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EFFECTS OF ADDING JERUSALEM ARTICHOKE (*HELIANTHUS TUBEROSUS*) ON THE QUALITY AND NUTRITIONAL VALUE OF GLUTEN-FREE BREAD

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ABSTRACT
Jerusalem artichoke, a plant that can be grown in areas with limited irrigable land, contains valuable macro and micro nutrients. Nowadays, there is an increased demand for gluten-free products. In this study, the physical, chemical, microbiological, and sensory effects of adding Jerusalem artichoke to gluten-free bread production were investigated. As a result of the study, it was determined that as the amount of Jerusalem artichoke powder increased in the gluten-free bread formulation, the specific volume, baking loss, moisture, and pH of the bread decreased, while the amounts of fiber and ash increased. Additionally, the selenium, calcium, and magnesium contents in the bread also increased significantly ($P < 0.05$). According to sensory evaluation results, gluten-free bread with 10% Jerusalem artichoke addition received the highest score in overall appreciation. The addition of Jerusalem artichoke powder to gluten-free bread dough improved the crumb and external appearance of the bread and eliminated some quality defects.
Keywords: Gluten-free bread, nutritional value, *Helianthus tuberosus*, microbiological quality, sensory analysis

YERELMASI (*HELIANTHUS TUBEROSUS)* İLAVESİNİN GLUTENSİZ EKMEK KALİTESİ VE BESİN DEĞERİ ÜZERİNDEKİ ETKİLERİ

ÖZ
Sulanabilir arazilerin kısıtlı olduğu yerlerde yetiştirilebilen bir bitki olan yer elması (*Jerusalem artichoke*), değerli makro ve mikro besinleri bünyesinde barındırır. Günümüzde glutensiz ürünlere olan talep artmıştır. Bu çalışmada Jerusalem artichoke ilavesinin glutensiz ekmek üretimine fiziksel, kimyasal, mikrobiyolojik ve duyusal etkileri araştırılmıştır. Çalışma sonucunda glutensiz ekmek formülasyonunda Jerusalem artichoke tozu miktarı arttıkça ekmeğin özgül hacminin, pişme kaybının, nem ve pH'ının azaldığı, lif ve kül miktarlarının ise arttığı belirlenmiştir. Ekmekteki selenyum, kalsiyum ve magnezyum içeriği de önemli ölçüde artmıştır ($P < 0.05$). Duyusal değerlendirme sonuçlarına göre, genel beğenide en yüksek puanı %10 yer elması ilaveli glutensiz ekmek almıştır. Glutensiz ekmek hamuruna *Jerusalem artichoke* tozu eklenmesi, ekmeğin iç yapısını ve dış görünümünü iyileştirmiş ve bazı kalite kusurlarını ortadan kaldırmıştır.
Anahtar kelimeler: Glutensiz ekmek, besin değeri, *Helianthus tuberosus*, mikrobiyolojik kalite, duyusal analiz

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INTRODUCTION

Gluten is a type of protein group found in grains such as barley, wheat, and rye and is one of the main elements required to produce quality bread. It is responsible for the dough's elasticity, appearance, and extensibility. It has an important role in the development of the rheological and baking properties of the dough and the stabilization of the structure (Gallagher et al., 2004; Paciulli et al., 2016). Gluten turns the dough into a hard but flexible structure with water, and its adhesive properties make it elastic and give it a chewy feature, allowing the dough to rise during baking, creating a soft and crispy texture.

Some people cannot digest gluten and have a special sensitivity to gluten. The most important of these disorders is celiac disease and gluten-related intolerance, which, together with the intake of gluten-containing foods, develop a malabsorption syndrome that occurs because of the deterioration of the natural structure of the intestines (Karaahmet, 2018). A gluten-free diet is the most reliable and basic treatment for celiac patients. In recent years, there has been an increase in the consumption and demand for gluten-free products due to the increasing number of individuals diagnosed with gluten-related disorders. Some problems still exist in producing gluten-free bread with the desired nutritional value and technological features. Unless fortified, gluten-free products may not contain the same level of minerals, vitamins, and dietary fiber as gluten-containing products (Wierdsma et al., 2013).

Studies on the development of functional foods have increased in the food industry as people focus more on healthy nutrition and demand additional benefits from foods beyond nutrition. Jerusalem artichoke tubers are a valuable vegetable that is suitable for developing functional food with its content, which is high-yield; and low-cost compared to traditional agricultural products, and is highly resistant to frost, pests, and diseases (Yang et al., 2015). Jerusalem artichoke, which contains high amounts of inulin, can be a valuable component of food products (Murphy, 2001). Jerusalem artichoke is from the family of *Compositeae* (central flowers). It is an important and valuable food with macro- and microelements, also known as "*Helianthus tuberosus*" in Latin and "Jerusalem artichoke, sunroot, sunchoke, earth apple, wild sunflower, and topinambur" in English (Monti et al., 2005; Tassoni et al., 2010; Ma et al., 2011). It is a good source of vitamins (C, B, and β-carotene), minerals (iron, potassium, calcium, sodium, and selenium), and dietary fiber (Radovanovic et al., 2014). Its antioxidant, anticancer, antidiabetic, antifungal, and antirheumatic activities are known, and it has gelling ability. The main nutrient of Jerusalem artichoke tubers is inulin instead of starch (Abou-Arab et al., 2011). Inulin is widely used in functional foods worldwide. Known as bifidogenic and prebiotic, inulin attracts the attention of consumers who care about conscious and healthy nutrition by supporting healthy gastrointestinal flora and mineral absorption from the colon. It is also preferred in the food industry because of its fat and sugar replacement, viscosity, and texture-changing properties (Mudannayake et al., 2022). It can improve the nutritional value of the final product by increasing the dietary fiber content, reducing the calorie content, and increasing the prebiotic capacities. Including dietary fibers in bakery products is known to improve product properties such as reducing loaf duration, increasing firmness, and prolonging freshness (Elleuch et al., 2011).

Although there are studies investigating the effect of adding Jerusalem artichoke to some bakery products (Cetin Babaoglu et al., 2021; Gedrovica et al., 2011; Ponomareva et al., 2009; Ozgoren et al., 2019), there are limited studies on its use in gluten-free bread production. This study aims to determine whether the addition of Jerusalem artichoke powder produced by a simple drying method to gluten-free bread would increase the nutritional content, technological and sensory qualities of the bread, and determine its microbiological effects.

MATERIALS AND METHODS

The Jerusalem artichoke tubers used in the study were obtained from the district market in

Istanbul/Türkiye (in December), and gluten-free flour mixture (Sinangil Glutensiz Un, Türkiye), salt (Billur Sofra Tuzu, Türkiye), sugar (Dogan Sofra Şekeri, Türkiye), and sunflower oil (Yudum Ayçiçek Yagi, Türkiye) were obtained from the local market in branded and closed packaging.

Production of Jerusalem Artichoke Powder
Fresh Jerusalem artichoke tubers do not have a long shelf life. To solve this problem and facilitate its use, it was aimed to turn the tubers into a smaller volume and lighter powder. For this purpose, fresh and undamaged Jerusalem artichoke tubers were washed with drinking water, sliced at 0.2 mm thickness with a slicing machine (Tefal slicer, France), and dried in an industrial drying oven (Bosch, HBF514BSOT, Germany) at 60±5°C for 8 hours. The dried slices were ground into powder with a grinding machine (Moulinex FP546810, France) for 2 minutes at the medium setting. The Jerusalem artichoke turned into powder was passed through a 35-mesh sieve (Figure 1).


Figure 1. Jerusalem artichoke powder

Production of Bread
The doughs with the contents shown in Table 1 were prepared by adding Jerusalem artichoke powder at different rates (0%, 5%, 10%, 15%, 20%, and 25%) to the gluten-free flour mixture and mixing in a professional kneading machine (Moulinex QA502G, France) at room temperature for 15 minutes. The gluten-free flour mixture consisted of cornstarch, rice flour, sugar, thickeners (pectin, xanthan gum), and raising agents (sodium bicarbonate, sodium acid pyrophosphate). The prepared doughs were covered with stretch film and left to ferment for 45 minutes in the oven (Nuve, EN300, Türkiye) set at 55˚C, and at the end of the fermentation period, they were divided into 100-gram pieces and shaped. It was baked in an oven preheated to 200˚C (Bosch HBF514BSOT, Germany) for 30 minutes.

Fourier Transform Infrared (ATR-FTIR) Spectroscopy
The functional units of the gluten-free flour mixture, Jerusalem artichoke powder, and Jerusalem artichoke-added bread samples were identified using FTIR (Skendi et al., 2018). The sample was placed in the ATR FTIR device with the pressing method and scanned in the range of 4000–400 cm^{-1}. The position of absorption peaks in the resulting spectrum was used to determine the presence of specific functional groups. FTIR spectroscopy spectrum plots were created using OriginPro 2024 (v10.1) (Origin Lab, Northampton, MA, USA).

Weight loss, volume, and inner and outer color of bread
After fermentation, the bread dough was weighed with a scale (And HR-250AZ-4, Japan), and its weight was determined. After baking, the weight of these breads was measured again, and the weight difference was determined as a percentage. Three repetitions were performed for weight loss, and the average value was given. To determine the bread volume, the volume (ml) values were found based on the seed displacement method. Results were reported as the average of three measurements performed on a freshly made loaf (AACC, 2001). Three replications were made to determine the bread's specific volume, and the results were averaged. A color measuring device (Hunter colorimeter, AOB 551, USA) was used for the inner and outer colors of the bread.

Table 1. Gluten-free bread formulations

Bread number	JA %	Gluten-free flour mixture (g)	Baker's yeast (g)	Salt (g)	Sugar(g)	SO** (g)	Water (ml)
1	0	200	6	3	3.6	4	110
2	5	190	6	3	3.6	4	100
3	10	180	6	3	3.6	4	92.8
4	15	170	6	3	3.6	4	86
5	20	160	6	3	3.6	4	80
6	25	150	6	3	3.6	4	78

[a]JA: Jerusalem artichoke powder ** SO: Sunflower oil

Textural Features

Texture analysis was performed on the day of bread production. Samples of 2 pieces of 3x3 cm were taken from the breads. Measurements of these samples were made with TA. XT plus C texture analysis instrument (Stable Microsystems, Godalming, Surrey, England) with a 1 mm cylinder probe at 5 mm/s speed, 10 mm penetrating depth, and 5 g detection force.

Sensory Evaluation

Sensory experiments were performed according to established ethical guidelines and informed consent from the participants. Thirty untrained panelists were selected from Istanbul Aydin University students and lecturers, and a hedonic scale of 1 (extremely bad) to 5 (very good) was used (Altug Onogur and Elmaci, 2011). Sensory evaluation of breads was performed on the day of bread production. The panelists were asked to evaluate the samples regarding pore structure, texture, crust color, inner color, taste and aroma, foreign taste and odor, and general appreciation criteria.

Chemical analysis

Moisture determination was made according to the method numbered AACC 44-01.01**,** and moisture content (%) was determined (AACC, 1999a). The pH measurement was made with the device pH meter (Hanna 211, Romania). In the determination of sugar and invert sugar, the Lane-Eynon method was used, which is based on the reduction of Cu-II-oxide in the Fehling solution of invert sugar to water-insoluble Cu-I-oxide in an alkaline environment and boiling temperature (AOAC, 1990).

Determination of saturated and unsaturated fatty acids as a percentage was made according to TGK 2014/53 (TGK, 2014).

Ash determination was made according to the method numbered AACC 08-01.01 (AACC, 1999b**)**. The ash amount (%) was calculated from the weight difference (Ozkaya and Kahveci, 1990). The amounts of selenium, potassium, magnesium, and calcium (mg/kg) in the Jerusalem artichoke-added breads were determined by the ICP-MS (Agilent 7700e) device, according to the NMKL-186 (Nordic Committee on Food Analysis) method (NMKL, 2007). Dietary fiber analysis was performed according to the AOAC 991.43 method (AOAC, 1995).

Microbiological Analysis

After the bread was taken out of the oven, they were cooled under aseptic conditions without contamination, put into sterile oven bags, and stored at 25°C until analysis. Microbiological analyses were made on the 1st, 3rd, 5th, and 7th days from each group of bread. From the bread samples, 10 g were weighed, and 90 ml of sterile sodium chloride solution (0.01% sodium chloride solution) was transferred after being placed in sterile bags. Then, homogenization was done with a stomacher device (Interscience Jumbomix 3500VP, France). 10-fold dilutions were prepared and inoculated in two parallels on suitable media. Microbiological analyses were performed according to the ISO 4833-1:2013 standard (ISO, 2013) and Unachukwu and Nwakanma (2018).

Statistical Analysis

The data were analyzed by ANOVA using the SPSS 22 program (SPSS Inc., Chicago, IL, USA). Duncan's Multiple Range Test (DMRT) was used to determine the difference between the means when the difference between samples was significant (SPSS Inc., Chicago, IL, USA). $P<0.05$ was accepted as the statistical significance level.

RESULTS AND DISCUSSION

Baking gluten-free bread is different from traditional bread making. Failure to provide the viscoelastic properties of gluten is an important technological problem. Gluten is necessary to capture the carbon dioxide produced during the leavening of bread dough; the lack of a protein network to provide this in gluten-free bread makes it very difficult to obtain an acceptable texture (Gallagher et al., 2004). This study aims to increase the nutritional value of gluten-free bread with the addition of Jerusalem artichoke, gain a functional feature, produce gluten-free bread with improved product quality, and create an alternative bread formulation. All trials were performed in triplicate, and all the results are given as the average of the three trials.

ATR-FTIR Spectrum of the Gluten-Free Flour Mix

The ATR-FTIR spectrum of the gluten-free flour mix is shown in Figure 2. When the main characteristic groups were observed in the FTIR spectrum of the gluten-free flour mixture, the band showing the vibrations of intermolecular and intramolecular hydroxyl (OH) groups by stretching and bending was detected in the range of 3650–3000 cm^{-1}. The band attributed to the vibration caused by the stretching of the bond (CH) of the starch anhydro-glucose unit is observed in the range of 3000–2850 cm^{-1} (Anchondo-Trejo et al., 2020). The absorption bands at 3287 cm^{-1}, 2919 cm^{-1}, and 1642 cm^{-1} correspond to O-H, C-H, and O-H stretching, respectively. Furthermore, the absorbance peak at 1412 cm^{-1} implied the presence of C-H symmetrical scissoring of the CH_2OH moiety. 1200–800 cm^{-1} are the fingerprinting regions of starch molecules. These characteristic functional groups in wheat flour and rice flour have been previously reported by different researchers (Ashwar et al., 2016; Bhat et al., 2016; Jan et al., 2022). The sugar region" (950–1200cm^{-1}) and "the anomeric region" (750–950 cm^{-1}) are considered important spectral regions for structural characterization of polysaccharides. In the region between 400 cm^{-1} and 1250 cm^{-1}, characteristic starch bands are observed. The band at 929 cm^{-1} is attributed to vibrations in the skeleton of α-1.4 glycosidic bonds, the band at 860 cm^{-1} to CH and C-H_2 deformation, and the band at 762 cm^{-1} to C-C stretching (Anchondo-Trejo et al., 2020). The absorption spectrum of 995 cm^{-1} is typical for most starches. This absorption band corresponds to the C=O extension of the glucose ring (Kacurakova et al., 2000; Wang et al., 2007; Wilson et al., 1988).

ATR-FTIR Spectrum of Oven-Dried Jerusalem Artichoke Powder

The ATR-FTIR spectrum of oven-dried Jerusalem artichoke powder contains general information about its molecular skeleton and functional groups. The ATR-FTIR spectra of the dried powder of Jerusalem artichoke are shown in Figure 2. When the ATR-FTIR spectrum was examined, characteristic polysaccharide peaks were observed. A broad absorption peak for O–H stretching vibrations is observed at 3298 cm^{-1}, and the absorption peak for C–H stretching vibrations is observed at 2925 cm^{-1}. Afoakwah (2022) determined these peaks at 3354 cm^{-1} for O–H stretching vibrations and absorption peaks for C–H stretching vibrations at 2931 cm^{-1}, and Shao et al. (2021) determined these peaks at 3370 cm^{-1} and 2950 cm^{-1}. C–O and C–C stretching and C–OH bending vibrations, which express a characteristic feature of a polysaccharide, were observed in a wide region of 900–1200 cm^{-1}. The absorption peak near 1024 cm^{-1} is attributed to the C-OH stretching vibration. Fructans from Jerusalem artichoke exhibited a band at 1596 cm^{-1}. This region is associated with the vibration modes of peptide bonds (amide I and II) (Diaz et al., 2022). Abou-Arab et al. (2011) determined the (C=C) functional groups at 3302–3360 cm^{-1}, (OH stretching) 2931–2932 cm⁻¹ (CH stretching), and 1592–1631 cm⁻¹. Differences in the spectrum may result from different structures. Absorption bands below 1500 cm-1 generally correspond to C-C, C-O-C, and C-OH vibration modes and glycosidic linkage vibrations and are called the “fingerprint” region (Smith et al., 1999). This area provides important information about organic compounds such as sugars and organic acids present in the sample; however, it is difficult to analyze due to its complexity. The presence of FTIR absorption bands at 1000 and 1140 cm-1 corresponds to stretching vibrations of (C-OH) side groups and (C-O-C) glycosidic bond vibrations (Liu et al., 2016).

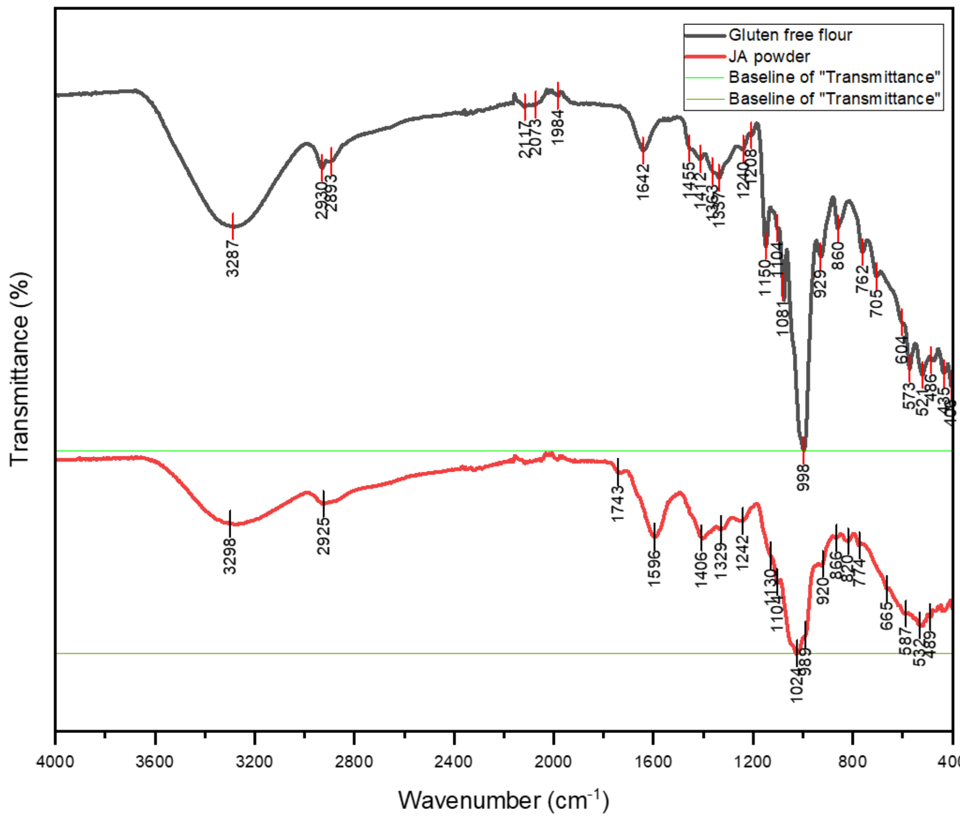

Figure 2. ATR-FTIR spectra of gluten-free flour and oven-dried powder of Jerusalem artichoke (JA)

ATR-FTIR Spectra of the Bread

The ATR-FTIR spectra of the breads are shown in Figure 3. Visual examination of the FTIR spectra of all bread samples revealed that blending Jerusalem artichoke and flour in different proportions reflected similar absorption bands and did not cause any significant changes in the functional groups studied. The broad main absorption peak around 3000–3600 cm⁻¹ indicates the stretching vibrations of intermolecular or intramolecular O-H bonds. The narrow, sharp, but small peaks centered at 2930 and 2856 cm⁻¹ are largely contributed to by symmetric stretching vibrations of the C–H bonds of $–CH_2/–CH_3$ alkyl groups. The narrow peak centered at 1744 cm corresponds to the presence of C=O stretching vibrations. In terms of protein structure analysis, FTIR spectra between 1500 and 1800 cm-1 provide important information. The “sugar region” (950–1200cm⁻¹) and the “anomeric region” (750–950 cm⁻¹) are considered important spectral regions for the structural characterization of polysaccharides (Skendi et al., 2018). The waves between 1200 and 800 cm-1 are characteristic of the backbone vibrations of CO, CN, and CC bonds, which are assigned to the presence of polysaccharides in bread flour (Sivam et al., 2013). Starch is the main constituent of the examined flours and has a fundamental role in dough production; the intense peak at 1012 cm⁻¹ is attributed to C-O stretching and CH_2 bending vibrations of $–CH_2OH$ units (Kacurakova et al., 2000; Wang et al., 2007; Wilson et al., 1988). A less intense peak at 1079 cm^{-1} was also noticed in all samples, which was attributed to C–O–H bending vibrations of glycosidic linkages. Similarly, another peak at 1145 cm^{-1} was associated with C-H stretching of starch (Mathlouthi et al., 1987).

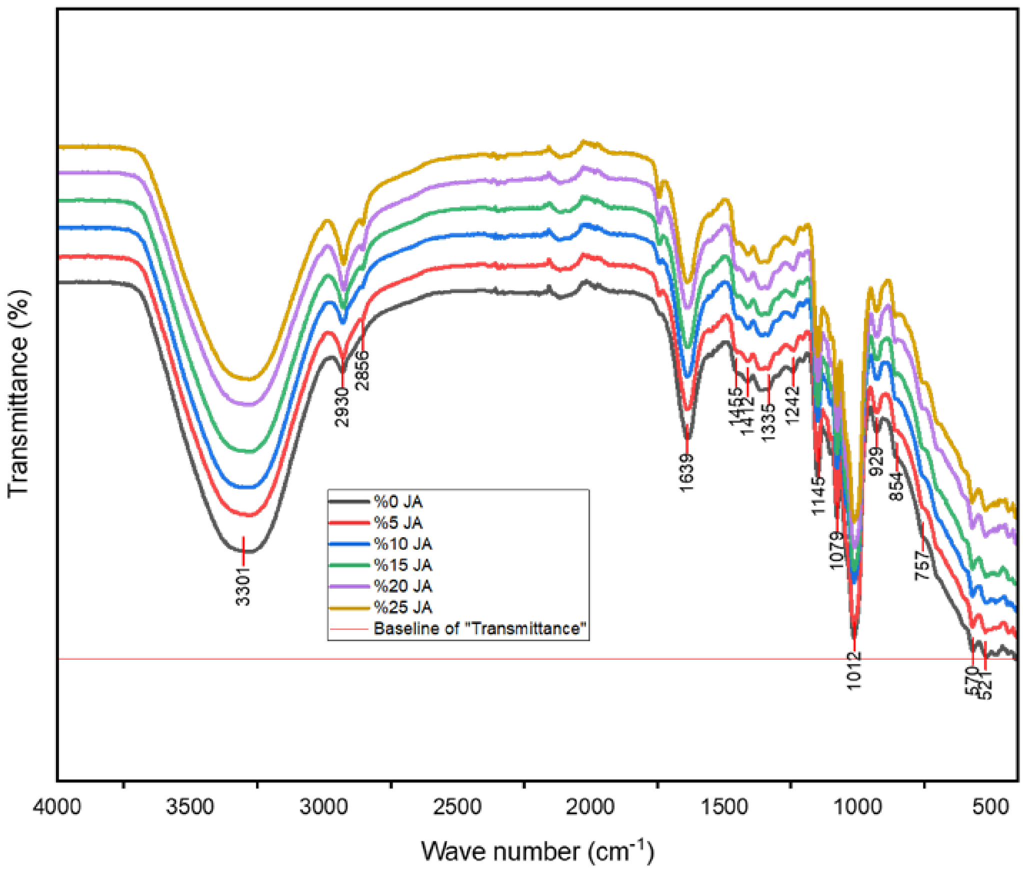

Figure 3. ATR-FTIR spectra of the bread samples incorporated with 0-25% Jerusalem artichoke (JA).

Weight Loss and Specific Volume of the Bread

According to the data obtained in this study, the highest weight loss occurred in bread with 5% Jerusalem artichoke, and this was determined as the closest value to bread produced as a control (0% Jerusalem artichoke). The lowest weight loss was observed in bread containing 20% and 25% Jerusalem artichoke. As a result of the analysis, the specific volume of the control bread (0%) obtained from the gluten-free mixture was higher than that of the other samples, and the specific volume decreased as the Jerusalem artichoke powder content increased. Weight loss and specific volume results of bread samples and statistical evaluation results are given in Table 2.

In our study, the specific volume of bread without Jerusalem artichoke was 1.85 g/ml. In comparison, the specific volume of breads prepared by Yilmaz and Dogan (2015) from 8 different gluten-free flour mixtures obtained from the market was 2.08-2.89 g/ml. The specific volume of our Jerusalem artichoke-added gluten-free bread was 1.51-1.25 g/ml. It is thought that the reason for the different results obtained from the research of Yilmaz and Dogan (2015) is the use of different flour mixtures. In the gluten-free breads produced in our study, a decrease was observed in the specific volume of the breads as the Jerusalem artichoke powder increased. In the study of Cetin Babaoglu et al. (2021), including 20% Jerusalem artichoke powder in sourdough wheat bread significantly decreased the specific volume of sourdough bread. In the gluten-free breads with taro plant (*Colocasia esculenta*) prepared by Pehlivan (2016), the specific volume of the bread decreased as the taro content increased. These results are consistent with the results of our study. There are also studies with different results. Praznik et al. (2002) determined an increase in bread volume, while Hager et al. (2011) did not find a significant change in volume by adding inulin. Peressini and Sensidoni (2009) reported that adding inulin causes a decrease or increase in the specific volume, depending on the type of flour. Ermosh et al. (2020) determined an increase in the specific volume of bread produced by adding Jerusalem artichoke powder to a mixture of wheat and rye flour.

Table 2. Weight loss and specific volume result graph of the bread samples

JA (%)	n	Weight loss (%)*	Specific volume (ml/g)*
0	3	13.50±0.67^{d}	1.85±0.01^{e}
5	3	12.00 ±0.37^{c}	1.51±0.01^{d}
10	3	11.30 ±0.09^{bc}	1.42±0.01^{c}
15	3	11.00 ±0.34^{b}	1.30±0.06^{b}
20	3	9.00 ±0.15^{a}	1.25±0.02^{a}
25	3	9.20 ±0.03^{a}	1.26±0.06^{a}

JA: Jerusalem artichoke powder. * Means within the same column with different superscript letters indicate a significant difference using the DMRT test ($P < 0.05$). Each represented mean±standard error of three samples (n).

In our study, the weight loss of breads without Jerusalem artichoke was 13.5%, while the specific volume of breads prepared by Yilmaz and Dogan (2015) from 8 different gluten-free flour mixtures obtained from the market was 17.92-20.97%. Weight loss was 9.20-12.00% in our Jerusalem artichoke-added gluten-free breads. In this study, weight loss decreased as the Jerusalem artichoke content increased, which may be related to the water-holding capacity of the Jerusalem artichoke. The high inulin and fiber content of the Jerusalem artichoke may increase the water-holding capacity as the hydroxyl groups form more hydrogen bonds with water (Shoaib Shehzad et al., 2016). According to another study, inulin can form a protective layer around starch granules, which may limit swelling and amylose release (Vazquez-Gutiérrez et al., 2017).

Bread Color Parameters

According to the data obtained in our study, it was observed that as the Jerusalem artichoke powder content increased, it affected both the inner and crust color values of the breads (Figure 4, Table 3).

When the breads with Jerusalem artichoke addition were compared, a significant difference was found in the L, a, and b values of the crust and inner color of the bread ($P < 0.05$). In general, it was determined that the color quality defects disappeared when the bread containing the Jerusalem artichoke was compared to the control bread (0%) (Figure 4). This makes the crust color more pleasing than gluten-free bread without added Jerusalem artichokes. The color of the bread crust, an important criterion for consumers' bread preference, is influenced by many factors, such as the type of flour used, the quality and quantity of ingredients, and the cooking temperature and duration (Salinas and Puppo, 2015). This color is related to enzymatic and non-enzymatic browning reactions (Maillard reaction) and is an important parameter in bread quality.

This study, along with an increased Jerusalem artichoke content, showed a decrease in the L* and b* values and an increase in the a* value of the crust and outer color. Since the baking time and temperature are the same in all manufactured formulations, we can conclude that the change in formulation caused a noticeable change in the color of the bread with added Jerusalem artichoke compared to the control bread (without Jerusalem artichoke). The results showed that jaundice and whiteness decreased, and redness increased in the bread crust. In the study by Vega et al. (2024), Jerusalem artichoke caused the dough and baked product to become darker. It has been reported that the high presence of inulin supports the Maillard reaction, which is responsible for non-enzymatic browning (Turksoy and Ozkaya, 2006). In the study of Ermosh et al. (2020), wheat bread containing Jerusalem artichoke powder was determined to have a brown crust. It is consistent with the results of this study.

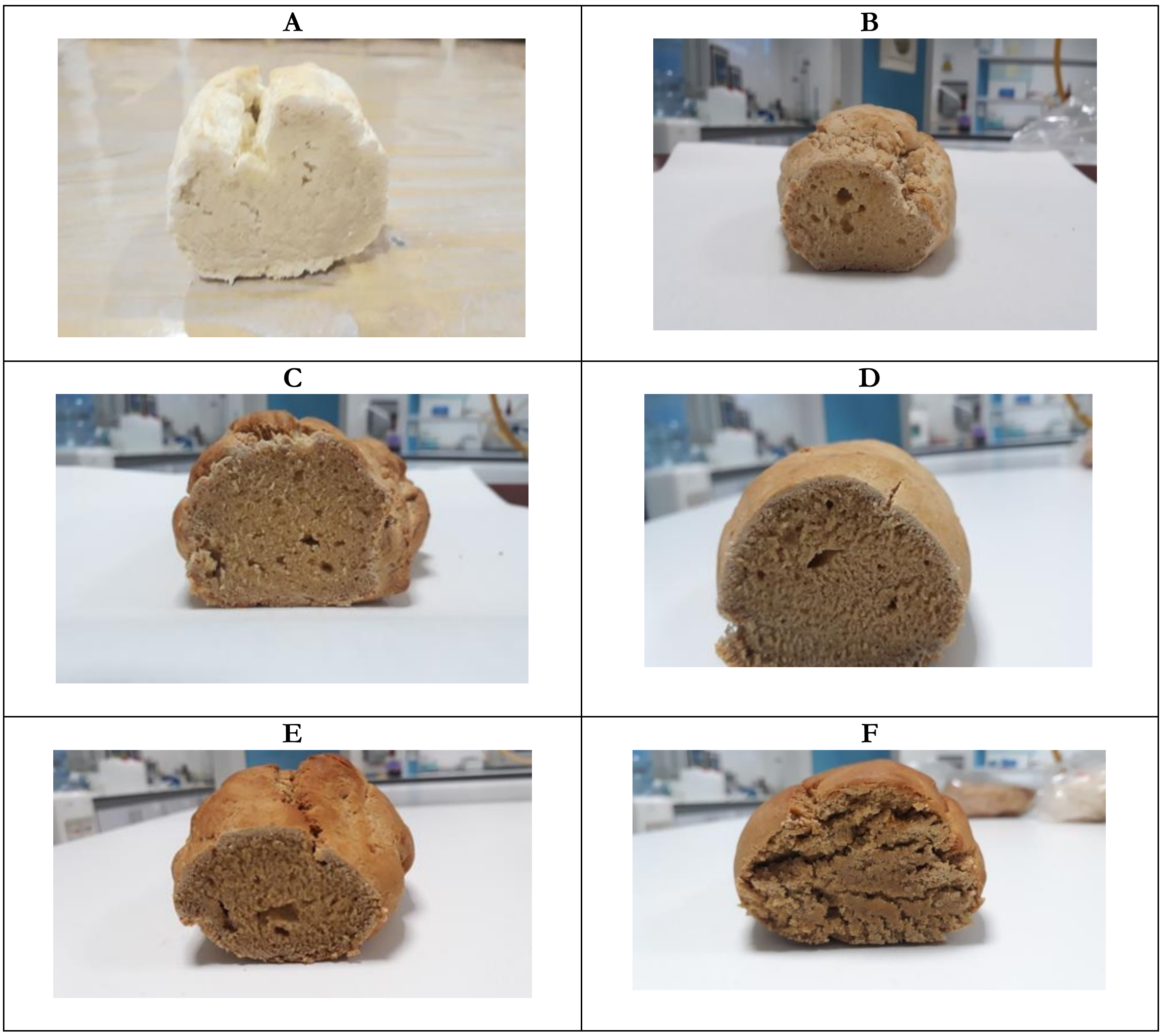

Figure 4. Cross-section photograph of bread with and without Jerusalem artichoke (A: 0% (control bread), B: 5 %, C: 10%, D: 15%, E: 20% and F: 25% JA).

Table 3. The color values of bread

		crust color			crumb color		
JA%	n	L*	a*	b*	L*	a*	b*
0	3	86.65±0.26[f]	3.01±0.12[a]	13.46±0.17[d]	79.95±0.03[f]	0.1±0.01[a]	33.38±0.28[f]
5	3	71.72±0.97[e]	5.37±0.18[b]	13.09±0.01[c]	58.19±0.06[e]	7.67±0.06[b]	26.26±0.07[e]
10	3	62.31±0.65[d]	8.13±0.20[c]	12.76±0.04[c]	48.63±0.23[d]	9.62±0.06[d]	24±0.04[d]
15	3	54.65±1.78[c]	9.55±0.06[d]	12.01±0.01[b]	44.27±0.04[c]	9.69±0.06[d]	21.39±0.04[c]
20	3	49.13±0.28[b]	10.17±0.02[e]	11.37±0.12[a]	43.85±.0.01[b]	9.72±0.03[d]	20.08±0.08[b]
25	3	46.18±0.11[a]	11.65±0.27[f]	11.21±0.07[a]	42.66±0.03[a]	9.36±0.85[c]	19.64±0.05[a]

JA: Jerusalem artichoke powder. * Means within the same column with different superscript letters indicate a significant difference using the DMRT test (P <0.05). Each represented mean ± standard error of three samples (n). L* –Lightness coordinate (L*=0 indicates black and L*=100 is white). a* is the red/green coordinate, +a* indicates red, –a* indicates green. b* is the yellow/blue coordinate and +b* indicates yellow and -b* indicates blue.

While a fresh Jerusalem artichoke tuber contains between 7% and 30% inulin, about 50% of the dry weight of the tuber is inulin (Kays and Nottingham, 2007). In the study of Salinas and Puppo (2015), the brightness (L*) decreased, and the a* and b* values increased during the production of inulin-fortified wheat bread. In their study, Frutos et al. (2008) mentioned that an increase in artichoke fiber increases the bread crust color. Hager et al. (2011) investigated the effect of adding inulin to wheat flour on the color of the bread crust and found that inulin darkened the bread crust and explained this by the fact that inulin leads to a stronger Maillard reaction. Peressini and Sensidoni (2009) observed that crust browning increases with fiber increase. Poinot et al. (2010) determined that adding inulin to white bread accelerates the formation of bread crust and the Maillard reaction and observed an increase in bread crust color (higher a* and b* values) with an increase in the amount of inulin.

The analysis of the inner color of the Jerusalem artichoke-added gluten-free bread showed that the redness increased as the content increased, the L* and b* values decreased, and the structure reached a more lively and normal bread appearance. Radovanovic et al. (2017) determined that bread enriched with 25% Jerusalem artichoke was well-baked, well-shaped, and dark brown inside, which was consistent with the results of this study.

Texture of Bread

In this study, Jerusalem artichoke powder added to gluten-free breads increased the hardness value of the bread. Hardness in bread is usually expressed by a decrease in the softness of the bread core (Gallagher et al., 2004). The results of the textural properties of the bread produced are shown in Figures 5-6 and Table 4. Cetin Babaoglu et al. (2021) determined that adding Jerusalem artichoke powder to the formula in sourdough breads significantly increased the hardness value (P <0.05). Rubel et al. (2014) determined that enrichment with Jerusalem artichoke powder increased the hardness value of bread. According to the results of this study, in gluten-free breads, the chewiness level decreased with increasing Jerusalem artichoke content. Cetin Babaoglu et al. (2021) determined that adding Jerusalem artichoke powder to the formula increased the chewiness value of sourdough breads. Wheat flour containing gluten was used in this study. Barisik and Tavman (2018) showed a positive effect as the chewiness and content increased in gluten-free bread made with chickpea and rice flour.

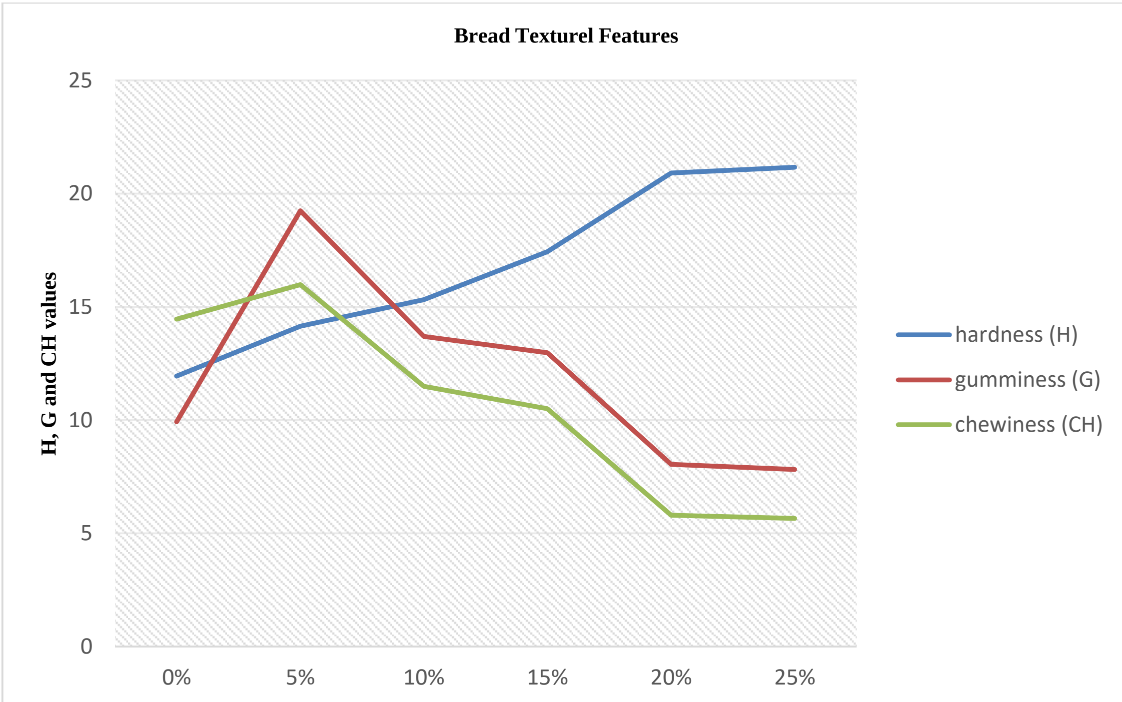

Figure 5. Textural properties of bread samples (hardness, gumminess, chewiness).

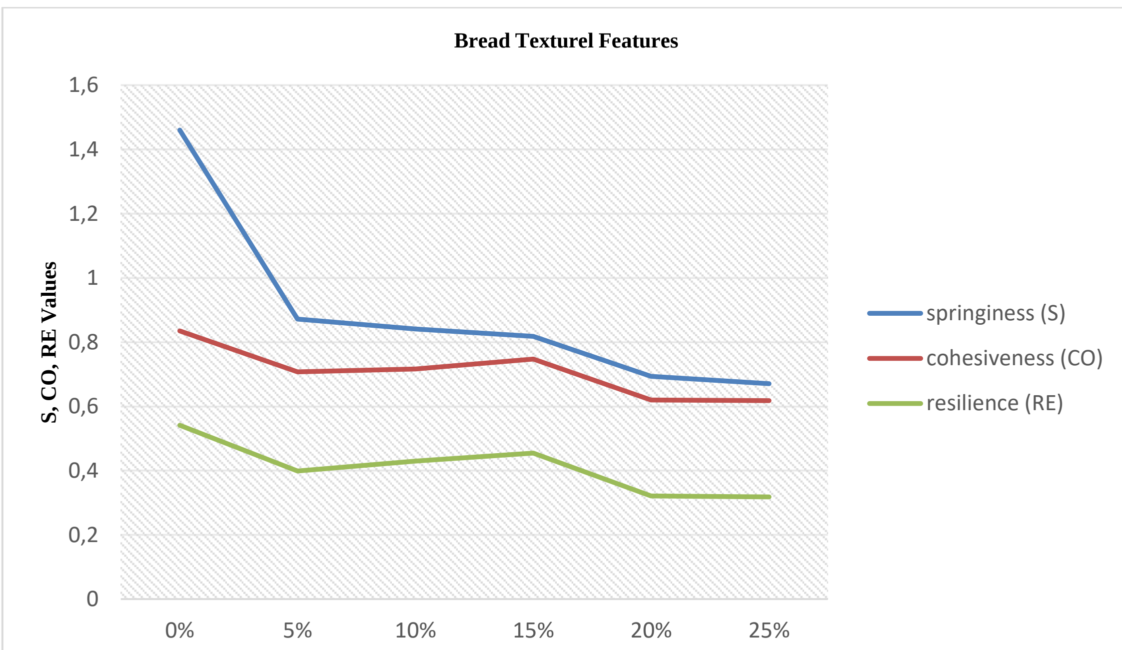

Figure 6. Textural properties of bread samples (springiness, cohesiveness, resilience).

Table 4. Textural properties of bread samples

JA powder (%)	Hardness (g)	Springiness (mj)	Cohesiveness	Gumminess (g)	Chewiness (mj)	Resilience (mm)
0	11.94±0.01^{a}	1.46±0.01^{f}	0.835±0.01^{e}	9.92±0.01^{c}	14.45±0.01^{e}	0.54±0.01^{e}
5	14.15±0.04^{b}	0.87±0.01^{e}	0.71±0.01^{b}	19.25±0.01^{f}	15.99±0.01^{f}	0.40±0.01^{b}
10	15.32±0.08^{c}	0.84±0.01^{d}	0.72±0.01^{c}	13.69±0.01^{e}	11.49±0.01^{d}	0.43±0.01^{c}
15	17.44±0.04^{d}	0.82±0.01^{c}	0.75±0.01^{d}	12.98±0.01^{d}	10.50±0.01^{c}	0.46±0.01^{d}
20	20.92±0.03^{e}	0.69±0.01^{b}	0.62±0.01^{a}	8.051±0.01^{b}	5.81±0.01^{b}	0.32±0.01^{a}
25	21.17± 0.01^{f}	0.67 ±0.06^{a}	0.62±0.01^{a}	7.82±0.01^{a}	5.65±0.01^{a}	0.32±0.0 ^{a}

JA: Jerusalem artichoke powder. * Means within the same column with different superscript letters indicate a significant difference using the DMRT test (*P* <0.05). Each represented mean±standard error of three samples (n).

In this study, increasing Jerusalem artichoke content showed a lowering effect on gumminess. Likewise, the flexibility and elasticity of bread decreased as the Jerusalem artichoke content increased. Wahyono et al. (2016) reported that adding inulin to the bread formula increased the hardness and chewiness values, and the flexibility and stickiness values decreased. In the study conducted by Paciulli et al. (2016), gluten-free bread was produced by adding 10% and 20% chestnut flour to two different commercial gluten-free flour mixtures. The elasticity values of the breads were 0.40-0.45, respectively. As the percentage of Jerusalem artichoke increased, cohesive adhesiveness increased to 15% and decreased after 20%. In a study by Erdemir (2015), the cohesive stickiness of wheat bread was 0.77, and this value was the closest (0.74) to gluten-free bread with a 15% Jerusalem artichoke content.

Chemical Analysis Results

Microbiological and chemical analysis results of Jerusalem artichoke and gluten-free flour used in bread production are given in Table 5. The chemical analysis results of the bread are shown in Table 6.

Table 5. Microbiological analysis and chemical analysis results of Jerusalem artichoke and gluten-free flour mix used in bread production

Sample	Ash	pH	Moisture (%)	Total Bacteria (log_{10})	Total Mold and Yeast (log10)
JA powder	8.170±0.363	4.90±0.001	4.00±0.34	2.27±0.001	<1
Gluten-free flour	1.080±0.21	4.98±0.002	11.83±0.12	1.69±0.001	<1

Table 6. Moisture, pH, and ash analysis results of gluten-free bread with Jerusalem artichoke powder (*P* <0.05)

JA (%)	Moisture %	pH	Ash %
0	28.63±0.005^{e}	5.872±0.001^{e}	1.998±0.001^{a}
5	27.49±0.006^{d}	5.713±0.001^{d}	2.093±0.001^{b}
10	27.49±0.008^{d}	5.654±0.001^{c}	2.309±0.001^{c}
15	26.57±0.003^{c}	5.613±0.001^{b}	2.403±0.001^{d}
20	24.99±0.008^{b}	5.57±0.001^{b}	2.512±0.001^{e}
25	23.98±0.38^{a}	5.574±0.001^{a}	2.751±0.650^{f}

JA: Jerusalem artichoke powder. * Means within the same column with different superscript letters indicate a significant difference using the DMRT test (*P* <0.05). Each represented mean±standard error of three samples (n).

In human health, dietary fibers have positive properties, such as regulating blood sugar, lowering cholesterol levels, and protecting against intestinal cancer and cardiovascular diseases (Kandıralı, 2014). In our study, the amount of dietary fiber, 1.90% in the control bread without Jerusalem artichoke, increased to 2.19% in the gluten-free bread with 25% Jerusalem artichoke powder added (Table 7). It has been reported that adding Jerusalem artichoke powder significantly increased the amount of non-starch polysaccharides in pastry products (cakes, butter biscuits, and honey biscuits), thereby increasing their fiber content, making these products healthier food (Gedrovica et al., 2011). Ponomareva et al. (2009) determined that adding 15% topinambur to rye and wheat bread improves the quality indicators of the finished product, increasing the dietary fiber in it by 0-25%. According to the research of Ozgoren et al. (2019), increasing the content of topinambur powder from 10% to 30% significantly increased the dietary fiber. Karklina et al. (2012), in their study investigating the nutritional value of biscuits by adding different amounts of dried Jerusalem artichoke powder, determined that adding up to 20% of Jerusalem artichoke powder instead of wheat flour increased the dietary fiber to 3.36 g/100 g. Cetin Babaoglu et al. (2021) determined that the total dietary fiber content increased from 2.62 to 5.30/100 g by including 20% Jerusalem artichoke powder in sourdough wheat bread.

Table 7. Some nutritional values of bread samples

JA* (%)	Total Sugar (%)	Dietary Fiber (%)	Energy (kcal/100 g)	S FA (%)	Unsaturated Fatty Acids	
					MFSA (%)	PFSA (%)
0	ND[a]	1.90±0.005[a]	276.5 ±0.006[a]	7.49±0.003[e]	38.05±0.003[d]	54.46±0.005[a]
5	4.25±0.008[b]	1.96±0.001[b]	285.9 ±0.012[f]	7.48±0.003[e]	38.03±0.003[d]	54.49±0.003[b]
10	5.92±0.006[c]	1.98±0.005[c]	277.1 3±0.003[b]	7.44±0.003[d]	38.01±0.003[d]	54.55±0.003[c]
15	11.4±0.006[d]	2.06±0.011[d]	281.4±0.023[e]	6.55±0.006[c]	37.75±0.006[c]	55.70±0.006[d]
20	15.18±0.006[e]	2.11±0.005[e]	280.2 ±0.005[d]	6.53±0.03[b]	36.95±0.003[b]	56.92±0.003[e]
25	16.74±0.015[f]	2.19±0.005[f]	279.1 ±0.006[c]	6.32±0.003[a]	36.82±0.003[a]	56.96±0.0003[f]

In our study, while the ash rate was 1.998% in gluten-free breads that did not contain Jerusalem artichoke powder, it was 2.093-2.751% in those containing Jerusalem artichoke powder. According to the study of Ozgoren et al. (2019), increasing the cracker content of topinambur powder from 10% to 30% increased the ash content from 1.09% to 2.06%. These values are close to the results of our research. This study determined that the amounts of selenium, calcium, magnesium, and potassium increased significantly in gluten-free breads with Jerusalem artichoke added. Therefore, the nutritional value of Jerusalem artichoke increased the nutritional value of gluten-free breads. This is due to the high amount of these components in the Jerusalem artichoke tuber. Another study determined that the mineral (magnesium, calcium, phosphorus, and iron) content and fiber content of cookies in which 2.5, 5, 7.5, and 10% dried Jerusalem artichoke tuber flour was used instead of wheat flour increased significantly (Solayman et al., 2023).

Our study determined that the energy value of the Jerusalem artichoke-added gluten-free bread was 286-279 kcal/100 g (Table 7). The values of saturated and monounsaturated fatty acids decreased, and polyunsaturated fatty acids increased. Radovanovic et al. (2014), in their study using 75% wheat flour (containing gluten) and 25% Jerusalem artichoke powder, determined that the bread enriched with Jerusalem artichoke had optimal nutritional and caloric value, a low glycemic index, and low glycemic load values. Radovanovic et al. (2014) determined the caloric value of wheat bread enriched with Jerusalem artichoke powder content as 226 kcal/100 g. When these results are compared, the caloric value is slightly higher than that of the 25%

Jerusalem artichoke-added breads in Radovanovic et al.'s study (2014). This is thought to be due to the use of gluten-free flour. Some microcomponent analysis results of bread samples are shown in Table 8.

Table 8. Some microcomponent analysis results of the bread samples

JA (%)	Selenium (mg/kg)	Calcium (mg/kg)	Magnesium (mg/kg)	Potassium (mg/kg)
0	0.017±0.003[a]	452.618±0.012[a]	113.899±0.025[a]	778.220±0.005[a]
5	0.018±0.003[ab]	454.748±0.008[b]	138.237±0.008[b]	1.734.313±0.008[b]
10	0.019±0.003[b]	482.696±0.015[c]	167.928±0.024c[d]	3.009.609±0.011[c]
15	0.021±0.005[c]	538.508±0.049[d]	237.045±0.005[d]	5.292.842±0.003[d]
20	0.021±0.006[c]	539.707±0.001[e]	237.768±0.005[e]	5.298.903±0.008[e]
25	0.024±0.005[d]	614.013±0.001[f]	280.760±0.008[f]	6.926.842±0.015[f]

JA: Jerusalem artichoke powder. Each value represented the mean±SD of three samples (n = 3). Means within the same column with different superscript letters indicate a significant difference using the DMRT test (P <0.05).

Sensory Evaluation

Gluten-free products generally have poorer sensory quality than gluten-containing baked goods (Gallagher et al., 2014). In this study, according to the sensory evaluation results obtained from the panelists, gluten-free bread with 10% Jerusalem artichoke added got the highest score in general appreciation. Cetin Babaoglu et al. (2021**)** found that adding up to 10% of Jerusalem artichoke powder was acceptable in their study. Like this study, adding more than 10% of Jerusalem artichoke powder resulted in extremely low scores on the sensory evaluation. Wahyono et al. (2016) suggested that Jerusalem artichoke powder above 5% should not be added to breads.

Microbiological Analysis Results

The content of Jerusalem artichoke in gluten-free breads and the effects of 9 days of storage at room temperature in sterile closed packaging on pH, moisture, total aerobic mesophilic bacteria, and total mold yeast are shown in Tables 9 and 10. In this study, significant results were obtained between the addition of Jerusalem artichoke powder to breads and the results of microbiological analysis (P <0.05). The reason for the significant relationship between the results of microbiological analysis and the Jerusalem artichoke content and storage in bread was thought to be related to these many different factors. Changes in pH and moisture values should be evaluated because of their preventive effects on the development of microbiological activities (Pala, 2012). Microbiological analyses are important because of their effect on the shelf life of gluten-free products. Shelf life is related to many factors, such as microbiological load and humidity.

Table 9. The relationship between Jerusalem artichoke content and pH, moisture, total aerobic mesophilic bacteria, and total mold yeast in gluten-free breads

Microorganism	JA%	N	Mean±Std. Error*	95% Confidence Interval		Minimum*	Maximum*
				Lower Bound	Upper Bound		
Moisture	0	15	27.33±0.18[d]	0.70	0.18	26.94	27.72
	5	15	27.07±0.19[d]	0.73	0.19	26.66	27.4
	10	15	26.73±0.26[d]	1.01	0.26	26.16	27.29
	15	15	24.28±0.43[c]	1.67	0.43	23.36	25.21
	20	15	22.20±0.37[b]	1.45	0.37	21.4	23.01
	25	15	20.33±0.52[a]	2.012	0.52	19.22	21.44

pH	0	15	5.76±0.02[d]	0.07	0.02	5.72	5.79
	5	15	5.68±0.01[c]	0.028	0.01	5.67	5.7
	10	15	5.56±0.01[b]	0.047	0.01	5.53	5.59
	15	15	5.57±0.01[b]	0.03	0.01	5.55	5.59
	20	15	5.54±0.01[b]	0.03	0.01	5.53	5.56
	25	15	5.4±50.04[a]	0.18	0.05	5.35	5.55
Total mold and yeast	0	15	13.73±1.86[c]	9.74	17.72	5	24
	5	15	10.8±2.53[c]	5.36	16.23	1	29
	10	15	6.73±0.95[b]	4.68	8.77	3	14
	15	15	4.53±0.41[b]	3.64	5.41	1	6
	20	15	0.4±0.13[a]	0.11	0.68	0	1
	25	15	6.13±1.133[b]	3.70	8.56	2	15
Total aerobic mesophilic bacteria (TAMB)	0	15	15.6±0.88[d]	13.69	17.50	9	20
	5	15	7±1.146[bc]	4.54	9.45	0	14
	10	15	5.46±0.77[b]	3.80	7.12	1	9
	15	15	9±1.29[c]	6.21	11.78	4	19
	20	15	2±0.48[a]	0.95	3.04	0	6
	25	15	7.66±0.53[bc]	6.52	8.80	3	10

*Values indicate the arithmetic mean of colony numbers. N: Sample numbers. Means within the same column with different superscript letters indicate a significant difference using the DMRT test (P <0.05) for each parameter.

Table 10. The relationship between the storage of gluten-free bread samples and the moisture, pH, total mold and yeast, and total aerobic mesophilic bacteria

	Storage day	N	Mean±Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
				Lower Bound	Upper Bound		
Moisture (%)	1	18	26.52±0.385[b]	25.70	27.33	23.95	28.66
	3	18	25.14±0.74[ab]	23.57	26.72	20.19	28.19
	5	18	24.44±0.70[a]	22.96	25.92	19.9	27.2
	7	18	23.76±0.68[a]	22.32	25.20	19.31	27.09
	9	18	23.41±0.73[a]	21.85	24.96	18.18	26.8
pH	1	18	5.66±0.025[b]	5.60	5.71	5.56	5.88
	3	18	5.62±0.021[ab]	5.58	5.67	5.52	5.79
	5	18	5.59±0.022[ab]	5.54	5.63	5.5	5.74
	7	18	5.55±0.038[a]	5.47	5.63	5	5.74
	9	18	5.53±0.035[a]	5.46	5.61	5	5.68
Total mold and yeast*	1	18	5.66±1.87[ab]	1.70	9.62	0	24
	3	18	5.94±1.017[ab]	3.79	8.09	0	15
	5	18	4.44±0.47[a]	3.43	5.45	0	7
	7	18	10.27±2.31[b]	5.38	15.16	0	29
	9	18	8.94±1.50[ab]	5.77	12.11	0	19
Total aerobic mesophilic bacteria*	1	18	4.83±0.84[a]	3.05	6.61	0	11
	3	18	8.5±0.99[ab]	6.40	10.59	3	16
	5	18	10±1.49[b]	6.84	13.15	1	19
	7	18	8.5556±1.23[ab]	5.95	11.15	0	19
	9	18	7.0556±1.41[ab]	4.05	10.05	0	20

*Values indicate the arithmetic mean of colony numbers. N:Sample numbers. Means within the same column with different superscript letters indicate a significant difference using the DMRT test (P <0.05) for each parameter.

CONCLUSION

Enriching the nutritional values and increasing the functionality of gluten-free breads, which have an important place in the diet for many patients, such as those with celiac disease and gluten intolerance, is among the important issues. The addition of Jerusalem artichoke reflected significant impacts on the product. As a result of the study, it was found that with the increase in the amount of Jerusalem artichoke powder in the gluten-free bread formulation, the specific volume and baking loss, moisture, and pH of the bread decreased, while the amounts of fiber, ash, selenium, calcium, magnesium, and potassium, which are macro- and micronutrients of the bread, increased ($P < 0.05$). In gluten-free breads that do not contain Jerusalem artichoke, this value is not high. Saturated fatty acids and monounsaturated fatty acids values decreased, and polyunsaturated fatty acids increased. When the effect of the decrease in the moisture content of bread containing Jerusalem artichoke is evaluated, such an effect is important because it reduces the risk of spoilage in bread.

As a result of the high dietary fiber properties of Jerusalem artichoke, it has become important to make evaluations based on this situation. The effects of dietary fiber on human health include regulating blood sugar, lowering cholesterol levels, and protecting against bowel cancer and cardiovascular diseases.

It was determined that with the addition of Jerusalem artichoke, L* and b* values of the inner and outer color of gluten-free bread decreased, a* values increased, and flexibility, cohesive chewiness, and elasticity decreased ($P < 0.05$). In this way, the external and internal color and textural properties of the bread have become more vibrant and have a normal bread appearance. Adding Jerusalem artichoke powder improved the internal and external appearance of gluten-free bread and caused some quality defects. According to the sensory analysis results from the panelists, the most liked Jerusalem artichoke-added bread is bread made with 10% content.

In addition, FTIR spectroscopy was performed to provide a database on the characteristic peak frequencies of gluten-free breads containing Jerusalem artichoke. It is thought that the results obtained will contribute to the scientific literature.

By adding Jerusalem artichoke powder obtained by a simple drying and grinding method, the nutritional value of standard specification gluten-free bread was increased, its sensory and textural properties were improved, and gluten-free bread with Jerusalem artichoke added became more acceptable. Adding Jerusalem artichoke when making gluten-free bread may provide some benefits in terms of both taste and nutritional value.

CONFLICT OF INTEREST

The authors declare that they have no financial conflict of interest.

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