analytical implementations. Extracts from bread samples were obtained to analyse volatile components, total phenolic substances, and antioxidant activity (Verardo et al. 2011). The extracts were stored at –18 °C until use. The total phenolic content analysis of the samples was done using the Folin-Ciocalteu method. The absorbance value of the solution was measured in a Spectrophotometer (Type 6300; Jenway, United Kingdom) at a wavelength of 765 nm against a blank reagent. The same procedures were applied to the standard solution, and the total phenolic content was expressed as gallic acid equivalents (GAE) per 100 g dry weight (Singleton and Rossi 1965). The antioxidant activity of bread samples was determined by the method of Bhebhe et al. (2015). Antioxidant activities were measured according to the radical scavenging potential of 2,2-diphenyl-1-picrylhydrazyl (DPPH), and the results were expressed as mmol Trolox equivalent per 100 g dry weight. In this study, the analysis of volatile compounds was carried out by gas chromatography-mass spectrometry (GC-MS) using the solid phase microextraction (SPME) method (Sabovics 2014). Carboxen/polydimethylsiloxane (CAR/PDMS) fibre was used in the SPME analysis. This fibre thermally absorbed volatile compounds into the GC-MS injector. The volatiles were separated in Elite-Wax (PerkinElmer, USA) capillary column (60 m × 0.25 mm, 0.25 μm). Compounds were identified according to their mass spectra by comparison with the Mass Spectral Database of the National Institute of Standards and Technology (NIST). As a quantitative measure, compounds were based on the area counts of the base peak of the mass spectrum of each compound. The average volume of bread samples was determined according to the rapeseed displacement method (AACC Method 10-05.01, 1998). Hardness analysis was performed at the end of the 0^{th}, 1^{st}, and 2^{nd} days using a texture analysis device (TA HD Plus Texture Analyser; Stable Micro Systems, United Kingdom) according to the method specified in the study of Lin et al. (2013). The texture profile curve settings were adjusted to P30C cylindrical aluminium probe (30 mm), pre-test speed 5 mm·s^{-1}, test speed 5 mm·s^{-1}, post-test velocity 5 mm·s^{-1}, and pressure distance 50%. Moisture content analysis of the samples was performed according to AACC Method 44-15A (2000) and calculated according to the Equation 1:

$$Moisture\,(\%) = \frac{A}{B} \times 100 \quad (1)$$

where: A – moisture loss (g); B – initial weight of the sample (g).

Sensory analyses were conducted by semi-trained volunteer participants (35 people, 20 women and 15 men, aged 18–50) in a sensory analysis laboratory (Sabovics et al. 2013). All panellists were food technology professionals who had training in sensory analysis. Panellists were asked to rate the fresh samples according to their colour, aroma, hardness, porosity, and buckwheat flavour characteristics on a 7-point hedonic scale, between 1 and 7 (1 – I did not like it, 7 – I liked it very much). All statistical analyses applied in this study were performed with the help of the SPSS package software (version 20) by applying one and two-way analysis of variance (ANOVA) and then the Tukey test at a 95% confidence level ($P \leq 0.05$).

RESULTS AND DISCUSSION

Total phenolic content and antioxidant capacity. As a result of the total phenolic content analysis findings, it was observed that the bread samples containing 20% buckwheat flour were the richest in terms of total phenolic content. It was determined that as the buckwheat content of the bread samples decreased, the total phenolic content decreased, and the sample with the least phenolic content was wheat bread made from 100% white flour. The same was true for the total antioxidant capacity analysis of the samples (Table 2).

As a result of the analyses made in the control bread samples, the phenolic content was found to be 43.6 mg GAE·100 g^{-1}, while it was observed that this ratio increased up to 116.2 mg GAE·100 g^{-1} in the 20% BWF bread samples. In BWG bread samples, the measurement of this ratio as 83.9 mg GAE·100 g^{-1} in the 30% formulation was interpreted as the phenolic compounds provided by the buckwheat components in the bread could be more effective in the form

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Table 2. Total phenolic content and total antioxidant capacity of bread samples

Sample		TPC (mg GAE·100 g^{-1})	TAC (mmol Trolox·100 g^{-1})
Control		43.6 ± 2.4[a]	6.86 ± 1.9[a]
BWF	10%	81.5 ± 5.4[c]	19.9 ± 3.4[bc]
	20%	116.2 ± 7.4[d]	27.2 ± 4.1[de]
	30%	112.5 ± 0.2[d]	26.2 ± 0.3[de]
BWG	10%	62.6 ± 3.3[b]	17.3 ± 0.2[b]
	20%	65.7 ± 3.8[b]	24.8 ± 1.4[cd]
	30%	83.9 ± 11.4[c]	31.6 ± 0.9[e]

[a–e] Mean values marked with the same letter in the row are not significantly different at $P < 0.05$; TPC – total phenolic content; GAE – gallic acid equivalent; TAC – total antioxidant capacity; BWF – bread with buckwheat flour; BWG – bread with buckwheat groats

of flour. According to a study, when wheat flour phenolic concentration was 55.45 mg GAE·100 g^{-1}, raw buckwheat flour had 974.74, and roasted buckwheat flour had 453 mg GAE·100 g^{-1} (Beitane et al. 2018). Lee et al. (2016) have reported that the rutin content of common and Tartary buckwheat directly increases this pseudocereal's total phenolic concentrations and antioxidant content. Thus enhancing the healthy properties of the food products prepared with it.

Antioxidant activity analyses were made with the DPPH method. As a result of the analysis, it was observed that the bread samples with the highest antioxidant activity were the samples containing 30% buckwheat groats. The findings are significant in increasing the total antioxidant content of buckwheat content. In addition, the samples with the lowest antioxidant activity, as in the total phenolic content results, were wheat bread samples (control) containing 100% white bread flour. After the bread samples containing 30% BWG, the highest total antioxidant capacity was determined in the bread samples containing 20% BWF (27.2 mmol Trolox·100 g^{-1}). Bread samples containing buckwheat were characterised by high antioxidant content compared to control samples. Świeca et al. (2019) reported that antioxidant activity increased in the bread they enriched using buckwheat in their study.

This study determined an imprecise positive correlation of 0.75 between total phenolic substance and total antioxidant capacity results. This ratio is consistent with the view that buckwheat increases the content of phenolic compounds and antioxidant substances, which are considered beneficial. A positive correlation was reported in the literature between antioxidant activity and total phenolic content (Kerienë et al. 2015). However, the results also show no significant changes in the samples containing 20% and 30% buckwheat values. This suggests that buckwheat supplementation increases total phenolic content and antioxidant activity significantly compared to the control samples but did not create significant differences between the percentiles.

Volatile compounds. As a result of volatile compound analysis, 30 different volatile compounds were detected in bread samples. 13 volatile compounds were detected in the control bread that did not contain buckwheat additives. This number increased to 17 in bread samples containing 20% BWF. It was also determined that the most striking compounds besides ethanol were benzaldehyde, phenylethanol, acetic acid, furfural, and benzylalcohol, and these compounds were present in all samples.

Among these compounds, it is known that acetic acid gives a sour aroma, furfural gives an almond-like aroma, benzaldehyde gives a caramel-like aroma, and phenylethanol gives a floral-honey flavour. In bread samples containing both flour and buckwheat groat, it was observed that benzaldehyde concentration increased in direct proportion to the percentage. The same is true for the concentration of benzaldehyde in the samples. It was observed that the benzaldehyde concentrations of the samples increased as the ratio of flour and buckwheat groat increased. While there was no significant increase in furfural and acetic acid compounds due to the addition of buckwheat, benzyl alcohol was slightly increased with the addition of buckwheat. These results can be interpreted as the unique aroma of buckwheat comes from phenylethanol and benzaldehyde compounds.

Similar compounds were detected by Prosen et al. (2009) when the same method (SPME) was used; acetic acid and benzaldehyde were found on buckwheat groats. Lin et al. (2009) reported that acetic acid was found in wheat bread but not buckwheat bread. They also reported that furfural and benzaldehyde were found in buckwheat bread but not wheat bread. Another study reported that different compounds were found in buckwheat-containing products but expressed a similar opinion on buckwheat's 'volatile compounds increasing capacity' (Starowicz et al. 2018).

Volume, moisture, and hardness analysis. As a result of the analyses made to measure the volume values, it was observed that the samples with the highest volume ratios were the control breads (Table 3). It was reported that the bread samples containing buckwheat

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Table 3. Volume analysis results

Sample		Volume (cm^3)
Control		762.6 ± 11.7[a]
BWG	10%	715.3 ± 7.6[b]
	20%	681.3 ± 10.3[c]
	30%	600.6 ± 21.9[d]
BWF	10%	731.3 ± 2.5[ab]
	20%	718.6 ± 8.0[b]
	30%	704.6 ± 4.7[bc]

[a–d] Mean values marked with the same letter in the row are not significantly different at $P < 0.05$; BWG – bread with buckwheat groats; BWF – bread with buckwheat flour

were considerably smaller in volume compared to the control samples (Sciarini et al. 2020).

While the volume results were 762.6 cm^3 in the control samples without buckwheat, it was seen that the volume value of the sample containing 30% BWF decreased to 704.6 cm^3. The volume value of the bread sample containing 30% BWG was found to be 600.6 cm^3. In previous studies, buckwheat flour addition was detected to have adverse effects on the volume of bread samples, affirming the results found in this study (Mohajan et al. 2019; Cotovanu et al. 2022). The main reason for these results is that buckwheat is a gluten-free pseudocereal, and that causes gluten deformation on samples.

Hardness is an essential characteristic of bread quality, and change in hardness is often accompanied by loss of elasticity during storage. In conclusion, it was determined that the hardness of the samples increased significantly after 24, 48, and 72 hours of storage at 25 °C (Figure 1). All samples reached the highest hardness values at the end of 72 hours. At the end of the 24th, 48th, and 72nd hour, the lowest hardness value was reached in the control bread, and the highest values were found in the bread containing 30% buckwheat groats.

It was reported that buckwheat flour substitution increased the hardness values by adding buckwheat flour to white wheat flour at different rates. In the same study, the researchers observed that the hardness values decreased as the amount of water in the bread formulation increased (Sciarini et al. 2020).

The hardness results conducted within this study's scope revealed that the addition of buckwheat increased firmness. The hardness of the bread samples increased in direct proportion with the increase in the buckwheat ratio in the formulation. It has been observed that these structural changes, which potentially cause undesirable results in sensory properties, are more pronounced when buckwheat is added as groats than when it is added as flour. It has also been observed that the buckwheat content, in the form of whole groat and flour, gives hardness to the bread samples due to the rigid structure of buckwheat (Lin et al. 2013). Cotovanu et al. (2022) reported that adding buckwheat flour increases bread hardness, which conforms with the results of this paper. The results also show that samples containing buckwheat are more resistant to staling. Wang et al. (2023) reported that

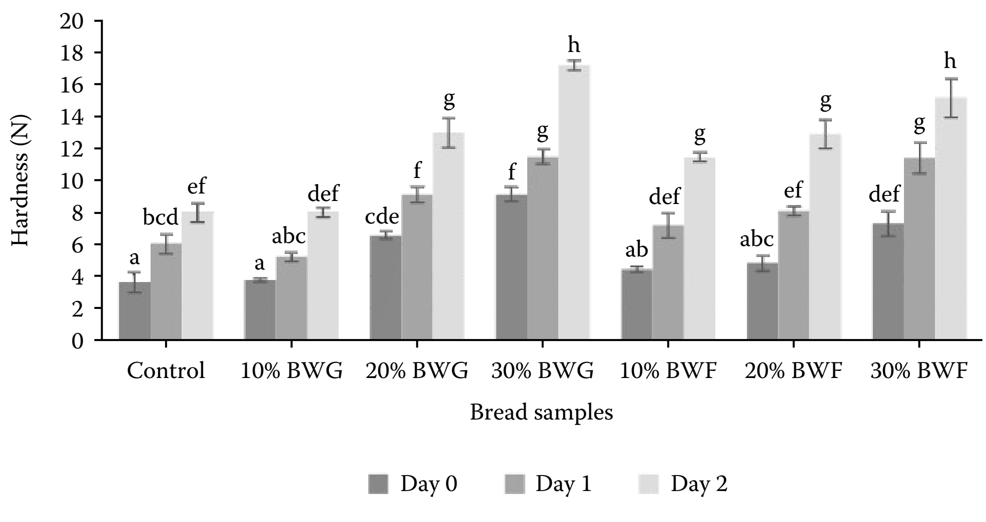

Figure 1. Hardness analysis results

a–h – mean values marked with the same letter in the row are not significantly different at $P < 0.05$; BWF – bread with buckwheat flour; BWG – bread with buckwheat groats

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buckwheat hulls can act against staling thanks to their water-binding properties. Staling indications such as crust softening and crumb firming were reduced by the insoluble fibre content provided by the whole buckwheat used in this study.

Moisture analysis findings agree with the hardness analysis of the samples, which showed that the hardness gradually increased daily. It was also observed that samples containing buckwheat flour had better water-holding capacity than those containing buckwheat grains. Mohajan et al. (2019) observed that buckwheat content caused a decrease in the moisture content of bread samples in their study. Similar results were also reported by Lin et al. (2013). The study revealed that the moisture contents of bread samples with and without buckwheat additives were lower than the control samples. The results are significant in terms of the findings of Kumari and Raghuvanshi (2015), which showed that buckwheat starch is effective in water holding/absorption capacity.

As a result of the analysis, the highest moisture content value was reached in bread samples containing 10% BWF in the fresh state. Bread samples containing 10% BWF, which had 43.9% moisture content on day 0, decreased to 42.2% moisture content at the end of day 1. It can be inferred that the water-holding capacity of BWF-containing bread samples, which were observed to be more consistent in terms of moisture loss than BWG-containing bread samples, was high. The higher water-holding capacity of BWF bread than BWG bread can be considered that small flour particles increase the water-holding capacity by holding water molecules better.

Sensory analysis. The sensory evaluations made within the scope of this study were made by 35 semi-trained participants, all of whom were of Latvian origin.

The results agree with the conclusions made by Beitane et al. (2018). All samples containing buckwheat outperformed control samples in sensory evaluations (Figure 2). Bread samples containing 30% BWG and BWF received the highest scores in colour evaluations. Bread samples containing 30% BWG and BWF were more prominent in the flavour evaluations of the bread. Another study emphasised that breads containing buckwheat got more positive scores than control breads regarding taste and aroma after swallowing (Lin et al. 2009). The hardness evaluations showed an excellent agreement with the hardness tests made within this study. The sensory analyses confirmed that the bread samples' hardness values increased as the buckwheat content increased. According to the results of the porosity tests, a clear inference could not be made from the buckwheat ratios. However, the bread samples containing buckwheat received more positive evaluations in the porosity tests than the control bread. Finally, as expected in the buckwheat flavour evaluations, the panellists revealed that the buckwheat flavour increased as the buckwheat content ratio increased. According to Drobot et al. (2014), buckwheat addition as groats improved the sensory properties of bread samples, while buckwheat flour addition resulted in lower scores. These results match the sensory properties of buckwheat bread samples of this study.

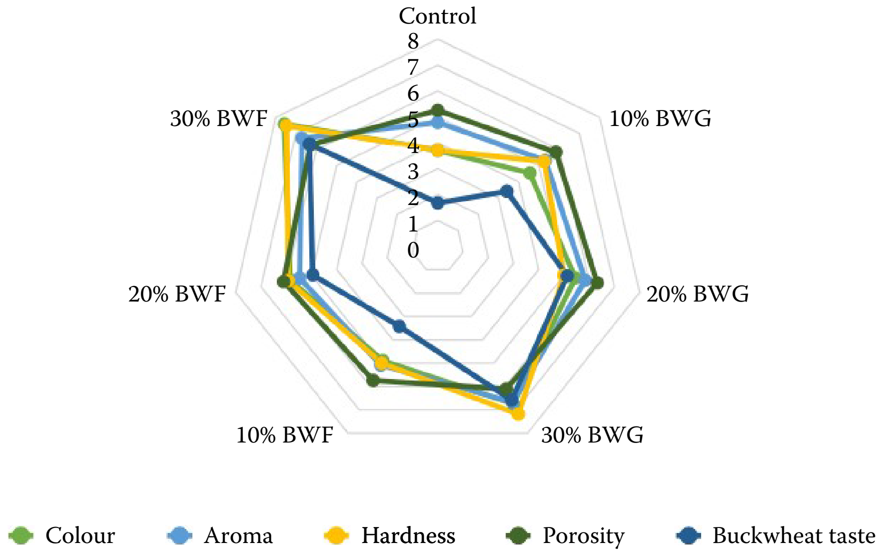

Figure 2. Web chart of sensory analysis results

BWF – bread with buckwheat flour; BWG – bread with buckwheat groats

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CONCLUSION

This study aimed to obtain enriched bread by adding buckwheat as flour and groats to the bread formulation in different proportions. As a result of the study, it was seen that the content of buckwheat, both in groat and flour, increased the antioxidant activity of the samples and the total amount of phenolic compounds. In line with these results, it was concluded that using buckwheat, which contains flavonol glycosides with antioxidant effects such as rutin, which is known to have healthy effects, can be entirely appropriate and beneficial for health in the production of classic white bread.

As a result of the volatile compounds analyses made in GC-MS within the scope of this study, 30 different volatile compounds were found in the bread samples. Apart from the ethanol used for the extraction, the most striking compounds are benzaldehyde, phenylethanol, acetic acid, furfural, and benzylalcohol, and these compounds were determined to be present in all samples. Benzaldehyde, which gives caramel flavour with a concentration in control bread, increased directly to the concentration in bread containing buckwheat. A similar situation was observed in the phenylethanol compound, which gives a flower-honey flavour. This compound, detected in low amounts in control bread samples, was found in high amounts in buckwheat samples, again in direct proportion to the concentration. While there was no significant increase in furfural and acetic acid compounds due to the addition of buckwheat, benzylalcohol increased slightly with the addition. These results may indicate that the unique aroma of buckwheat comes from phenylethanol and benzaldehyde compounds. Even though the decrease of volume values and increase of hardness on bread samples with buckwheat addition are unwanted, these results do not cause considerable differences in the sensory qualities of bread, as seen on sensory analysis. In addition, moisture analysis results indicate that the buckwheat additive can increase the water-holding capacity and extend the shelf life. As a result of this study, 20% buckwheat flour substitution was the proper formulation, nutrition, and flavour-wise.

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