Texture profile analysis and sensory evaluation of commercially available gluten-free bread samples

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Received: 20 October 2021 / Revised: 13 December 2021 / Accepted: 18 December 2021 / Published online: 19 March 2022
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Abstract

The need for better quality gluten-free (GF) bread is constantly growing. This can be ascribed to the rising incidence of celiac disease or other gluten-associated allergies and the widespread incorrect public belief, that GF diet is healthier. Although there is a remarkable scientific interest shown to this topic, among the numerous studies only a few deals with commercially available products. The gap between research and commercial reality is already identified and communicated from a nutritional point of view, but up to date texture studies of commercial GF breads are underrepresented. In this study, 9 commercially available GF bread were compared to their wheat-based counterparts from texture and sensory viewpoints. Results showed that among GF loaves products, some performed significantly better at hardness and springiness attributes during the 4-day-long storage test compared to the wheat-based products. Two of GF cob breads performed significantly better or on the same level as the wheat-based cob regarding to hardness and cohesiveness during 3 days. Among sensorial properties mouth-feel, softness and smell were evaluated as significantly better or similarly for some GF versus wheat-based products. Two GF bread had more salty taste which reduced the flavor experience. Both the texture and sensory data of the storage test indicate that the quality of some GF bread products has significantly improved in the recent years; they stayed comparable with their wheat-based counterparts even for a 4-day-long storage period.

Keywords Gluten-free bread · Texture · Commercial · Quality · Shelf life · Sensory

Introduction

However, Celiac disease (CD) was already mentioned by Aretaeus of Cappadocia probably in the second century (AD) [1], it became an emphasized scientific and commercially important topic in the last decades. The consumption of gluten-free (GF) products is significantly increasing, just as the demand for good-quality GF products [2]. The underlying reason for the expanded interest can be attributed to better diagnostic methods of CD, wheat allergy, non-celiac gluten sensitivity and dermatitis herpetiformis [3, 4], and to the widespread incorrect public belief that GFD is healthier [5].

Gluten—as a term used to encompass prolamin proteins—can be found in wheat, barley and rye, including all their subtypes and genus [6]. It is the key structure-forming protein, which is the most common and important protein ingredient in the bakery industry. Absence of gluten in the GF formulation ends up with much weaker gas-holding properties; therefore, it causes low loaf volume [7], crumbling texture, poor color [8], choky dry mouth-feel and shorter shelf life [9–11].

Consumer survey studies revealed that the consumers are satisfied with the quality of GF sweets, biscuits and pasta, but still significant improvement is needed in GF bread and cakes to meet the consumers’ expectations [12–14]. The constantly growing number of published articles shows that several approaches were studied mostly using different modified starches, pseudocereals, enzymes, protein supplementation and/or hydrocolloids to improve the quality and nutritional properties of GF flours and breads [6, 15]. Among these numerous studies, only a few deals with commercially available products, the majority rather focuses on self-made prototypes from different raw materials. The publications that are based on commercial products concentrate on composition, nutrition values and/or prices. Based on
their detailed and thorough study by examining 228 commercial products Roman et al. [12] declared a gap between commercial reality and research. Studying the ingredient list of breads they noticed that the commercial breads do not seek to use one single starch or gluten replacer, but a combination of several ingredients to optimize bread quality (hydrocolloids, acidifiers, emulsifiers, leavening agents, preservatives, and aromas or flavorings). They observed that some ingredients which have momentous attention and focus in the scientific world (e.g., pseudocereals) are hardly used in commercial products. On the UK market, GF products are 159% more expensive than their regular version, most GF bread and flour products contain higher amount of salt, fat and sugar, while some GF products are lower in fiber and protein content [16]. Similar differences were found on the Italian market [17, 18]. Spanish market sample study revealed that sodium, fat and cholesterol content were significantly higher in 20 commercial GF bread samples due to having egg, different oils like coconut, olive, sunflower, palm [19]. Although it is true that dietary fiber and sugar levels are more adequate than in the past, the GF diet might lead to CD patients’ inadequate intake of fats, proteins, sodium and vitamins [20].

In general, it can be declared that GF products are significantly more expensive compared to their wheat-based counterparts, and their on-shelf availability can be limited [21–23].

The studies mentioned above, give important and valuable information for the scientific community and draw attention to the gap between research and commercial reality. Despite the fact that this gap is already identified and communicated from a nutritional point of view regarding ingredients, up to date rheological studies are hardly available dealing with commercial GF breads (Table 1).

Considering the rapid and constant development and changes in the GF bakery industry (ingredients, technologies, consumer needs), more and more GF bakeries are appearing on the market and selling freshly baked, preservative-free bread products. These products are based on different ingredients and recipes, but trying to be comparable with the gluten containing products in terms of lookalike, size, taste and shelf life. Therefore, it would be essential to continuously examine the textural and sensory properties of the GF freshly baked and sold bread products available on the different local markets. Following this approach, the current study aims to compare these GF commercially available, preservative-free bread products with their gluten containing wheat flour-based counterparts, focusing on their texture and sensory properties.

**Materials and methods**

Bread samples

The studied 9 different GF commercial bread samples were purchased from different specialized GF bakeries, while the wheat-based products from a supermarket. All the samples were selected with the aim to compare them regarding the product’s name, appearance and packaging. Special attention was taken to ensure that the products did not contain preservatives and gas or modified atmosphere in the packaging. In this study, three types of bread were selected: cob (artisan, round shaped bread), white and wholegrain loaf (baked in loaf tin). From each bread type, GF and wheat-based products were selected and compared (Table 2).

All the samples considered in this study were sliced and ready to eat, without prior heating requirement. Ingredients

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**Table 1** Published articles regarding commercial GF breads

| Year | Scope |
|------|-------|
| 2003 | Commercial wheat starch containing GF flour supplemented with different dairy powders [24] |
| 2004 | Studies were conducted with two newly developed GF bread and GF bread made from commercial flour mix were included for comparison [25] |
| 2012 | The bread-making potential of seven commercial GF flours, wheat and wholemeal wheat flour was compared [26] |
| 2012 | Characterizes diverse GF breads to discriminate them and to establish possible correlations among descriptive parameters of GF bread features determined by instrumental methods and sensory analysis [27] |
| 2013 | Investigation of 2 commercial GF flour mixtures with HPMC and buckwheat addition [28] |
| 2014 | Analyzing the in vitro starch digestibility of five GF breads and commercial GF sample [29] |
| 2014 | Investigate the visual and taste liking of 3 commercial GF foods in a group of celiac children [30] |
| 2016 | 2 commercial GF mixtures were enriched with 10 or 20 g/100 g of chestnut flour, and compared to commercial GF breads, and monitored during three-day storage [31] |
| 2018 | Sensory, digestion and texture quality of commercial GF bread were analyzed using rice flour derived from different cultivars [32] |
| 2020 | Study of the bolus properties of commercial GF and regular breads in relation to the dynamics of sensations perceived during its consumption [33] |

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and nutrition values of the samples which were noted on the product’s packaging are presented in Table 3.

| Type             | Sign                  |
|------------------|-----------------------|
| Cob              | Wheat based           |
| Wheat based      | Cob Wheat based       |
| Gluten-free Sample 1, 2, 3 | C1, C2, C3 |
| White loaf       | Wheat based           |
| Wheat based      | White loaf            |
| Gluten-free Sample 1, 2, 3 | WL1, WL2, WL3 |
| Wholegrain loaf  | Wheat based           |
| Wheat based      | Wholegrain loaf       |
| Gluten-free Sample 1, 2, 3 | WG1, WG2, WG3 |

**Texture measurement**

Texture profile analysis (TPA) was performed at room temperature using Stable Micro Systems TA.XT2. Samples were taken and measured from the first, middle and last third of the sliced bread products, doing 7 different measurements on different slices of the same bread sample. The measurement was placed on the middle of the bread slices, avoiding region near to the crust. Each bread slice had 12 mm thickness. The applied settings were 35 mm diametric acryl cylindrical probe, 50% strain, 5 mm/sec crosshead speed and 5 s of waiting time between the two measurements. Firmness, cohesiveness and springiness were the main representative

| Product | Ingredients | Energy (kcal) | Fat (g) | Carb. (g) | Sugar (g) | Fiber (g) | Protein (g) | Salt (g) |
|---------|-------------|---------------|---------|-----------|-----------|-----------|-------------|---------|
| CW      | Wheat flour, water, whole grain wheat flour, wheat bran, yeast, salt, pork fat, vegetable oil (palm, rapeseed), fermented wheat flour, acidity regulator, emulsifiers, ascorbic acid | 252 | 2.4 | 46 | 1.6 | 5.1 | 8.9 | 1.2 |
| C1      | Water, corn starch, modified starch, tapioca starch, rice flour, psyllium fiber, guar gum, HPMC, potato and apple fiber, pea protein, buckwheat flour, amaranth flour, water, sunflower oil, yeast, salt, sugar, coconut oil | 285 | 6 | 48 | 0.2 | 11 | 1.9 | 2 |
| C2      | Water, sorghum flour, millet flour, rice flour, linseed flour, potato starch, tapioca starch, egg, olive oil, apple vinegar, sodium-bicarbonate, yeast, salt, sugar, xanthan gum, psyllium fiber, sunflower seed, linseed, sesame seed | 313 | 9 | 54 | 3 | 2 | 4 | 2 |
| C3      | Water, GF flour mix (GF wheat starch, dextrose, guar gum, Xanthan gum), E464, ascorbic acid, yeast, psyllium fiber, salt | 198 | 0 | 47 | 2.6 | 4.6 | 0 | 1.4 |
| WLW     | Water, wheat flour, water, butter, yeast, sugar, salt, dried sourdough, soy flour, milk powder, rye flour, emulsifiers, ascorbic acid | 272 | 4.7 | 48 | 3.1 | 1.8 | 8.5 | 1.2 |
| WL1     | Water, GF flour mix (corn starch, modified starch, potato fiber, HPMC, psyllium fiber, guar gum, apple fiber, amaranth flour, sugar, pea protein), water, sunflower oil, yeast, salt, sugar, coconut oil | 221 | 1.9 | 46 | 0.9 | 8.5 | 0.8 | 2 |
| WL2     | Water, rice flour, potato starch, potato flakes, dextrose, yeast, psyllium fiber, HPMC, salt, emulsifier (E491), sunflower oil | 116 | 0.38 | 25.3 | 0.26 | 1.3 | 2.5 | 1.3 |
| WL3     | Water, GF wheat starch, maize flour, potato flakes, millet flour, dextrose, potato fiber, guar gum, gluten-free oat fiber, sodium-bicarbonate, yeast, salt, oil, vinegar, psyllium fiber, ascorbic acid | 208 | 1.2 | 47 | 1.9 | 3.3 | 0.6 | 1.4 |
| WGW     | Wheat flour, water, seeds (flax, sunflower, sesame), yeast, whole grain wheat flour, sunflower oil, salt rye flour, millet, soy flour, wheat gluten, sugar, emulsifiers, ascorbic acid | 286 | 7.3 | 43 | 3.8 | 3.5 | 10 | 1.3 |
| WG1     | Water, GF flour mix (corn starch, modified starch, apple fiber, seeds/sunflower, flex, sesame, pumpkin, apple fiber, HPMC, buckwheat flour, psyllium fiber, guar gum, baking soda, amaranth flour, sugar, pea protein), water, vegetable oil, yeast, salt, sugar, coconut oil | 232 | 3.3 | 44 | 1.4 | 11 | 1 | 2 |
| WG2     | Water, GF wheat starch, linseed, sunflower seed, dextrose, pumpkin seed, buckwheat, rice flour, guar gum, xanthan gum, gluten-free oat fiber, yeast, salt, sunflower oil | 233 | 6.9 | 36.8 | 3.11 | 6.3 | 3.8 | 1.5 |
| WG3     | Water, GF wheat starch, linseed, buckwheat, pumpkin seed, sunflower seed, dextrose, potato fiber, gluten-free oat fiber, rice flour, apple fiber, guar gum, sodium-bicarbonate, yeast, salt, vinegar, psyllium fiber, ascorbic acid | 207 | 2.7 | 42 | 2.9 | 4.1 | 1.8 | 1.3 |
parameters of the sample texture. Results obtained from the GF and wheat bread samples were compared and followed up.

**Sensory evaluation**

During the sensory evaluation group of 15 people (13 females and 2 males, aged between 22 and 47 years) tested the bread samples. The ethical statement for the study was applied from the Hungarian University of Agriculture and Life Sciences and informed consent was obtained from each subject prior to their participation in the study. Subjects confirmed not having any known gluten, rye, milk protein, egg or lactose consumption-related disorder. All participants were recognized as regular bread consumers, consuming bread at least once per day.

The assessors received 1 full slice of the sample without any spreading, and were asked to appraise the intensity of 17 sensory attributes, which were described as relevant ones for GF bread by Pagliarini et al. [34] to cover appearance, color, taste and texture. For evaluation purpose a continuous, unstructured 10 cm long line scale with extremes at the ends (absolutely not intense and immensely intense) was used for every attribute. Samples were served with 3-digit codes on white plastic plates under white light at room temperature.

**Data analysis**

Received data were analyzed with IBM SPSS Statistics 25.0.2.2 software. Significant difference between the measured groups was determined by one-way analysis of variance (ANOVA) with 95% confidence level. Tukey HSD test was used after normality and standard deviation homogeneity test. Linear discriminant analysis (LDA) was performed to examine the separability of each bread type. Sensorial test data were analyzed by ANOVA. When there is significant difference, Tukey test was applied using a level of 5% of significance.

**Results and discussion**

**Nutritional values of the bread samples**

In line with the previously published data, the examined GF bread samples contained different starches, hydrocolloids, fibers and protein supplements all at the same time. The type of starches (corn, tapioca, potato, and rice) and hydrocolloids (HPMC, guar gum, xanthan gum) were the most commonly used ones among various GF breads on different markets [12, 17]. The fiber and salt content of C1, WL1 and WG1 samples were higher while the protein content was lower than in their wheat-based counterparts. Lower protein level was also detected for GF breads previously [12], but in this case of C1, WL1, WG1 samples according to the statement on the manufacturer’s website keeping the protein level low was a conscious decision, so their products can be used for people diagnosed with phenylketonuria (PKU) as well. People with PKU have to follow a low protein and phenylalanine containing diet [35]; therefore, these products are suitable not just for celiac people. Following gluten-free option as dietary practice is known and should be followed [36]. The energy and carbohydrate values were similar between the GF and wheat-based samples expect for WL2, which had the lowest level of energy and carbohydrate level among all the samples.

**Texture profile changes**

Results of the TPA measurements during the shelf-life test are presented in Table 4. Overall, it can be seen that C2 sample had significantly \( p < 0.05 \) higher hardness but lower cohesiveness during the whole study. C1 was significantly softer on day 1, but not different from CW on the following days. C3 showed non-significant difference in hardness from CW during the whole study. Among the GF white loaf samples compared to WLW, WL1 was significantly lower in hardness except on day 3, while WL2 was also significantly softer versus WLW except for day 2. WL3 after day 1 was not significantly different from WLW. In case of whole grain loaves, on day 1 all the GF samples were significantly softer than WGW. On the following days, there were no significant difference detected among them, except for day 3, when WG1 was significantly softer versus WGW.

High cohesiveness leads to no disintegration during mastication, in case of low cohesiveness the bread crumbles [37]. Crumbling texture of GF bread during storage test was reported in the last decades, raising awareness as a general quality issue of these products [38]. Moore et al. [25] experienced decrease in cohesiveness \( p < 0.01 \) in GF bread samples after a two-day storage. In this study, all the GF white loaf samples had significantly higher cohesiveness during the storage test versus the wheat-based white loaf sample. In case of whole grain samples, WG1 was not significantly different in cohesiveness from WGW. WG2 and WG3 samples showed significantly higher values compared to WGW until day 4, when only WG2 was different. Among cob samples C2 and C3 were significantly different from CW, and in general C2 was different from the other cob samples during the whole study.

In bread, springiness is associated with freshness, and products with low values are linked with crumb brittleness [27]; therefore, having high springiness values during the shelf life is desired. In this study WL2 sample showed significantly \( p < 0.05 \) lower springiness during the 4-day-long storage test compared to all other bread samples. Despite
Table 4  TPA results during the shelf-life test (Means with the same letters in the same row do not statistically differ ($p > 0.05$) by Tukey's test)

|                  | LWGF1 | GWGF1 | CWGF1 | LWGF2 | GWGF2 | CWGF2 | LWGF3 | GWGF3 | CWGF3 | WLW  | WGW  | CW   |
|------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|------|------|
| **Hardness (N)** |       |       |       |       |       |       |       |       |       |      |      |      |
| Day 1            | 5.28  | 7.08  | 3.94  | 4.45  | 6.19  | 44.80 | 8.07  | 5.15  | 6.38  | 10.98| 8.97 | 8.19 |
| Day 2            | 5.6   | 6.81  | 11.20 | 6.98  | 9.57  | 10.58 | 6.02  | 6.29  | 9.08  | 9.99 | 9.95 | 8.95 |
| Day 3            | 9.18  | 7.96  | 7.16  | 6.90  | 53.57 | 11.15 | 8.88  | 9.14  | 10.54 | 10.55| 8.65 | 6.34 |
| Day 4            | 7.02  | 8.48  | 8.33  | 6.94  | 8.40  | 9.03  | 15.96 | 9.52  | 9.16  | 8.31 | 8.31 | 8.31 |
| **Cohesiveness (−)** |       |       |       |       |       |       |       |       |       |      |      |      |
| Day 1            | 0.71  | 0.65  | 0.69  | 0.62  | 0.79  | 0.53  | 0.75  | 0.76  | 0.79  | 0.54 | 0.65 | 0.65 |
| Day 2            | 0.67  | 0.66  | 0.64  | 0.74  | 0.52  | 0.71  | 0.72  | 0.78  | 0.58  | 0.65 | 0.62 | 0.62 |
| Day 3            | 0.66  | 0.63  | 0.65  | 0.69  | 0.47  | 0.63  | 0.66  | 0.73  | 0.54  | 0.61 | 0.61 | 0.61 |
| Day 4            | 0.64  | 0.64  | 0.65  | 0.64  | 0.69  | 0.46  | 0.64  | 0.69  | 0.57  | 0.63 | 0.63 | 0.63 |
| **Springiness (%)** |       |       |       |       |       |       |       |       |       |      |      |      |
| Day 1            | 92.66 | 90.86 | 86.75 | 67.69 | 93.72 | 92.10 | 94.18 | 90.01 | 87.78 | 91.38| 89.88| 92.89|
| Day 2            | 92.13 | 91.48 | 89.32 | 79.22 | 93.08 | 91.96 | 92.76 | 90.69 | 89.85 | 91.63| 89.88| 92.89|
| Day 3            | 91.73 | 91.56 | 89.79 | 80.16 | 92.11 | 91.96 | 92.88 | 89.92 | 87.99 | 91.88| 91.88| 91.88|
| Day 4            | 92.44 | 91.38 | 90.93 | 88.93 | 92.17 | 91.23 | 90.53 | 88.58 | 87.54 | 92.49| 91.38| 91.38|
| **Resilience (−)** |       |       |       |       |       |       |       |       |       |      |      |      |
| Day 1            | 40.81 | 35.11 | 34.09 | 30.55 | 55.06 | 30.80 | 52.89 | 49.77 | 47.12 | 20.16| 29.14| 32.22|
| Day 2            | 38.54 | 39.28 | 36.08 | 35.48 | 51.54 | 30.07 | 49.04 | 47.37 | 46.56 | 21.82| 30.32| 29.25|
| Day 3            | 38.51 | 35.99 | 34.93 | 32.48 | 47.57 | 27.16 | 40.42 | 41.69 | 43.58 | 19.49| 25.66| 29.17|
| Day 4            | 37.74 | 37.19 | 34.26 | 32.76 | 46.63 | 25.97 | 42.92 | 40.79 | 41.02 | 20.16| 26.86| 30.92|
the level of springiness grew day by day, but on the 4th day, it could barely reach 80%, still being more rigid. During the storage test, WL3 had significantly higher springiness values versus WLW sample, while WL1 was significantly better or comparable with WLW. Among the whole grain samples, WG2 showed higher springiness values every day compared to WGW, while WG1 and WG3 were better or comparable with WGW. Within the cob samples only on day 1 C1 showed significantly lower springiness value, but on the other days all the GF cob samples were comparable with the wheat-based cob.

Resilience characterizes the beginning of a sample’s elasticity and calculated from the ratio of the area under curve of the second half of the first cycle to the first half of the cycle. Reduction in springiness and resilience reflects alteration of the crumb elasticity [39]. The GF white loaves and the GF whole grain samples showed higher (p < 0.05) resilience values compared to their wheat-based counterparts. This is in line with the springiness values, where the GF samples had higher or comparable values. In case of the cob samples, C3 always had higher (p < 0.05) values than CW, C1 on days 1 and 4, while C2 was all the way consentaneous with CW.

According to the results, C1, C3, WL1, WL3, WG1, WG2 and WG3 bread samples in general can be described as soft and spongy [33] as they had comparable or lower hardness, higher springiness and resilience values than their wheat-based counterparts. From cohesiveness point of view the mentioned samples performed better or comparable to their wheat-based counterparts.

LDA results (Fig. 1) showed that WLW and WGW samples were classified as different groups from the others during the whole storage test. The significant difference in cohesiveness and resilience for both group, the springiness of WLW and the hardness of WGW attributes led together

![Fig. 1 LDA results of the storage test](image-url)
to show these samples as different product groups from the others.

Due to its hardness results C2 was also classified as a separate group (Fig. 1a), and WL2 because of its springiness and resilience attribute (Fig. 1b). LDA result without these two groups (Fig. 1c) showed an overlap between C1 and CW samples (79.3% of cross-validated grouped cases were correctly classified). This result clearly showed that the quality and texture profile attribute changes of C1 during a 4-day-long storage test were as good as the highest quality wheat-based product’s considered to be artisan.

**Sensory evaluation**

Mean ratings (given in cm) for the 17 sensory descriptors of the 12 bread samples are presented in Table 5. Less homogeneous crumb porosity for GF bread samples were previously reported [40, 41], which was linked to high starch and low protein content, impacting the dough interfacial properties and rheological attributes. Pagliarini et al. [34] found commercial GF bread product with uniform crumb porosity but with higher protein value. The commercial GF samples included in the study had significantly lower protein content versus the wheat-based ones, but received as high or even significantly higher values for crumb homogeneity perception. The reason for that could be linked to more effective protein supplements and/or better understanding of starch–protein–hydrocolloid interactions.

From crumb color behavior point of view, participants found this attribute at same or more intense level than their wheat-based counterparts, except for WL3 and WG3. This result showed that it was achievable with the combination of GF ingredients like starches (corn, tapioca, rice), pseudocereals (amaranth, buckwheat) and fibers (apple, potato, psyllium) to create crumb color for GF breads, which was typical for the wheat-based counterparts, and preferable even for non-celiac consumers. However, the exact ratio just based on the ingredient list information could not be determined. The improvement of crumb and crust color intensity indicating that appearance, as one of the most important factors at bread purchasing had significantly improved in the last decade in the case of fresh baked GF breads.

One of the biggest struggle with GF bread formulations had been their flavor. GF products were often described as having dry, tasteless or unpleasantly strong corny taste [15, 17, 27, 34]. In this study the GF samples did not have type-unusual corny and cheesy flavor and/or odor. From taste point of view, the two most dominant difference were detected by the saltiness of C1 and the sweetness of WGW.

| Sensory descriptor      | Samples          | CW   | C1   | C2   | C3   | WL1  | WL2  | WL3  | WG1  | WG2  | WG3  |
|-------------------------|------------------|------|------|------|------|------|------|------|------|------|------|
| Appearance              |                  |      |      |      |      |      |      |      |      |      |      |
| Porosity                |                  | 7.3b | 7.5b | 8.2a | 8.6a | 8.5a | 5.3c | 8.3a | 7.3b | 7.1b,c| 6.8d,d| 6.5d |
| Crumb color             |                  | 7.8b,c| 7.7c | 8.8a | 7.6c | 5.9c | 8.2b | 7.9b,c| 4.2c | 5.1c | 6.4d | 6.5d |
| Crust color             |                  | 7.9a,b| 7.4b | 8.4a | 7.9a,b| 5.3d | 6.8c | 6.6c | 5.7d | 6.4b | 7.6b | 7.3b | 6.6c |
| Touch                   |                  |      |      |      |      |      |      |      |      |      |      |      |
| Soft                    |                  | 7.5a | 7.3a | 4.3  | 7.1ab| 6.2a | 7.3a | 6.5bc| 6.5bc| 6.3a | 6.9bc| 6.6a | 6.7bh,c|
| Smell                   |                  |      |      |      |      |      |      |      |      |      |      |      |
| Corn                    |                  | 0.8b | 0.7b | 0.5b | 0.9b | 0.8b | 0.7b | 0.7b | 1.6b | 1.8a | 1.6a | 1.8a |
| Yeast                   |                  | 2.2d | 1.7de| 3.4b | 1.8de| 2.4d-d| 0.9d | 1.8de| 1.2f | 2.8b | 3.1b | 2.4d-d| 4.2a |
| Cheese                  |                  | 0.8a | 0.7a | 0.9a | 0.5a | 0.8a | 0.6a | 0.5a | 0.7a | 0.9a | 0.7a | 0.8a |
| Fermented               |                  | 1.5d | 0.6a | 3.1b | 0.8a | 5.2a | 0.6a | 0.5a | 3.5b | 2.6b | 1.9d | 2.2cd-d| 1.7d |
| Taste                   |                  | 2.3c | 0.7c | 1.5a | 3.9b | 3.2b | 1.8cd| 2.1c | 1.9cd| 6.1a | 1.1de-d| 1.1d,e| 1.4d |
| Salty                   |                  | 2.3c | 0.7c | 1.5a | 3.9b | 3.2b | 1.8cd| 2.1c | 1.9cd| 6.1a | 1.1de-d| 1.1d,e| 1.4d |
| Flavor (by gustation)   |                  |      |      |      |      |      |      |      |      |      |      |      |      |
| Corn                    |                  | 0.8a,b | 0.8b,c| 0.8b,c| 0.8bc| 0.8bc| 0.6a | 0.5a | 0.4a | 1.4a | 1.1ab | 0.9ab | 1.2ab |
| Yeast                   |                  | 1.1c | 1.2c | 1.4bc| 1.2bc| 1.2bc| 1.3bc| 1.6c | 2.6a | 2.2ab| 1.8bc| 2.1b | 2.5a |
| Cheese                  |                  | 0.8a | 0.7a | 0.6a | 0.6a | 0.8a | 0.6a | 0.5a | 0.5a | 0.6a | 0.7a | 0.5a | 0.5a |
| Fermented               |                  | 0.9d | 0.8d | 1.1cd| 0.7cd| 3.8a | 1.9bc| 2.5b | 1.4c | 2.4b | 2.3b | 1.9bc | 2.1b |
| Texture (by gustation)  |                  |      |      |      |      |      |      |      |      |      |      |      |      |
| Adhesive                |                  | 4.2d | 4.4a | 5.2b | 4.9bc | 5.3b | 5.2b | 6.8a | 3.8d | 3.3d | 3.5d | 3.6d | 3.1d |
| Rubbery                 |                  | 2.1d | 2.3cd| 3.7bc| 3.3bc| 2.2d | 2.1d | 7.7a | 3.2c | 3.8b | 1.6b | 2.2d | 1.6d |
| Soft                    |                  | 7.9a | 8.3c | 4.6c | 7.1ab| 6.8b | 7.9a | 4.8c | 6.7b | 5.2e | 8.1a | 7.6bc | 7.9a |
Latter can be explained with the highest level of added sugar (3.8 g/100 g).

WLW was characterized by the most intense fermented taste and smell, which was probably due to the presence of sourdough.

Concerning texture properties, sensory results were in line with the instrumental measurements. The link between hardness and springiness measurement and softness scores was confirmed, they strengthened each other. C2 sample was the hardest during all days, which was reflected in the sensory test as well with the least intense softness value. WL2 sample is not just hard, but also rubbery. However, the exact level of ingredients was not mentioned on the labels, which can be linked to a higher level of hydrocolloids.

In general, checking all the texture properties together, C1, WL1 and WG1 samples were performing at the same level or better \( p < 0.05 \) compared to their wheat-based counterparts.

### Conclusion

This study aims to provide up to date data regarding the so far neglected topic of texture and sensory aspects of commercially available, freshly baked, preservative-free GF bread products designed for celiac consumers. Results show that the market has the ability to produce preservative-free, ready-to-eat bread products with comparable texture properties and attributes to their wheat-based counterparts during storage at room temperature. The higher fiber and the comparable or even lower energy and carbohydrates values decrease the gap in the nutrition area between GF and wheat-based bread products. In the future, it would be important that shelf-life studies aiming to evaluate the texture and sensory qualities of GF bread samples would concentrate on the commercially available GF products and in that case, these results and parameters could be used as reference. If the focus would shift more to the commercially available GF products, it would become more apparent that these products are not as low quality anymore. The hardness, springiness and cohesiveness data of the storage test prove the very opposite, the quality of these products has significantly improved during the last few years.

### Acknowledgements

The authors appreciated Barbara Pén and Nikolett Lázár for their high-level assistance in proofreading and editing. The authors acknowledge the Hungarian University of Agriculture and Life Sciences’ Doctoral School of Food Science for the support in this study.

### Funding

Open access funding provided by Hungarian University of Agriculture and Life Sciences.

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### Declaration

#### Conflict of interest

Authors have no conflict of interest to declare.

#### Compliance with ethics requirements

This article does not contain any studies with human or animal subjects.

#### Ethical approval

Ethics approval was not required for this study.

### Availability of data and material

Data which support the outcome of the study are available from the corresponding author upon request.

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