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Quality characteristics of gluten-free muffins fortified with watermelon rind powder

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Abstract

The aim of the study was to obtain gluten-free muffin cakes for celiac patients with improved functional properties with the addition of watermelon rind. Muffins were produced by substituting the watermelon rind powder (7%, 14%, 21% and 28%) into rice flour, and some physicochemical and sensory properties of the samples were determined. With the substitution of watermelon rind powder, the protein, fat, ash, dietary fiber, Na, K, P, Mg and Ca contents of the muffins increased significantly. It was observed a decrease in the volume, volume index and spesific volume by the addition of watermelon rind powder. The *L**, *a** (crust and crumb) and *b** values (crust) of the muffins were decreased and also *b** value of the crumb of them was increased. Smaller pores and rough structure formation were detected with increasing watermelon rind powder ratio in SEM images. Moreover, it was determined that the addition of watermelon rind powder to muffins has increased the hardness, gumminess and chewiness, while the springiness was decreased. In sensory analysis, it was stated that 7% and 14% watermelon rind powder substituted muffins were liked similarly with control sample in terms of overall acceptance and other parameters.

Keywords: gluten-free muffin; watermelon rind; dietary fiber; SEM; sensory evaluation.

Practical Application: It was determined that the substitution of watermelon rind powder to gluten-free cakes produced with rice flour brought enhancement of cakes in dietary fibers and minerals. In addition, the muffins substituted with 14% of watermelon rind powder had similar volume characteristics and sensory scores with control sample. In the light of these results, it is seen that watermelon peel has the potential to be used in gluten-free cakes up to a certain ratio.

1 Introduction

Celiac disease is a small intestine disease in which genetically susceptible individuals are genetically sensitive to gluten in wheat and other gluten-like grain proteins in grains such as barley, rye, and oats. This disease affects children and adults throughout life and can occur at any age. The reported prevalence of celiac disease ranges from 1/658 to 1/37 within different countries (Garnier-Lengliné et al., 2015; Gao et al., 2018). Due to the damage to the intestinal mucosa, classical symptoms such as malabsorption and accordingly growth and development retardation, diarrhea, abdominal distension, and oily stools develop in patients. Currently, the only treatment for celiac disease is the complete avoidance of foods containing gluten, a wheat protein (Hayıt & Gül, 2017; Bozdogan et al., 2022). This increases the demand for gluten-free foods.

Finding good-quality gluten-free products can be a major challenge for celiac patients, as the majority of grain-based foods on the market are made with gluten-containing grains. Non-use of gluten causes major problems for bakers. In gluten-free products, especially texture and volume and other end product qualities such as color, appearance, and taste are adversely affected and quality problems arise. Commercially available gluten-free products are often of low quality. These products, which have starch-based composition, become stale quickly and may have negative properties due to the deficiency of some components such as fiber, protein, and minerals in their nutritional content. Therefore, there is a need for research and development of gluten-free bakery products (Hayıt & Gül, 2017; Gao et al., 2018; Yesilkanat & Savlak, 2021; Scarton & Clerici, 2022).

Watermelon (*Citruthis lanatus*) is a tropical fruit from the adipsous cucumber family that grows in almost all regions of Africa and South East Asia (Al-Sayed & Ahmed, 2013). In the world, 100 million tons of watermelon are produced every year in an area of approximately 3 million hectares, ranking second after banana among the most grown fresh fruit in the world (Institute of Agricultural Economy and Policy Development, 2021). Of the total weight of watermelon, which is generally consumed as a snack or side order, approximately 54-68% consists of meat; 30-40% consists of rind; 2-3% consists of seeds (Hoque & Iqbal, 2015).

Considering that approximately 100 million tons of watermelon are produced in the world and that 30-40% of the watermelon is composed of the rind, approximately 30-40 million tons of watermelon rind waste are obtained annually. Watermelon rind is usually discarded, added to feed, or used as fertilizer. However, the watermelon rind contains some important food and functional components that can be used in human diet. Previous studies reported the protein content in the watermelon rind as 7.94-16.49%, fat content as 2.38-12.61%, dietary fiber content as 37.30-68.43%, and ash as 5.03-14.56% (Al-Sayed & Ahmed, 2013; Badr, 2015; Hoque & Iqbal, 2015; Romelle et al., 2016; Zhivkova, 2021). Investigation of the possibilities of using watermelon rinds, which can be a good source of dietary fibers and protein, in human diet

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is thought to be beneficial both in terms of nutrition and waste reduction. From this point of view, in the present study, it was decided that it would be appropriate to examine the potential use of watermelon rinds in one of the gluten-free product varieties that are poorer in nutritional and textural aspects. Cake, which is one of the widely consumed bakery products, was chosen as the product. The chemical, physical, and sensory properties of gluten-free muffin cakes, in which different ratios of watermelon rind powder were used, were examined.

2 Materials and methods

2.1 Materials

Celine F1 (*Cucurbita maxima, C. moschata*) type watermelon was collected from local producers. rice flour (Itır), milk (Yörükoğlu), egg (Mutlubaş), baking powder (Dr.Oetker), corn oil (Orchid), granulated sugar (Ekmel) and xanthan gum (Additive World) were obtained from local markets in Denizli.

2.2 Methods

Preparation of watermelon rind powder (WRP)

The watermelons purchased from the market to obtain WRP were washed in the laboratory in order to eliminate the contamination elements on the surface. After drying, the rinds were separated from the fleshy part. The obtained green and white rinds were cut into 5 x 5 mm cubes. The cubes were dried in an incubator (Yücebaş Machine, İzmir, Turkey) at 50 °C, with a constant air velocity of 0.2 m/s and relative humidity of 19-20%. The drying process was terminated after the moisture content of the watermelon rinds fell below 10%. Then, the dried watermelon rinds were ground with a blender (Waring commercial blender, USA) to form a powder, and passed through a sieve of ≤ 400 μm to reach the desired particle size.

Production of muffins

The specified amounts of eggs and sugar (Table 1) in the cake production were mixed at high speed for 5 minutes in a mixer (KMM060 Kitchen Chef, Kenwood) to obtain a creamy temper. Then, milk and corn oil were added and mixed at medium speed for 1 minute. Cake mixes were prepared by adding rice flour, watermelon rind powder, baking powder, and xanthan gum and mixing for 1 more minute at medium speed. 35 g cake mix was weighed in muffin molds (5 cm diameter Teflon mold, Turkey) greased with margarine and baked in the oven (Özköseoğlu Oven, Istanbul, Turkey) at 150 °C for 17 minutes. After the trays were taken out of the oven and cooled, the cakes were taken out of their molds and prepared for analysis. Physical analyses of the cakes were performed 2 hours after the production. Chemical analyses were performed in the following days and the cakes were stored in zip lock bags at -18 °C.

Chemical analyses

Moisture (method 934.01), ash (method 942.05), fat (method 954.02), and protein (method 988.05) analyses were performed according to Association of Official Analytical Chemists (2005a). Dietary fiber analysis was performed according to the AOAC 991.43 (Association of Official Analytical Chemists (2005b) and AACC 32-07 (American Association of Cereal Chemists, 2000a) methods using the Megazyme total dietary fiber analysis kit including α-amylase, protease, and amyloglucosidase enzymes.

The minerals (P, K, Ca, Mg, Fe) were determined by Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES, Perkin Elmer, Optima 8000, Massachusetts, USA) with following the method that Isik & Topkaya (2016) reported. Sensitive wavelengths for mineral identification were obtained from the tables provided by the manufacturer (Boss & Fredeen, 2004).

Physical and textural properties

A Hunter Lab Miniscan XE colorimeter (Hunter Associates Laboratory, Reston, VA) was used to measure the crumb and crust colors of the muffins (Hunterlab, 1995).

The volume of the muffins was identified through the rapeseed displacement method, and the specific volume was determined from the ratio of cake volume/weight. The volume, symmetry and uniformity index values were measured using a plastic measuring template (Figure 1), following AACC method 10-91 (American Association of Cereal Chemists, 2000b). These index values were calculated using the following Equations 1, 2 and 3:

$$Volume\,index = B + C + D \quad (1)$$

$$Symmetry\,index = 2C - B - D \quad (2)$$

$$Uniformity\,index = B - D \quad (3)$$

Table 1. Formulations of gluten free muffins.

Ingredients (g)	C	WRP7	WRP14	WRP21	WRP28
Rice flour	31.50	29.30	27.09	24.89	22.68
WRP	0.00	2.20	4.41	6.61	8.82
Egg	24.60	24.60	24.60	24.60	24.60
Sugar	21.00	21.00	21.00	21.00	21.00
Milk	14.80	14.80	14.80	14.80	14.80
Corn oil	6.30	6.30	6.30	6.30	6.30
Baking powder	1.80	1.80	1.80	1.80	1.80
Ksanthan gum	0.09	0.09	0.09	0.09	0.09

C: Control gluten free muffin. WRP7: Gluten free muffin of whose 7% of rice flour was substituted with WRP. WRP14: Gluten free muffin of whose 14% of rice flour was substituted with WRP. WRP21: Gluten free muffin of whose 21% of rice flour was substituted with WRP. WRP28: Gluten free muffin of whose 28% of rice flour was substituted with WRP.

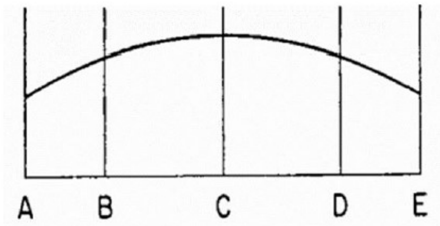

Figure 1. The template used for measuring the volume, symmetry and uniformity index values of cake samples.

In the texture profile analysis (TPA) of the cakes, the texture properties of the samples, including hardness, chewiness, cohesiveness, gumminess, and springeness, were determined. Analysis was performed using the TA4/1000 probe at room temperature, 2 hours after the production of the cakes. The test parameters were a pre-test speed of 1 mm/s, a test speed of 1 mm/s, a compression of 50%, and an initial sensing force of 4.5 g.

Microstructure properties

Internal texture images of the cakes were taken by scanning electron microscopy (SEM) (FEI Quanta 250 FEG brand, Hillsboro, Oregon, USA) at 200X magnification. Before taking the SEM image, the samples were lyophilized and their surfaces were spray-coated with gold/palladium (80:20) using a rotary pump coater (Quorum, Q150R ES).

Sensory characteristics

The muffins were evaluated for crust color, crumb color, odor, taste, crumb texture, chewiness, after taste and overall acceptability by 48 untrained panelists (24 male; 24 female) from Pamukkale University using a 7-point hedonic scale (7 = like extremely, 1 = dislike extremely).

Statistical analysis

All data were analyzed with a one-way ANOVA in "*Minitab 16 Statistical Software*" (Minitab Inc., State College, PA, USA). Tukey multiple comparison test was used to determine the differences among the treatment means at $p < 0.05$.

3 Results and discussion

3.1 Some properties of rice flour and WRP

Table 2 shows the chemical and color properties of rice flour and WRP used in muffin cake formulations. In studies (Al-Sayed & Ahmed, 2013; Badr, 2015; Hoque & Iqbal 2015; Romelle et al., 2016; Feizy et al., 2020; Zhivkova, 2021; Naknaen et al., 2016) examining the composition of watermelon rinds, it was found that the rinds compose of 7.94-16.49% protein, 2.38-12.61% fat, 37.30-68.43% dietary fiber, and 5.03-14.56% ash. The values obtained in this study are within the range reported by literature findings. In the current study, the protein, fat, dietary fiber, and ash contents of rice flour were also similar to those reported in other studies (Torbica et al., 2012; Topaloğlu, 2019; Sahan, 2022). When the raw material results were compared, it was seen that the protein, fat, dietary fiber, and ash ratios of WRP were higher than those of rice flour.

Table 2. Some properties of rice flour and WRP.

	Rice flour	WRP
Crude protein (%)[1]	7.82 ± 0.25	11.17 ± 0.58
Crude fat (%)[1]	0.75 ± 0.11	11.42 ± 0.12
Insoluble dietary fiber (%)[1]	2.46 ± 0.53	48.15 ± 1.46
Soluble dietary fiber (%)[1]	0.23 ± 0.05	3.95 ± 0.69
Total dietary fiber (%)[1]	2.69 ± 0.58	52.10 ± 1.68
Crude ash (%)[1]	0.65 ± 0.03	8.98 ± 0.42
Minerals (mg/kg) [1]		
K	1750.62 ± 98.12	39615.68 ± 700.13
P	2648.90 ± 102.54	4799.70 ± 167.92
Mg	769.63 ± 45.09	3681.47 ± 105.10
Ca	946.41 ± 43.87	7371.62 ± 201.30
Fe	38.03 ± 4.02	39.26 ± 2.86
Hunter color values		
L^*	90.04 ± 1.30	64.81 ± 1.13
a^*	-1.13 ± 0.18	-2.81 ± 0.17
b^*	7.75 ± 0.19	24.02 ± 1.61

WRP: Watermelon rind powder. [1]: In dry basis.

As seen in Table 2, the Na, K, P, Mg, and Ca contents of WRP were higher than in rice flour, and the Fe content was close to each other. The mineral results for WRP and rice flour are generally consistent with the results found in the literature (Badr, 2015; Feizy et al., 2020; Zhivkova, 2021; Sahan, 2022). Some differences between values are thought to be due to various factors such as different watermelon species, maturity status of the fruits, the soil type, the soil condition, and the irrigation regime (Leterme et al., 2006).

The color results of raw materials indicate that the watermelon rind is darker, greener, and yellower compared to rice flour.

3.2 Chemical properties of gluten-free muffin cakes

Significant increases were detected in the protein, fat, ash, soluble, insoluble, and total dietary fiber ratios of the cakes as the amount of WRP added to the cakes increased (Table 3). Protein, fat, dietary fiber, and ash contents of WRP, which were higher than in rice flour (Table 2), also affected the results of the cake samples accordingly.

In Awad's (2017) study, cakes were produced by substituting wheat flour with WRP (5, 10, 15%), and as the WRP substitution ratio in the control cake increased, crude protein and fat content decreased whereas ash, dietary fiber, and carbohydrate values increased. In the study conducted by Al-Sayed & Ahmed (2013), moisture, fat, ash, and protein values were determined in the cakes produced by substituting wheat flour with WRP at ratios of 2.5%, 5.0%, and 7.5%. As the substitution ratio of WRP increased, the protein content of the cakes decreased whereas the fat and ash content increased. In their study, Naknaen et al. (2016) examined the potential of using watermelon rind waste in cookie production. In the study, the dried watermelon rinds were ground and substituted with wheat flour at 10, 20, and 30% ratios to produce cookies. The control cookie had 6.18% protein content whereas those containing 10, 20, and 30% rind had a protein content of 5.71%, 5.20%, and 5.00%, respectively. It was

Table 3. Some chemical properties of gluten free muffin samples.

Parameter	C	WRP7	WRP14	WRP21	WRP28
Crude protein (Nx6.25) (%)[1]	9.17 ± 0.06[b]	9.47 ± 0.09 [ab]	9.35 ± 0.07 [ab]	9.50 ± 0.04[ab]	9.52 ± 0.08 [a]
Crude fat (%)[1]	29.81 ± 0.37[d]	29.86 ± 0.59 [d]	32.85 ± 0.27 [c]	34.10 ± 0.15 [b]	35.92 ± 0.63[a]
Insoluble dietary fiber (%)[1]	1.55 ± 0.12[e]	2.96 ± 0.26[d]	8.69 ± 0.02[c]	11.05 ± 0.32[b]	14.20 ± 1.19[a]
Soluble dietary fiber (%)[1]	0.91 ± 0.11[d]	1.14 ± 0.09[d]	1.38 ± 0.08[c]	2.88 ± 0.15[b]	3.33 ± 0.25[a]
Total dietary fiber (%)[1]	2.45 ± 0.22[d]	4.10 ± 0.35[d]	10.07 ± 0.09[c]	13.93 ± 0.47[b]	17.53 ± 1.43[a]
Crude ash (%)[1]	2.17 ± 0.06[c]	2.41 ± 0.08 [b]	2.57 ± 0.01 [a]	2.65 ± 0.04[a]	2.67 ± 0.02[a]
Minerals(mg/100g)[1]					
K	1444.39 ± 92.92[e]	2806.97 ± 71.43[d]	3828.12 ± 74.37[c]	4364.70 ± 62.83[b]	5441.48 ± 94.30[a]
P	6032.05 ± 82.86[e]	6529.40 ± 10.57[d]	6658.13 ± 31.48[c]	6868.69 ± 21.45[b]	7179.34 ± 99.87[a]
Mg	290.41 ± 13.86[e]	392.54 ± 16.43[d]	468.60 ± 11.50[c]	523.01 ± 20.01[b]	601.88 ± 29.08[a]
Ca	397.50 ± 90.70[e]	727.96 ± 52.85[d]	1097.28 ± 72.89[c]	1210.20 ± 33.11[b]	1589.43 ± 67.01[a]
Fe	19.06 ± 13.56	16.17 ± 12.86	16.75 ± 10.02	17.96 ± 13.01	19.42 ± 9.03

C: Control gluten free muffin, WRP7: Gluten free muffin of whose 7% of rice flour was substituted with WRP, WRP14: Gluten free muffin of whose 14% of rice flour was substituted with WRP, WRP21: Gluten free muffin of whose 21% of rice flour was substituted with WRP, WRP28: Gluten free muffin of whose 28% of rice flour was substituted with WRP. Different superscript letters (a, b, c, …) in rows indicate statistical differences ($p < 0.05$). [1]: in dry basis

determined that the protein and fat value decreased and the ash and moisture value increased as the watermelon rind substitution ratio of the cookies increased. In the above-summarized studies, the substitution of WRP with wheat flour appears to reduce the protein content of the products, and this finding is contrary to the findings of the present study. It can be suggested that this finding was due to the higher protein (9.0-13.50%) ratio of wheat flour used in the related studies compared to the rice flour (7.35-9.00%) in which WRP was substituted in this study.

Dietary fibers are the indigestible and more solid contents of vegetables and fruits, such as peel, membrane, stem, and seed. In the literature, it was reported that dietary fibers play a role in the regulation of the excretory system and the prevention of many diseases such as various types of cancer, cardiovascular diseases, obesity, and gastrointestinal diseases (Ozgoren et al., 2019; Zheng et al., 2022).

Considering the role of dietary fibers in reducing health problems, the World Health Organization reported that the amount of dietary fiber required per day is 25-40 g (Ozgoren et al., 2019). In the current study, assuming that 1 serving of the cake is 40 g (Turkey, 2017) and that the amount of fiber to be taken per day is 25 g, the ratio of meeting the daily fiber need of a person by 1 serving was calculated. According to calculations, a person consuming one serving of the control cake a day met 3.28% of the daily dietary fiber needs whereas this rate was 5.42% in WRP7, 13.17% in WRP14, 18.36% in WRP21, and 23.20% in WRP28. A person consuming one serving of WRP28 meets approximately 7 times more of the daily dietary fiber need compared to the control cake. As the results indicate, it can be suggested that the dietary fiber content, which has many positive effects on human health, can be enriched with the addition of WRP in gluten-free cakes.

In their study, Badr (2015) investigated the effect of watermelon rind on bread by substituting wheat flour with 3, 6, 9, and 12% WRP. In the study, it was found that the fiber content increased as the WRP substitution increased, and the fiber ratio was 1.80, 2.70, 3.35, 4.05 and 4.80 in the control bread and the breads with 3, 6, 9, and 12% WRP substitution, respectively. In the study conducted by Ho & Dahri (2016), noodles were produced by substituting wheat flour with 5%, 10%, and 15% WRP. In the study, it was found that the crude fiber values of the noodles increased as the WRP substitution ratios increased. The crude fiber content was 1.0 g/kg in the control noodle, 7.6 g/kg in 5% substituted noodles, 16.70 g/kg in 10% substituted noodles, and 24.20 g/kg in 15% substituted noodle.

Minerals are indispensable nutritious substances for the organism, because promote since the bones constitution, teeth, muscles, blood, and nervous cells until the water balance. (Silva et al., 2017). The K, P, Mg, and Ca contents of the cakes increased ($p < 0.05$) as the amount of WRP added to the cakes increased (Table 3). The effect of the addition of WRP on the Fe content of the cakes was insignificant ($p > 0.05$).

The average daily amounts of minerals, which were analyzed in the study, are as follows for adults: K 3000 mg, P 800 mg, Mg 350 mg, Ca 1000 mg, and Fe 15 mg (Işık, 2013). As a result of the calculation made with the data shown in Table 4, a person consuming 1 serving (40 g) of the control cake can meet 1.62% of daily K need, 25.37% of P need, 2.8% of Mg need, and 1.34% of Ca need. In the case of consuming 1 serving of WRP28 cake, 6.11% of K need, 30.21% of P need, 5.79% of Mg need, and 5.35% of Ca need can be met.

In their study, Olaitan et al. (2017) produced cookies by substituting 2.5, 5.0, and 7.5% of wheat flour with WRP and determined that the K, P, Mg, Ca, and Fe contents of the cookies increased as the WRP substitution ratio increased. Ashoka et al. (2021) found that the cookies whose white wheat flour substituted by 30% WRP had 3.85, 1.43 and 2.88 times of Ca, P, and Fe contents respectively.

3.3 Physical and textural properties of gluten-free muffin cakes

The color values of gluten-free muffin cakes are presented in Table 4. There was a statistically significant ($p<0.05$) decrease in both internal and external color L^* values of the cakes as

Table 4. Physical and textural properties of gluten free muffin samples.

Parameter	C	WRP7	WRP14	WRP21	WRP28
Crumb color					
*L**	72.82 ± 0.80^{a}	64.73 ± 1.13^{b}	61.15 ± 0.60^{c}	59.31 ± 0.78^{d}	57.30 ± 1.39^{e}
*a**	3.41 ± 0.31^{a}	1.08 ± 0.26^{b}	-0.56 ± 0.18^{c}	-1.04 ± 0.35^{c}	-1.81 ± 0.53^{d}
*b**	34.87 ± 0.53^{c}	36.80 ± 0.59^{ab}	37.32 ± 1.05^{b}	37.24 ± 0.63^{b}	38.60 ± 0.95^{a}
Crust color					
*L**	56.09 ± 5.01^{a}	43.09 ± 1.62^{b}	40.99 ± 1.40^{b}	41.09 ± 3.53^{b}	39.68 ± 3.05^{b}
*a**	14.33 ± 3.18 ^{a}	14.86 ± 1.01 ^{a}	12.90 ± 1.35 ^{ab}	11.47 ± 1.61 ^{ab}	9.91 ± 3.76 ^{b}
*b**	45.89 ± 3.96^{a}	37.06 ± 2.94^{b}	33.88 ± 1.56^{bc}	32.78 ± 2.24^{bc}	32.48 ± 1.04^{c}
Some physical properties					
Volume (mL)	74.67 ± 5.03^{a}	72.00 ± 2.00^{a}	69.00 ± 4.58^{ab}	62.68 ± 0.58^{bc}	58.67 ± 1.15^{c}
Specific volume (mL/g)	2.33 ± 0.14^{a}	2.28 ± 0.05^{a}	2.17 ± 0.14^{ab}	1.96 ± 0.03^{bc}	1.80 ± 0.03^{c}
Volume index (mm)	95.00 ± 1.41^{a}	95.50 ± 2.38^{a}	92.75 ± 3.77^{ab}	87.00 ± 3.83^{bc}	84.00 ± 4.83^{c}
Symmetry index (mm)	10.75 ± 3.77^{ab}	13.50 ± 3.00^{a}	11.50 ± 1.91^{ab}	8.00 ± 0.82^{b}	5.75 ± 1.71^{c}
Uniformity index (mm)	0.25 ± 0.50^{a}	0.50 ± 0.50^{a}	0.75 ± 0.40^{a}	0.25 ± 0.36^{a}	0.50 ± 0.28^{a}
Textural properties					
Hardness (g)	1801.31 ± 180.20^{c}	2012.02 ± 392.51^{c}	3193.30 ± 209.21^{b}	3975.43 ± 327.52^{a}	4358.81 ± 231.12^{a}
Springiness (mm)	6.74 ± 0.07^{a}	6.60 ± 0.15^{a}	6.42 ± 0.06^{ab}	5.91 ± 0.47^{bc}	5.53 ± 0.42^{c}
Cohesiveness	0.65 ± 0.03	0.60 ± 0.03	0.59 ± 0.03	0.69 ± 0.10	0.67 ± 0.13
Gumminess (g)	1160.41± 254.40^{c}	1209.91± 263.32^{c}	1887.83 ± 220.91^{b}	2755.42 ± 355.21^{a}	2934.83 ± 319.71^{a}
Chewiness (mJ)	76.74 ± 17.31^{c}	78.27 ± 10.30^{c}	118.85 ± 13.84^{b}	157.38 ± 14.20^{a}	155.03 ± 13.50^{a}

C: Control gluten free muffin, WRP7: Gluten free muffin of whose 7% of rice flour was substituted with WRP, WRP14: Gluten free muffin of whose 14% of rice flour was substituted with WRP, WRP21: Gluten free muffin of whose 21% of rice flour was substituted with WRP, WRP28: Gluten free muffin of whose 28% of rice flour was substituted with WRP. Different superscript letters (a, b, c, …) in rows indicate statistical differences ($p < 0.05$).

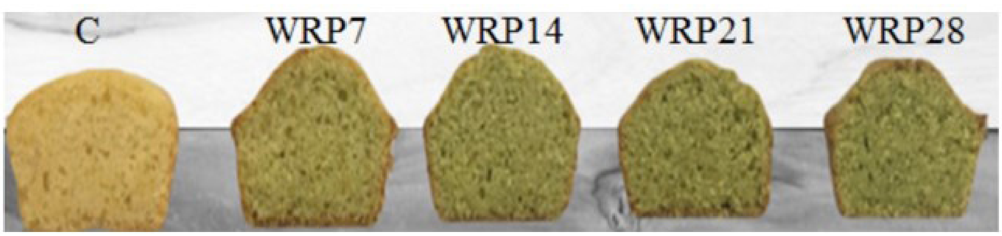

Figure 2. Photographs of muffins cross sectional areas. C: Control gluten free muffin, WRP7: Gluten free muffin of whose 7% of rice flour was substituted with WRP, WRP14: Gluten free muffin of whose 14% of rice flour was substituted with WRP, WRP21: Gluten free muffin of whose 21% of rice flour was substituted with WRP, WRP28: Gluten free muffin of whose 28% of rice flour was substituted with WRP.

the WRP substitution ratios for rice flour increased due to the natural color components (carotene, chlorophyll, riboflavin, niacin) found in WRP (Zeyada et al., 2008; Terlemez, 2017).

The colors of the cakes are always important for the consumers' perceptions of cake. As expected, statistically significant ($p < 0.05$) changes were determined in the internal and external color *a** values of the cakes due to the natural green color of the WRP. In the internal color, the control cake had the highest redness level and the WRP28 cake had the highest greenness level (Figure 2). Moreover, regarding the color properties of the raw materials, the internal color *b** value of the cakes increased significantly as the amount of WRP added to the cakes increased. During baking, the core temperature does not exceed 100 °C; therefore, Maillard reactions do not occur in the inner part of the product (Awad, 2017). It is thought that the internal color is directly associated with the raw materials used.

The external color *a** and *b** values of the cakes decreased significantly as the WRP substitution ratio increased ($p < 0.05$). It is thought that this decrease may be due to the degradation of the color materials in the WRP due to the high temperature the cake surface is exposed to during baking and the browning due to the Maillard reaction (Topkaya & Isik, 2019).

In the study of Awad (2017), in which cakes were produced by substituting wheat flour with 5, 10, and 15% WRP, it was found that the change in the external *a** values of the cakes was insignificant with the increase in the WRP substitution ratio. The ratio of WRP substituted for wheat flour in Awad's (2017) study was at most 15%. In the present study, the external color *a** value in samples where the substitution ratio for rice flour was 14% was also similar to that in the control sample. The changes determined in the internal and external *L** and *b** values and the internal *a** value of the cakes in Awad (2017) were similar to those determined in the present study.

In the study conducted by Naknaen et al. (2016), where WRP was substituted for wheat flour at ratios of 10, 20, and 30%, it was determined that as the substitution ratio increased, the L^* and b^* values of the biscuits decreased and that the a^* value increased. The researchers stated that browning in color increased as the amount of substituted WRP increased and emphasized that the color of the biscuits was affected by Maillard reactions between reducing sugars and proteins during baking, starch dextrinization and caramelization during cooking, and the pigments of the raw materials.

In the literature, it is stated that cakes of good quality should have a voluminous and uniform structure as much as possible. As a result of the analysis, it was determined that the volume, specific volume, volume index, and symmetry index values decreased significantly ($p < 0.05$) as the WRP substitution ratio increased (Table 4). It is thought that this decrease in volume properties was due to the fact that WRP, which has high dietary fiber content, retains more water in the cake mix and increases the density of the mix (Bozdogan et al., 2022). The density of the mix is one of the factors affecting the rise in cakes. If the density exceeds the ideal temper, it generally affects the rising negatively (Wilderjans et al., 2013).

Hoque & Iqbal (2015) produced cakes by substituting wheat flour with 10%, 20%, and 30% WRP and found that the volume of the cakes with 20% and 30% WRP substitution was lower than that of the control cake. In the present study, in which WRP was substituted for rice flour, the volume, specific volume, and volume index values associated with the rising properties of the cakes were significantly ($p < 0.05$) lower than those of the control cakes in 21% and 28% KKT substituted samples. Uniformity index values were found similar ($p > 0.05$) for all cake samples in the study.

Another important quality parameter affecting consumers' preferences in cakes is texture. Hardness is among the most distinct textural properties in the evaluation of bakery products, as it is closely associated with individuals' perception of freshness. Foods are classified as soft or hard according to their hardness values (Göksel, 2011). As a result of the analyses made, the hardness value statistically significantly ($p < 0.05$) increased as the WRP substitution ratio increased (Table 4). It is thought that the higher level of hardness of WRP-substituted cakes was due to the higher dietary fiber content of WRP than rice flour and the presence of fruit-derived dietary fibers. Dietary fibers in fruit by-products have greater water and oil binding capacity than cereal fibers (Elleuch et al., 2011). It is thought that the high water and oil binding capacity of WRP due to its high dietary fiber content results in more consistent cake mixes and cakes with a harder structure and low volume. In the study of Kırbaş et al. (2019), it was determined that the hardness value of the products increased as the substitution ratio (0-15%) increased in the cakes produced by substituting apple, orange, and carrot pulp powders for rice flour. The increased hardness values reported in the study was associated with the increased dietary fiber contents of the samples.

Cohesiveness is defined as a measure of the difficulty of breaking down the internal structure of a sample, or as a textural parameter that expresses how much the cake core sticks together (Göksel, 2011). In the study, no statistical difference was determined in the cohesiveness values of gluten-free cakes in which rice flour was substituted with WRP.

Gumminess is defined as the energy required to break down a semi-solid food material until it is ready to be swallowed. Gumminess measured in TPA analysis is the parameter obtained by multiplying the hardness and cohesiveness values (Göksel 2011; Türker, 2016). As a result of the analysis, a significant ($p < 0.05$) increase was determined in the gumminess value as the WRP substitution ratio increased. The increase in the gumminess value was due to the fact that this parameter is associated with the hardness parameter.

Springeness is defined as the product's rate of returning to its original height between the first compression and the second compression cycle in instrumental analyses and the elasticity is expected to be high in bakery products such as cakes (Göksel 2011). As seen in Table 4, the springeness value decreased statistically as the WRP substitution ratio increased ($p < 0.05$). It was thought that springeness decreased due to the increase in dietary fiber content and hardness. Similar results were reached in the studies conducted by Adegunwa et al. (2019), Kırbaş et al. (2019), and Topkaya & Isik (2019).

Chewiness is defined as the energy required to break a solid food into pieces and make it swallowable as well as the number of chews required until the product becomes swallowable. Chewiness is calculated by multiplying the hardness, cohesiveness, and springiness values in the TPA test, and is a parameter that is closely associated with hardness and cohesiveness (Türker, 2016). As a result of the analysis, it was determined that the chewiness value significantly ($p < 0.05$) increased as the WRP substitution ratio increased.

The results found in this study regarding hardness, gumminess, and chewiness parameters were similar to those reported in the studies conducted by Sharoba et al. (2013), Kaur et al. (2017), Türker (2016), Hosseini Ghaboos et al. (2018), and Topkaya & Isik (2019). In the study by Sharoba et al. (2013), the rheological properties of the cakes produced by substituting wheat flour with carrot pulp, orange waste, potato peel, and green pea peel at ratios of 5, 10, 15, and 20%, hardness, gumminess and chewiness values of the cakes were found to increase as the substitution ratio increased. In the study conducted by Kaur et al. (2017), hardness, gumminess, and chewiness values were higher in muffins produced with 100% green banana flour than in muffins produced with wheat flour. In the study of Türker (2016), gluten-free cakes were produced by substituting rice flour with green banana peel at ratios of 5, 10, 15, and 20% or with green banana at ratios of 20, 40, 60, and 80%. It was reported that these additions significantly increased the hardness, gumminess, and chewiness values of the cakes. In the study by Hosseini Ghaboos et al. (2018), it was determined that the hardness, gumminess, and chewiness values of cakes increased as the ratio of pumpkin powder substituted for flour (0-20%) increased. In the study conducted by Topkaya & Isik (2019), the hardness, gumminess, and chewiness values increased as the pomegranate peel powder substituted for wheat flour (5, 10, 15%) in cakes increased.

3.4 Microstructure of muffin samples

SEM images of the cakes are given in Figure 3. It was observed that the cakes became uneven in surface and had smaller pores as the WRP substitution increased. This smaller and denser pore structure in the cakes is thought to be due to the WRP containing higher dietary fiber compared to rice flour. Dietary fibers have a water-binding capacity. The high dietary fiber content of WRP caused the cakes to have tight texture, low volume, and small pores.

In their study, Saeidi et al. (2018) investigated the effects of pomegranate seed powder and transglutaminase enzyme substitution to rice flour on gluten-free cakes and determined that cakes substituted with pomegranate seed powder and transglutaminase enzyme had smaller pores in SEM images of the internal structure of the samples.

Kırbaş et al. (2019) examined the effects of substituting apple, carrot, and orange pulp powder for rice flour at different ratios on gluten-free cake quality. In the study, it was observed that there were great differences between the SEM images of the gluten-free control cake with rice flour and the cakes with pulp powder and that the cakes had a more uneven and irregular structure as the pulp ratio increased. In the study, it was also observed that the appearance changed according to the type and ratio of fruit pulp added and that the gluten-free cake with 15% carrot pulp powder substitution had the most irregular and uneven structure.

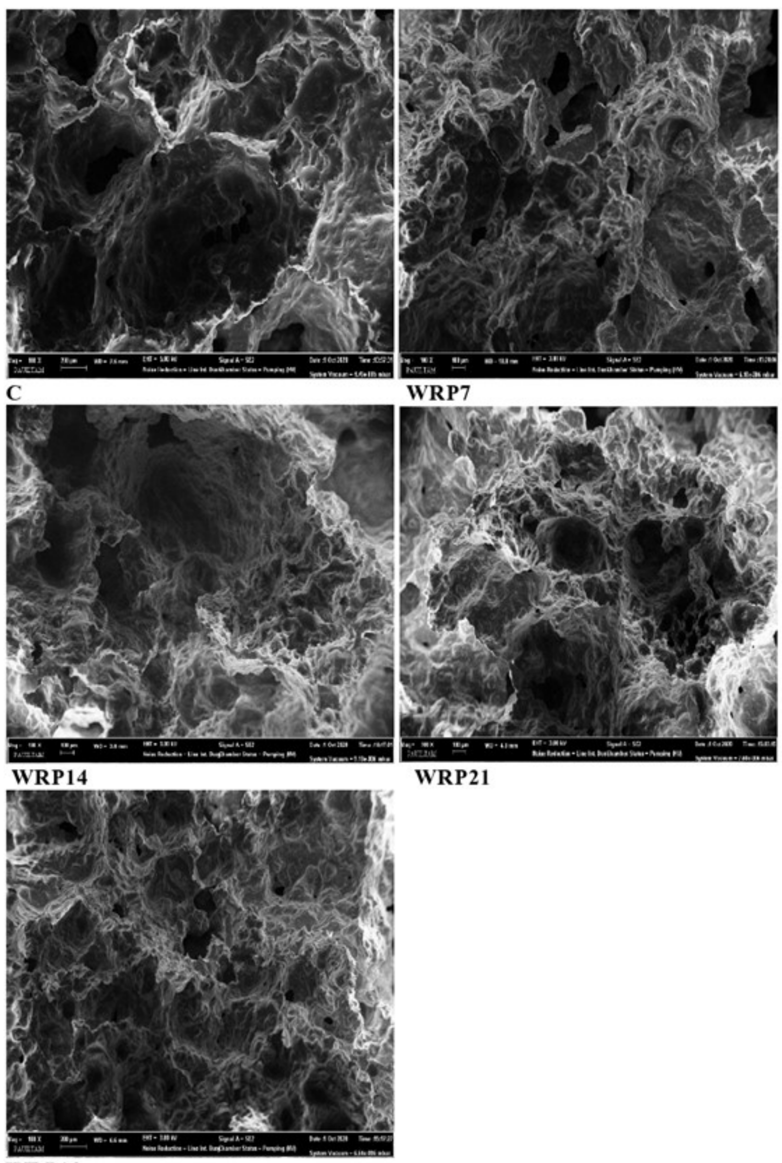

Figure 3. SEM micrographs of muffin samples for inner structure at 200x magnification. C: Control gluten free muffin, WRP7: Gluten free muffin of whose 7% of rice flour was substituted with WRP, WRP14: Gluten free muffin of whose 14% of rice flour was substituted with WRP, WRP21: Gluten free muffin of whose 21% of rice flour was substituted with WRP, WRP28: Gluten free muffin of whose 28% of rice flour was substituted with WRP.

Table 5. Sensory analysis results of gluten free muffin samples.

Parameter	C	WRP7	WRP14	WRP21	WRP28
Crust color	5.25 ± 1.08[ab]	5.48 ± 1.01[a]	5.56 ± 1.13[a]	4.67 ± 1.26[b]	5.00 ± 1.32[ab]
Crumb color	5.19 ± 1.08[ab]	5.27 ± 1.02[ab]	5.60 ± 1.12[a]	4.67 ± 1.23[b]	4.90 ± 1.19[b]
Odor	5.14 ± 1.01[ab]	5.40 ± 0.96[a]	5.33 ± 1.21[a]	4.69 ± 0.95[b]	4.69 ± 1.01[b]
Taste	5.10 ± 1.26[ab]	5.27 ± 1.11[a]	5.41 ± 1.11[a]	4.31 ± 1.43[c]	4.44 ± 1.38[bc]
Crumb texture	5.31 ± 0.97[a]	5.31 ± 0.99[a]	5.58 ± 1.05[a]	4.27 ± 1.20[b]	4.46 ± 1.17[b]
Chewiness	5.33 ± 1.02[ab]	5.34 ± 1.02[a]	5.48 ± 1.03[a]	4.60 ± 1.21[c]	4.73 ± 1.09[bc]
After taste	5.12 ± 1.20[ab]	5.31 ± .1.01[a]	5.42 ± 1.03[a]	4.31 ± 1.17 [c]	4.58 ± 1.14[bc]
Overall acceptability	5.17 ± 1.10[a]	5.31 ± 1.10[a]	5.54 ± 1.07[a]	4.50 ± 1.17[b]	4.54 ± 1.11[b]

C: Control gluten free muffin, WRP7: Gluten free muffin of whose 7% of rice flour was substituted with WRP, WRP14: Gluten free muffin of whose 14% of rice flour was substituted with WRP, WRP21: Gluten free muffin of whose 21% of rice flour was substituted with WRP, WRP28: Gluten free muffin of whose 28% of rice flour was substituted with WRP. Different superscript letters (a, b, c, …) in rows indicate statistical differences ($p < 0.05$).

3.5 Sensory evaluation of muffin samples

The sensory properties of foods are considered an important indicator of consumers' preferences since consumers test the sensory properties of the product when purchasing it. Some significant changes were observed in the sensory properties of the cakes with the addition of WRP in this study (Table 5).

Control, WRP7, and WRP14 cakes were found to be statistically similar ($p > 0.05$) in terms of all sensory properties. In addition, WRP14 had the highest scores in terms of internal color, external color, texture, chewiness, taste, impression after taste, and overall acceptability. Although the cakes with 21% and 28% WRP substitutions were less liked than the other cakes in all parameters, they scored above 4.00, which corresponds to moderate liking. In the statements made by the panelists, it was stated that the cake with 28% substitution left an astringence taste in the mouth.

In the study conducted by Hoque & Iqbal (2015) in which they produced cakes by substituting wheat flour with 0%, 10%, 20%, and 30% WRP, it was reported that the cake containing 10% WRP scored the highest in terms of color, texture, taste, and general acceptability parameters.

In the study conducted by Badr (2015), it was determined that breads with 3 and 6% WRP substitution were similar to the control bread in terms of odor, shape, taste, crust color, internal color, internal texture, and general acceptability parameters ($p > 0.05$). In the study, a decrease was observed in sensory analysis scores, when the ratio of substituted WRP exceeded 6%, inversely proportional to the increasing ratio of WRP.

In their study, Olaitan et al. (2017) produced cookies by substituting wheat flour with WRP at ratios of 0.0, 2.5, 5.0, and 7.5% and reported that cookies containing 2.5% and 5.0% WRP were similar to the control sample in terms of crispiness, texture, impression after taste, and general acceptability parameters ($p > 0.05$).

In the study conducted by Naknaen et al. (2016), it was found that cookies containing 10% WRP were similar to the control sample in terms of color, appearance, texture, taste, and general acceptability parameters. These parameters were found to decrease as the watermelon rind ratio increased and it was stated that acceptable quality cookies could be produced with the addition of up to 20% WRP in terms of sensory properties. It was suggested that the reason for the decrease observed in the taste score with the increase in the WRP ratio may be associated with the mild bitterness and sourness caused by the polyphenols in WRP.

4 Conclusion

Gluten-free products are products that do not have a wide product range, and are generally poor in beneficial nutrients. In this study, the purposes of producing gluten-free cake with WRP were to expand the product range of celiac people, to benefit from the functional nutrients of WRP and to play a role in decreasing environmental pollution problem. At the end of the study, it has been determined that WRP had a high potential for use in gluten-free cakes to enhance product with some beneficial nutrient components, and in the light of sensory analysis, it is recommended to produce gluten-free cakes with up to 14% substitution rate.

Conflict of interest

The author declares no conflicts of interest.

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Author contributions

Cansu ÇELİK - Production of muffins, laboratory analysis, software, data curation. Fatma ISIK - Project administration, methodology, writing - original draft, writing - review & editing.

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