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Evaluation of Production and Quality of Boiled Simit Enriched with Wheat Germ, a By-Product of Wheat Milling

Buğday Değirmenciliği Yan Ürünü Olan Buğday Rüşeymi ile Zenginleştirilmiş Kazan Simidinin Üretimi ve Kalitesinin Değerlendirilmesi

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ABSTRACT

Wheat germ (WG), a nutrient-rich by-product obtained during the wheat milling process, is recognized as a valuable ingredient due to its high content of essential vitamins, minerals, and natural antioxidants, and was utilized in this study to enhance the functional and nutritional properties of boiled simit (BS). BS is a traditional Turkish ring-shaped bakery product covered in sesame seeds. WG has limited utility due to an important risk of rancidity, which was minimized with the application of heat treatment. Heat stabilized wheat germ flour (HSWGF) was substituted with wheat flour at four different ratios (0%, 10%, 20% and 30%) and used in BS production. The BSs were evaluated in terms of their chemical (moisture, protein, ash, and total dietary fiber contents), physical (weight, dimensions, and color), and textural (hardness, springiness, and cohesiveness) properties. The moisture, ash, protein, and dietary fibre contents, as well as the weight of BS, increased proportionally with the HSWGF replacement ratio, and these increases were statistically significant ($p < 0.05$). The wall thickness and height of BS increased up to the 20% substitution level of HSWGF and then decreased. As the level of HSWGF supplementation increased, the redness (a^*) value significantly increased, while the brightness (L^*) value decreased, as determined using a color-measuring instrument and expressed in the CIE L^*, a^*, b^* color space. Furthermore, the substitution of HSWGF resulted in a notable increment in the hardness measurements of the BSs. Sensory analysis found BSs with 20% HSWGF replacement to be more favourably accepted. The study concluded that by replacing up to 20% of wheat flour with HSWGF, it is possible to produce a BS that has enhanced functional characteristics while maintaining acceptable technological and sensory attributes.

Keywords: Functional food; Heat-stabilization; Traditional; Bakery

ÖZET

Buğday ruşeymi (WG), buğday öğütme süreci sırasında elde edilen besin açısından zengin bir yan ürün olup, temel vitaminler, mineraller ve doğal antioksidanlar bakımından yüksek içeriği nedeniyle değerli bir bileşen olarak kabul edilmektedir ve bu çalışmada haşlanmış simidin (BS) fonksiyonel ve besinsel özelliklerini geliştirmek amacıyla kullanılmıştır. BS, susamla kaplanmış, geleneksel Türk halkası şeklinde bir unlu mamuldür. WG'nin önemli ölçüde acılaşma (ransidite) riski nedeniyle kullanım alanı sınırlıdır; bu risk ısıl işlem uygulanarak azaltılmıştır. Isıl işlemle stabilize edilmiş buğday rüşeymi unu (HSWGF), buğday ununun yerine dört farklı oranda (%0, %10, %20 ve %30) ikame edilerek BS üretiminde kullanılmıştır. BS'ler kimyasal, fiziksel, tekstürel ve duyusal özellikler açısından değerlendirilmiştir. HSWGF ikame oranının artmasıyla birlikte BS'nin nem, kül, protein ve diyet lif içerikleri ile ağırlığında orantılı artışlar meydana gelmiş ve bu artışlar istatistiksel olarak anlamlı bulunmuştur ($p < 0.05$). BS'nin duvar kalınlığı ve yüksekliği %20 ikame seviyesine kadar artmış, bu seviyeden sonra azalma göstermiştir. HSWGF ilave oranı arttıkça kırmızılık (a^*) değeri anlamlı biçimde artarken, açıklık (L^*) değeri azalma göstermiştir; bu değerler bir renk ölçüm cihazı ile belirlenmiş ve CIE L^*, a^*, b^* renk uzayı cinsinden ifade edilmiştir. Ayrıca, HSWGF kullanımı BS'nin sertlik değerlerinde belirgin bir artışa yol açmıştır. Duyusal analizler, %20 HSWGF ikamesiyle üretilen BS'nin daha yüksek kabul gördüğünü ortaya koymuştur. Çalışma, buğday ununun %20'sine kadar HSWGF ikame edilerek hem fonksiyonel özellikleri geliştirilmiş hem de teknolojik ve duyusal açıdan kabul edilebilir özelliklere sahip BS üretilebileceğini göstermiştir.

Anahtar Kelimeler: Fonksiyonel gıda; Isıl stabilizasyon; Geleneksel ürün; Unlu mamuller

1. INTRODUCTION

Wheat grains are made up of endosperm, WG and bran. WG, which contains 3% of the wheat, is rich in wheat germ oil, water-soluble protein, carbohydrates, vitamin E, and enzymes (Demir et al., 2019; Öney et al., 2020). Wheat grains are composed of endosperm, bran, and germ. The germ typically accounts for about 2–3% of the kernel and is rich in lipids, proteins, vitamin E, and other bioactives (Marzocchi et al., 2022). Importantly, both the composition and the recoverable yield of wheat germ vary with wheat variety and kernel size, and are strongly influenced by the milling/separation and extraction methods applied (Boukid et al., 2018).

Wheat germ contains approximately 26–35% protein, 17% sugar, 10–15% wheat germ oil, 1.5–4.5% fiber, and 4% mineral substances, with the values reported on both wet and dry weight bases (Attia and Abou-Gharbia, 2011; Demir et al., 2021; Liu et al., 2022). WG is an cost-effective source of plant protein, and the bioavailability of its protein is high and comparable to that of egg protein, which is called a complete protein (Mahmoud et al., 2023).

Sucrose is the predominant soluble sugar in wheat germ, accounting for about 56% of the total soluble sugars, followed by raffinose (approximately 38%) and minor amounts of glucose and fructose (Linko et al., 1960). Along with pantothenic acid, thiamine, riboflavin, niacin, and folic acid, wheat germ also contains a significant amount of vitamin E, as well as minerals such as potassium, phosphorus, magnesium, sodium, and calcium (Hadjadj et al., 2025).

Essential fatty acids, also known as vitamin F, constitute an important part of the fatty acids found in WG. Polyunsaturated fatty acids in WG-oil account for about 80% of total triglycerides. Linoleic acid accounts for only 42-59% of the polyunsaturated fats in WG-oil. The most common saturated fatty acid in WG-oil is palmitic acid, which accounts for 73.5% (Türker and Elgün, 1998; Brandolini and Hidalgo, 2012; Liu et al., 2024).

Depending on the wheat variety, storage, growth, and extraction conditions, the total WG-oil concentration may change. WG-oil contains high levels of the antioxidants tocopherol (1300-2700 mg/kg) and carotenoid (56 mg/kg). Because of its phenolic content, WG-oil decreases the effects of aging, lowers cholesterol, and prevents tumor growth (Brandolini and Hidalgo, 2012).

Because of its high amounts of protein, fat, sugar, vitamins, and minerals, as well as phenolic components, WG has the quality of being a functional food. All these nutritional benefits have made WG widely used in various food industries, including cereal products, dairy products, meat products and beverages (Brandolini and Hidalgo, 2012; Boukid et al., 2018;

Mehanna et al., 2020; Gül et al., 2018; Hassanzadeh et al., 2022; Teterycz et al., 2023). However, the presence of the high concentration of oxidative and hydrolytic enzymes in WG, when it is added to flour, the quality of the flour is negatively affected and a rancid taste occurs. The bioavailability of minerals is decreased by phytic acid in WG, and raffinose can cause discomfort like gas compression in the stomach and intestines (Demir et al., 2019). Lipase, which shows significant activity in WG, must be inactivated in order to eliminate these disadvantages that limit storage time and increase the product's shelf life. Heat treatment is used in industry to provide enzyme inactivation (Haridas Rao et al., 1980). Stabilization techniques used today include autoclaving, roasting, dry heating, microwave applications, infrared heating, radiofrequency, and antioxidant treatment (Kahveci and Özkaya, 1991; Xu et al., 2013; Gili et al., 2017). Arslan et al. (2020) reported that in the industry, thermal stabilization of WG using a low-power microwave (180 instead of 360 W) and oven heating at a lower temperature (90 instead of 160 °C) would be preferable.

Given its rich nutritional profile and functional attributes, wheat germ has the potential to improve the quality and functionality of traditional cereal-based products such as simit. Simit is a traditional bakery product that is produced in a variety of methods in different regions of Türkiye and consumed with a great love. In the 1590s, the simit, which derives from the Arabic term "samid" for refined white flour, was first mentioned with its current meaning. Although simit production, which is influenced by culture and geography, varies regionally, it is generally regarded as a product with its own flavor and aroma. Wheat flour, drinking water, yeast, salt, and other ingredients, depending on the variety, are used for simit making (Özbay, 2020; Acun and Gül, 2022). Due to its high nutritional value, simit is also consumed as a meal by various age and income groups, primarily for breakfast (Öney et al., 2020). According to Başlar et al. (2023), 5.1% of the Turkish population consumes simit daily, 46.4% at least once a week, and 64.7% at least once a month, indicating its strong market presence and cultural importance in Turkish dietary habits. In addition to regional differences, there are also methodological distinctions in simit production. There are essentially three varieties of simit production: the "taban simit," which is thrown into the oven and baked like bread, the "pan simit," which is cooked in pans, and the "BS," which has a bright appearance and less sesame (Acun and Gül, 2022).

In this study, boiled simit (BS), which is widely produced in Türkiye, was enriched with wheat germ (WG). For this purpose, WG was stabilized in the oven, ground, and used in BS

production at different substitution levels. The aim of this study was to increase the nutritive value and aroma of BS.

2. MATERIALS AND METHODS

2.1 Materials

Special purpose wheat flour (Hediye Flour Factory, Isparta, Türkiye), fresh yeast (Pakmaya, Türkiye), sesame seeds (Bağdat Baharat, Türkiye), granulated sugar and grape molasses (Torku, Konya, Türkiye), and salt (Billur Tuz, Türkiye) used in the production of BS were purchased from local markets in Isparta, Türkiye. WG of the *Triticum aestivum L.* variety was freshly obtained from Hediye Flour Factory (Isparta, Türkiye) immediately after milling.

2.2 Methods

2.2.1 *Preparation of WG*

Fresh wheat germ was obtained from the factory on the day of production and brought to the laboratory. The initial moisture content of the wheat germ was approximately 12%. It was stabilized by oven roasting to reduce enzyme activity, following the parameters described by Gül et al. (2018), at 130 °C for 20 minutes. The stabilized samples were ground using a hammer mill (Tekpa, Ankara), and the grinding process was performed under temperature-controlled conditions to prevent overheating. The ground HSWGF was sieved, and the fraction with a particle size below 200 µm was used in the production of BS.

2.2.2 *Production of BS*

The production of BS is derived from the methodologies utilized by a traditional BS manufacturer (Güneştepe Bakery Products Industry and Trade. Inc., Isparta) located in Isparta, Türkiye. The formulation, components, ratios, and methodologies have been applied with some modifications. The production of simit involved the use of one kilogram of flour mixed with 20 grams of salt and 30 grams of yeast. The quantity of water was determined by farinograph for each HSWGF addition level separately. HSWGF was replaced with simit flour at 10%, 20% and 30%.



a) b) c) d) e) f)

Figure 1. Production stages of BS

During the production of the BS, wheat flour, yeast, and 600 mL of water per 1 kg of flour were transferred to the spiral shaft kneader (Günsa, İzmir) and subjected to kneading for 9 minutes (Fig. 1a). Kneading time was determined by preliminary experiments. In the second minute of kneading, 20 g of salt dissolved in the remaining water was added. After the kneading process was completed, the dough was formed into equal pieces of 110 grams each and shaped into round simits by hand (Fig. 1b). The shaped doughs were placed in the boiling molasses + water mixture (600 ml grape molasses + 300 ml water) and kept in this mixture for 30 seconds. (Fig. 1c). After the boiled simits were taken out of the mixture were coated with sesame seeds (Fig. 1d), they were given their final shapes by hand, and placed on a baking tray (Fig. 1e). Then they were baked in a stone-based oven (Enkomak, Antalya, Türkiye) at 270°C for 8 minutes (Fig. 1f). BS produced in this way and containing no HSWGF were referred to as control samples. The production of BS's with HSWGF was carried out by adding 10%, 20% and 30% HSWGF according to the principle of substitution with 100% wheat flour and applying the same method.

2.2.3 *Analysis of wheat flour and HSWGF*

Moisture (AACC Method 44-01.01, AACC, 2000), ash (AACC Method 08-01.01, AACC, 2000), Zeleny and delayed Zeleny sedimentation (AACC Method 56-60.01, AACC, 2000; Greenaway et al., 1965), wet and dry gluten, gluten index (AACC, 2000), and amylase activity (falling number, AACC Method 56-81.03, AACC, 2000) were analyzed in wheat flour. For HSWGF, only moisture (AACC Method 44-01.01, AACC, 2000) and ash (AACC Method 08-01.01, AACC, 2000) were determined. All analyses were performed in triplicate, and the results were expressed as mean values.

2.3 Chemical analysis of BS

Moisture (AACC Method, 44-01.01), protein (AACC Method, 950.36), ash (AACC Method, 08-01.01), and total dietary fiber (AACC Method, 32-07.01) content of BSs were determined according to the appropriate AACC methods (AACC, 2000).

2.4 Physical analysis of BS

The weight of BSs was determined after cooling for one hour at room temperature. The dimensions of height, diameter, and wall thickness were measured using a digital caliper to evaluate the structural uniformity of the samples. The inner color values of BSs were determined using a colorimeter (Minolta CR-410, Minolta Co. Ltd., Tokyo, Japan) after transverse cutting. The colorimeter was calibrated using the standard white calibration plate

supplied by the manufacturer before each measurement to ensure accuracy and consistency. Measurements were taken from three distinct regions of each sample, and the color parameters L^*, a^*, and b^* were recorded. The L^* value represents brightness (0 = black, 100 = white), a^* indicates redness (+) or greenness (–), and b^* represents yellowness (+) or blueness (–). The hue angle (h°), which indicates the color tone, was calculated as $\tan^{-1}(b^*/a^*)$ (Öney et al., 2020). All analyses were performed in triplicate, and results were expressed as mean values.

2.5 Texture profile analysis (TPA) of BS

The textural characteristics of the BS's were examined using the AACC Method 74-09.01 (AACC, 2000) with a texture analyser (TA.XT Plus, Stable Micro Systems, UK) and 0.5 mm cylinder probe. In order to perform TPA analysis, BS's were sliced into parts with a thickness of 1.25 cm. The properties of the texture were then measured using the specified parameters, which included a pretest speed of 1 mm/sec, a test velocity of 1.7 mm/sec, a posttest velocity of 10 mm/sec, and a strain of 40%.

2.6 Sensory analysis of BS

The sensory evaluation of BS was conducted with a panel of 20 participants. Prior to testing, panelists were informed about the sensory evaluation criteria. Randomly coded samples were presented individually, with cold tap water provided between evaluations. Sensory quality was assessed using a 5-point hedonic scale, where 5 = very good, 4 = good, 3 = acceptable, 2 = insufficient, and 1 = poor. The attributes evaluated included visual appeal, taste, color, texture, aftertaste, and overall acceptability (Meilgaard et al., 1999).

2.7 Statistical analyses

All statistical analyses were performed using SPSS 16.0 software (IBM Corp., Armonk, NY, USA). One-way analysis of variance (ANOVA) was conducted to determine the significance of differences among the samples, and when significant effects were detected ($p < 0.05$), Duncan's multiple range test was applied to compare the mean values. (Yıldız and Bircan, 2003).

3. RESULTS

3.1 Some chemical and physicochemical properties of wheat flour and HSWGF

Table 1 displays the chemical and physicochemical properties of wheat flour and HSWGF.

Table 1. Some chemical and physicochemical properties of wheat flour and HSWGF.

	Wheat flour	**HSWGF**
Moisture (%)	11.82±0.42	1.42±0.76
Ash (%)	1.12±0.07	4.42±0.03
Falling number(sec)	373±1.3	-
Wet gluten (%)	33.7±1.43	-
Dry gluten (%)	10.55±0.65	-
Gluten index (%)	98.52±0.13	-
Sedimentation (ml)	30±3.54	-
Delayed sedimentation (ml)	47.5±2.63	-

[1] HSWGF: Heat stabilized wheat germ flour

According to the Wheat Flour Communiqué of the Turkish Food Codex, flour may contain up to 14.5% moisture (Anonymous, 2018). Flour quality significantly affects simit characteristics and depends on parameters such as ash and protein content, gluten quality, and wheat variety. Excess bran content darkens the crumb color and weakens the gluten structure, thereby reducing product volume. This reduction in volume is mainly attributed to the interference of bran with gluten network formation, as bran particles dilute gluten-forming proteins and hinder the development of a continuous gluten matrix. Previous studies have consistently reported that adding bran to wheat flour decreases dough strength and ultimately lowers the final loaf or baked product volüme (Alfaris et al., 2022). For simit production, suitable flour should contain 0.7–0.8% ash, 12.5–13.0% protein, and a sedimentation value of around 30 ml (Yeyinli Savlak, 2011; Öney et al., 2020). In various studies, it has been found that the moisture and ash contents of the simit flours ranged from 10.42% to 13.9% and 0.45% to 1.52%, respectively (Lent and Grant, 2001; Gül et al., 2018; Öney et al., 2020). Based on the information that is offered, it can be noticed the moisture content of the flour utilized in the production of simit is within the desired range. Despite the ash value exceeding the desired rate slightly, it was found to be within the same range as reported in the literature.

The wet gluten value of the wheat-flour was determined as 33.7% and the gluten index value as 98.52%. A number of studies have shown the wide range in wet gluten content of flour, ranging from 21.37% to 35.8% (Lent and Grant, 2001; Elawad et al., 2016). Similarly, the sedimentation value of flour has been observed to vary between 31 ml and 58 ml (Mahdavi et al., 2022; Aydoğan et al., 2023). When comparison with previous studies, it was determined that the sedimentation value (30 ml) and the delayed sedimentation value (47.5 ml) got within

comparable ranges.

The moisture and ash contents of HSWGF were found to be 1.42% and 4.42%, respectively, on a dry weight basis after oven stabilization. These values indicate that the stabilization process effectively reduced the moisture content while maintaining the mineral composition of the germ. The preservation of ash content after stabilization aligns with earlier reports indicating that heat treatment effectively inactivates lipase and lipoxygenase—thereby lowering the risk of rancidity—while retaining the mineral-rich fractions of wheat germ. As a result, stabilized germ can enhance the nutritional quality of products without impairing dough structure when used at appropriate inclusion levels (Noori and Sabir, 2019). The wheat germ ash value reported in the literature matches the findings of previous studies, ranging from 3.88 to 4.56 (Gül et al., 2018; Şahin, 2021).

3.2 Chemical properties of BS

The chemical properties of BS's are given in Table 2. HSWGF0 has the lowest dry matter (28.43%), ash (1.19%) and protein (8.86%) contents.

Table 2. Some chemical properties of BS.

Sample	Moisture (%)	Ash (%)	Protein (%)	Total Dietary Fiber (%)
HSWGF-0	28.43±1.06$^{c(1)}$	1.19±0.09^{d}	8.86±0.48^{d}	6.20±1.15^{d}
HSWGF-10	30.06±1.15^{b}	1.39±0.05^{c}	10.44±0.10^{c}	6.77±0.67^{c}
HSWGF-20	31.49±1.42^{a}	1.50±0.04^{b}	11.17±0.07^{b}	7.60±1.95^{b}
HSWGF-30	31.96±1.08^{a}	1.87±0.15^{a}	12.95±0.05^{a}	7.90±1.06^{a}

[1] :There is no statistical difference between the means with the same letter in the same column (p<0.05)

The adding of substances in the enrichment process of bakery products has been found to improve the water retention properties of the resulting products. So higher rates of addition of these substances have been observed to correspond with increased moisture content in the products (Handa et al., 2012; Heo et al., 2019; Jeong and Chung, 2019; Ataman and Gül, 2020). In the same way, it was observed that the moisture content of the simits exhibited a positive correlation with the enhanced addition rate of HSWGF to the simits. This increase in moisture is consistent with the high water-binding capacity of wheat germ, as its protein and fiber fractions retain water effectively during mixing and baking (Majzoobi et al., 2022). Notably, the HSWGF-30 displayed the highest moisture content (31.96%). The differences in moisture, ash, protein, and dietary fiber contents among the samples were found to be statistically significant ($p < 0.05$), indicating that the enrichment level had a clear impact on the chemical

composition of the BSs. The ash content of the simits exhibited a range of 1.19% to 1.87%, while the protein ratio displayed a range of 8.86 to 12.95%. The addition of HSWGF to simits resulted in an increase in their ash values, owing to the high mineral content of wheat germ. The increase in ash content reflects the naturally high mineral density of the wheat germ fraction, which carries essential minerals in much greater concentrations than refined flour components (Majzoobi et al., 2022). Wheat germ contains a significant amount of protein and essential amino acids (Ghelich et al., 2022). Therefore, the rise in protein content is expected, as wheat germ provides considerable amounts of non-gluten proteins and amino acids that directly enrich the overall protein level of the product (Du et al., 2022). This situation increased the protein ratio of simits to which wheat germ was added, depending on the addition rate. Likewise, the inclusion rate was found to be positively associated with the enhancement of dietary fiber content. This increase aligns with the fiber-rich structure of wheat germ, which naturally contains hemicellulosic and lignocellulosic components contributing to higher dietary fiber levels (Gao et al., 2023). According to Soliman (2019), the recommended daily intake of dietary fiber for men aged 19-50 is 38 g/day, whereas for women it is 25 g/day. When consuming 100 grams of HSWGF-30, men are able to fulfill 20% of their recommended daily dietary fiber intake, whereas women are able to fulfill 30.4% of theirs. From a practical perspective, the observed increase in protein and dietary fiber contents may enhance the nutritional and functional value of the product for consumers. Higher protein levels can contribute to better satiety and support muscle maintenance (Carbone and Pasiakos, 2019), while increased dietary fiber intake is associated with improved digestive health and reduced risk of chronic diseases (Alahmari, 2024). Therefore, the incorporation of HSWGF into simit formulation can be considered a promising approach to developing nutritionally enriched bakery products

3.3 Physical properties of BS

The physical properties of HSWGF are given in Table 3. The weights of simit exhibit a range of variability, ranging from 98.52 to 112.40 grams. The increase in the proportion of HSWGF added to the simits resulted in a corresponding increase in the weights of the simits. This trend may be attributed to the relatively high water-binding capacity of wheat germ, which is likely to reduce moisture loss during baking and thereby contribute to increased final product weight. The differences in weight, wall thickness, and inner diameter among samples were statistically significant ($p < 0.05$), indicating that the enrichment level had a measurable impact on product structure. Since the added HSWGF enables more water to be retained, the moisture

loss during cooking decreased and the weight of the simits increased. When the HSWGF addition rate increased from 10% to 30%, simit weight increased by approximately 9.5% and became 112.40 g.

Table 3. Some physical properties of BS.

Sample	Simit weight (g)	Wall thickness (mm)	Thickness (mm)	Inner diameter (mm)	Outer diameter (mm)
HSWGF-0	98.52±1.37$^{d\,(1)}$	29.23±0.90^{c}	24.48±0.98^{ab}	94.62±4.86^{a}	145.55±4.06^{a}
HSWGF-10	102.64±4.31^{c}	30.65±0.79^{b}	21.74±8.56^{b}	81.20±2.00^{c}	132.53±4.02^{a}
HSWGF-20	105.96±3.04^{b}	34.98±0.63^{a}	26.56±1.47^{a}	78.89±2.81^{c}	140.78±3.86^{a}
HSWGF-30	112.40±0.84^{a}	30.54b±1.52^{c}	22.97±0.90^{ab}	90.37±2.89^{b}	148.32±1.75^{a}

[1] :There is no statistical difference between the means with the same letter in the same column (p<0.05)

The wall thickness and height of the BS increased until the addition of 20% HSWGF, and then decreased. Moderate levels of wheat germ may initially support product expansion by helping retain moisture, whereas higher levels are likely to dilute gluten-forming proteins, which can weaken gas retention and result in reduced height. The reported situation is believed to be linked to the degradation of gluten networks resulting from a HSWGF rate. The gluten networks, which experienced compromised structural integrity, were unable to withstand the gas pressure exerted during the cooking process. The presence of fiber-rich germ particles may interfere with gluten alignment, which could further weaken the structure's ability to withstand internal gas pressure. Consequently, carbon dioxide permeated through the networks, resulting in a reduction in height. HSWGF-0 has the lowest wall thickness (29.23 mm) and height (24.48 mm). While no statistically significant difference was observed in the outer diameters of the simits, the inner diameters decreased up to HSWGF-20 (78.89 mm) and increased in HSWGF-30 to 90.37 mm.

3.4 Colors of BS

The substitution of wheat flour with HSWGF resulted in a decrease in lightness (L*) of BS as indicated in Table 4. The inclusion of HSWGF led to a discernible increase in the redness (a*) value of the BS's, as illustrated in Fig. 2.

Table 4. Inner color values of BS.

Sample	*L**	*a**	*b**	Hue
HSWGF-0	95.01±2.54$^{a\,(1)}$	6.21±0.98^{d}	42.06±1.92^{a}	6.77±2.95^{a}
HSWGF-10	81.62±6.06^{b}	10.69±0.88^{c}	40.89±1.48^{a}	3.82±1.76^{b}
HSWGF-20	75.63±3.55^{c}	13.07±1.14^{b}	40.64±1.19^{a}	3.10±1.94^{c}
HSWGF-30	49.70±5.67^{d}	16.20±0.81^{a}	29.62±3.10^{b}	1.83±2.84^{d}

[1] :There is no statistical difference between the means with the same letter in the same column (p<0.05)

The conclusion of the non-enzymatic browning reaction, an indicator of the baking process in bakery products, is characterized by increased redness (a^*) and color darkening (Tolay, 2006). Çakır (2018) and Yağcı (2019) reported that increasing the addition rate of milling by-products decreased the L^* value and increased redness. Similarly, Çakır (2018) observed that the hue value of cakes enriched with wheat germ decreased with higher addition rates.

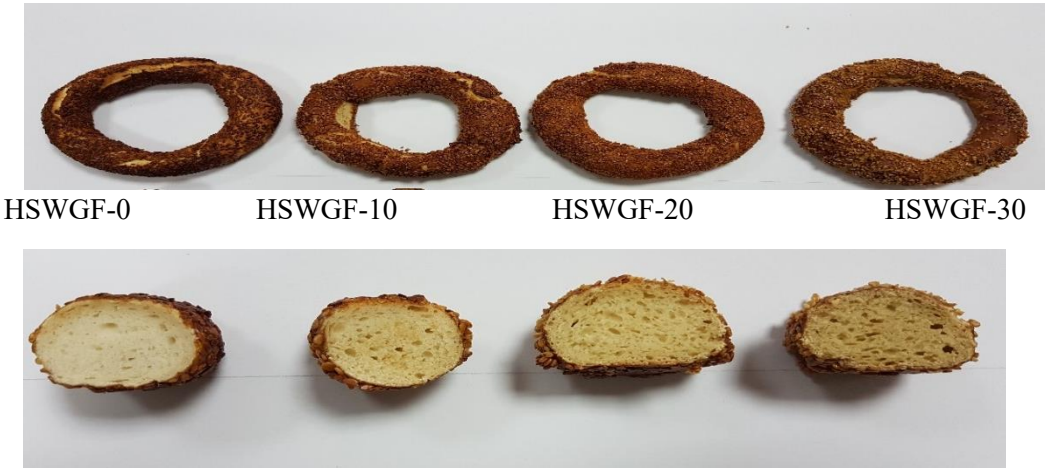


Figure 2. Whole (top) and cross-section (bottom) images of simits with added stabilized wheat germ.

As shown in Figure 2, the HSWGF-30 sample exhibited a noticeably darker color compared to the other simit samples. This darker appearance may be attributed to the higher levels of proteins and reducing sugars naturally present in wheat germ, which can accelerate Maillard browning during baking. The a^* value increased from 6.21 in HSWGF-0 to nearly three times that value in HSWGF-30. Ascorbic acid is typically added to flour to improve dough rheology and enhance resistance during simit production. In addition, enzymes are incorporated to promote surface browning and prevent excessive darkening of the crumb (Yeyinli Savlak, 2011; Öney et al., 2020). Therefore, while the crust color deepened with increasing HSWGF addition, the inner parts of the simits may have remained lighter due to enzyme activity. Differences in heat transfer and moisture distribution between the crust and the crumb may also contribute to this contrast, as Maillard reactions progress more rapidly under lower moisture and higher temperature conditions. Although darker tones in bakery products are sometimes associated by consumers with whole-grain content and higher nutritional value, literature indicates that for some consumer groups darker color may negatively influence purchase intentions (Jeżewska-Zychowicz and Królak, 2020). Consistent with this, the sensory results (Figure 3) showed that the darker appearance of the HSWGF-30 sample slightly reduced consumer acceptability. For some consumers, darker coloration may also evoke perceptions of

overbaking or quality deterioration, which could explain the slight decline in acceptability observed for the HSWGF-30 sample. Hence, optimizing color intensity is important to balance nutritional enrichment with consumer appeal and marketability.

3.5 Textural properties of BS

Table 5 presents the textural characteristics of BSs. The hardness of the samples increased progressively with higher HSWGF replacement levels, with HSWGF-30 exhibiting approximately twice the hardness of HSWGF-0. This increase can be attributed to the high fiber content of wheat germ, which binds water and contributes to a firmer texture (Zarzycki et al., 2024). Additionally, gluten–fiber interactions may have reinforced the dough matrix, leading to higher hardness values (Dur et al., 2019). Reduced free water availability may also lead to a denser and less extensible structure, which increases resistance during compression and results in higher hardness values. Similar to our findings, Gómez et al. (2012) reported a rise in bread hardness when the addition rate of extruded wheat germ increased from 5% to 10%.

Table 5. Textural properties of BS.

Sample	HSWGF-0	HSWGF-10	HSWGF-20	HSWGF-30
Hardness (g)	651.61±68.71$^{a\,(1)}$	730.27±47.83^{b}	999.10±55.44^{c}	1135.19±44.95^{a}
Springness	0.96±0.04^{a}	0.94±0.04^{a}	0.94±0.03^{a}	0.93±0.07^{a}
Cohesiveness (gxs)	0.63±0.06^{ab}	0.62±0.04^{b}	0.66±0.01^{a}	0.51±0.03^{c}
Gumniess	406.99±48.17^{d}	618.86±46.63^{a}	468.10±28.74^{c}	578.98±38.73^{b}
Chewiness	390.88±57.67^{d}	580.32±4.54^{a}	438.97±26.18^{c}	539.50±35.34^{b}
Resiliance	0.27±0.04^{b}	0.27±0.03^{b}	0.32±0.04^{a}	0.17±0.02^{c}

[1] : There is no statistical difference between the means with the same letter in the same row (p<0.05).

The inclusion of HSWGF led to improved cohesiveness in simits. Nevertheless, upon increasing the addition rate to 30%, a decline in the cohesiveness value was observed. This reduction may be attributed to the disruption of the gluten network caused by the high fiber content of wheat germ. At higher substitution levels, fibers can interfere with gluten formation by competing for water and physically diluting gluten proteins, thereby weakening the dough structure and decreasing cohesiveness (Xu et al., 2021). At moderate substitution levels, fiber particles may contribute to structural binding by forming additional physical linkages, whereas excessive fiber can disrupt gluten continuity, leading to reduced cohesiveness.

Furthermore, it was reported that the hardness value increased at a 10% addition rate and decreased at a 5% addition rate when extruded wheat germ was added (Gómez et al., 2012).

The study revealed that the hardness value of simits decreased by 20%. However, the inclusion of HSWGF at a rate of 30% resulted in an increase in the hardness of simits. The situation is believed to arise from the interplay between lipids present in the wheat germ and starch. This effect may be linked to the formation of amylose–lipid complexes, which can restrict starch swelling and promote a firmer, more compact structure during and after baking.

The gumminess value of simits varies between 406.99-618.86. The lowest gumminess value was determined in HSWGF-0. Similarly, the chewiness value of HSWGF-0 (390.88) has the lowest value.

3.6 Sensory evaluation of BS

The sensory attributes of BSs are presented in Figure 3. Among the samples, HSWGF-20 showed remarkable similarity to the control (HSWGF-0) in overall acceptability and even exceeded it in some sensory parameters. It received the highest mean scores for appearance, chewiness, crispness, and taste, indicating that partial enrichment with HSWGF can enhance the sensory quality of simit without compromising consumer preference. This optimal performance may be associated with moderate levels of wheat germ enhancing aroma and mouthfeel without introducing overpowering flavors or excessive color darkening. In contrast, when the addition level exceeded 20%, the sensory scores declined. The HSWGF-30 sample, in particular, was rated less favorably in terms of interior and exterior color, taste, and texture. This reduction in acceptability may be due to the intensified wheat germ flavor and darker color associated with high fiber and lipid content, as noted by Gül et al. (2018). At higher substitution levels, the intensified germ flavor and increased fiber content may have produced slightly bitter or roasted notes and a drier mouthfeel, which could negatively affect overall acceptability. Similarly, Gómez et al. (2012) reported that bread fortified with 10% wheat germ received lower scores for appearance, taste, and odor compared to the control. In the present study, consumers generally preferred simits containing up to 20% HSWGF, beyond which the overall flavor and crispness decreased significantly. The reduction in crispness may be linked to the higher water-binding capacity of wheat germ, which can limit moisture evaporation during baking and result in a less brittle crust.

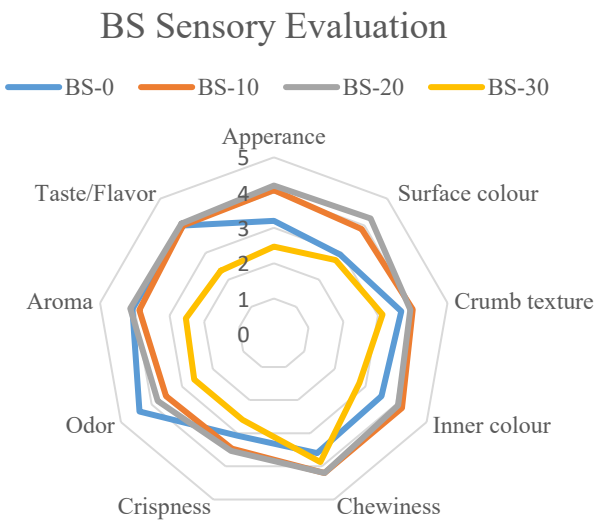


Fig. 3. Sensory evaluation of BS's produced with different levels of HSWGF

Previous research has also emphasized the influence of formulation changes on the sensory properties of simit. Şentürk and Ötleş (2017) observed that the addition of kefir yeast enhanced the texture, flavor, and aroma of simits, whereas higher levels slowed staling. Likewise, Öney et al. (2020) demonstrated that using sourdough in simit production improved appearance and flavor while delaying staling. These findings collectively indicate that both the type and level of enrichment play a crucial role in determining the sensory quality and consumer acceptability of simit products.

4. CONCLUSIONS

Wheat germ, a nutrient-rich by-product of wheat milling, represents a promising source for addressing protein and calorie deficiencies, particularly in developing countries. In this study, simit, a widely consumed traditional bakery product, was enriched with heat-stabilized wheat germ flour (HSWGF) at substitution levels ranging from 0% to 30%. The incorporation of HSWGF significantly ($p < 0.05$) increased the protein, ash, and mineral contents of simits, thereby improving their nutritional value. Sensory analysis revealed that the 20% substitution level provided the most favorable balance, maintaining desirable texture and consumer acceptance, whereas higher levels (30%) led to a significant ($p < 0.05$) decline in sensory quality, especially in texture and flavor. Overall, the results demonstrate that the inclusion of 20% HSWGF in simit formulations is an effective and statistically supported strategy for developing functional bakery products with enhanced nutritional quality and consumer appeal. From a consumer perspective, the enrichment of simit with HSWGF can contribute to improved dietary quality by increasing protein, mineral, and fiber intake and supporting satiety and

digestive health. Although these findings are promising, several aspects remain open for further investigation. Additional work is needed to investigate the effects of different wheat germ stabilization techniques, evaluate the long-term storage stability of HSWGF-enriched simits, optimize processing conditions at higher substitution levels, and determine the applicability of this enrichment approach in other traditional bakery products.

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