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EVALUATION OF FUNCTIONAL PROPERTIES OF PHYSICALLY TREATED SORGHUM FLOURS AND DEVELOPMENT OF GLUTEN-FREE SORGHUM BREAD

Róbert Nagy[1], Chaima Neji,[1] Judit Remenyik[2], Péter Sipos[1]

Address(es):
[1] Institute of Nutrition, Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, 138 Böszörményi street, 4032 Debrecen, Hajdú–Bihar, Hungary.
[2] Center for Complex Systems and Microbiom Innovations, Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, 1 Egyetem square., 4032 Debrecen, Hajdú–Bihar, Hungary.

*Corresponding author: nagy.robert@agr.unideb.hu

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ABSTRACT

Recently, sorghum production and utilisation experienced a considerable increase in the food industry due to its outstanding nutritional and functional properties as a gluten-free material. Depending on the genotype, it is a good source of antioxidants and contains a high amount of slowly digestible and resistant starch. This study evaluated the effect of physical (heat) treatment on the functional and rheological properties (water and oil absorption capacities etc.) of commercial sorghum flour. Gluten-free bread were also developed with the use of sorghum as base material and the addition of other gluten-free ingredients and the utilisation of heat treatment. Bread quality and texture profile characteristics (hardness, springiness) were evaluated, and an organoleptic test was also performed. Heat treatment proved to be beneficial in improving some of the functional properties of sorghum flour: it increased water absorption capacity by 20% compared to the control flour. It also improved the development of dough and the texture profile of bread on the baking day but resulted in a rapid quality decrease during storage. Sorghum bread with 10 % fibre content received the highest score during sensory evaluation, and a higher fibre content combined with heat treatment caused a significant decrease in hardness values. In conclusion, physical treatment had a favourable effect on some of the functional properties of sorghum flour and bread, especially water absorption capacity and dough development, and according to the organoleptic evaluation results sorghum bread products can potentially compete with other gluten-free bakery products.

Keywords: pseudocereals, heat treatment, rheology, celiac disease

INTRODUCTION

Sorghum has been a primary food source since ancient times, originating from Africa, and widely grown mainly in semi–arid and arid areas around the globe (**Xiong *et al.* 2019; Hossain *et al.* 2022**). It is a gluten–free, antioxidant-rich grain, with many health benefits for human consumption, like preventing chronic diseases, reducing inflammatory effects, and inhibiting bacterial growth. **(Awika 2017; Girard and Awika 2018; de Oliveira *et al.* 2022**). Sorghum is a multipurpose crop as food, feed, and industrial material. Consumption of sorghum is widely spread in Africa and South–Asia, where it is consumed as porridge, flatbread, snacks or alcoholic and non–alcoholic beverages **(Waniska *et al.* 2016; Orr *et al.* 2016; Taylor and Kruger 2019)**. In the Western diet it was considered as marginalised food crop an used mainly as animal feed or industrial material (**Berenji and Dahlberg 2004; Rumler *et al.* 2022**). However, it has recently become the focus of interest due to environmental changes and rising production costs of other cereals. Sorghum has excellent agronomic properties with good tolerance against drought, high-salinity conditions, and other biotic and abiotic factors (**Sharan *et al.* 2018; Thilakarathna *et al.* 2022**). In Europe, sorghum production has been steadily increasing since around 2017, after the 1st Sorghum Congress, and it is increasingly popular in household use and the food industry due to its gluten–free property. Composite flours, pasta, cookies, cakes, and bread are the main sorghum products in developed countries **(Stefoska-Needham and Tapsell 2020**).
Breadmaking from gluten–free material is fairly challenging, with severe limitations due to the lack of a gluten network, which is the foundation of dough structure development (**Naqash *et al.* 2017**). For this reason, natural or artificial bulking agents and thickeners are used to improve the textural and rheological parameters of gluten–free bread (**Ronda *et al.* 2013; Kittisuban *et al.* 2014**). The end quality of a bakery products depends on various factors, many of them related to the composition of the ingredients, like starch content and starch fractions ratio, dietary fibre content, type of proteins, and the presence of anti–nutrient agents (**Bourekoua *et al.* 2018; Effah-Manu *et al.* 2022**). These factors together determine the flour's functional properties, which are the physicochemical properties of food materials, representing the behaviour of the food matrices during food production and preparation. Furthermore, these attributes can help us predict and evaluate how a new ingredient, a substitution of a material, or a treatment will affect the overall quality of the product (**Chandra *et al.* 2015; Awuchi 2019**). Physical treatments like wet or dry heat, pressure and radiation can alter some of the characteristics of the material or the composition of the food matrices, which can affect the texture and rheology of the final product (**Marston *et al.* 2016**).
In our study, sorghum flour was used as a basis for a gluten–free bread development with physical treatments. We aimed to develop a bakery product with high nutritional value suitable for celiac disease patients. During development, some of the functional characteristics of different sorghum flours with or without treatments were evaluated, while sorghum bread prototypes were evaluated for their texture and sensory properties.

MATERIALS AND METHODS

Materials

Commercial sorghum flour "Éden Prémium was sourced in one batch directly from the producer (Naturtrade Hungary Kft., Szeged, Hungary). The supplier described the flour as whole grain flour with high fiber content. The producer recommended it for the production of breads, biscuits and pancakes. Commercial wheat, millet and oat flours were also sourced as reference material from a local shop. All flour samples were stored in airtight moisture-proof packaging at room temperature until further use. Unmodified potato and sunflower lecithin were bought from regional retailers in Hungary. Iodised salt, granulated sugar, skimmed milk powder and freeze–dried yeast were sourced from the local market. All ingredients were stored at room temperature until further use.

Flour heat treatment

Heat treatment was done according to the method of Marston with some modifications (**Marston *et al.* 2016**). Fifty grams of commercial flour was distributed evenly on a metal plate approximately 0.5 cm thick. The plate was placed in a baking tray oven (HP833, FM INDUSTRIAL Lucena, Spain) without steam regulation at 125 °C, for 30 minutes. After treatment the flour was cooled to room temperature and stored in an airtight plastic bag until further analysis. For bread making, approximately 1.5 kg of flour was treated under the same conditions.

Water and oil absorbing capacity of sorghum flours

Water absorbing capacity (WAC) and oil absorbing capacity (OAC) measurements were done according to the method of Elkhalifa and Bernhardt (**Elkhalifa and Bernhardt 2010**). Three grams of flour samples were weighed in pre–weighed 50 ml centrifuge tubes, and they were suspended in 30 ml of water/oil and stirred gently for 1 minute on a vortex. The tubes were shaken every 10 minutes by hand for 30 minutes and centrifuged at 3000 rpm for 15 minutes. After centrifugation, the supernatant was decanted, and the tubes were left to dry in an upside–down position for 5 minutes on a paper towel. Finally, the weight of the wet samples was taken, and WAC/OAC were calculated as a percentage for each sample.

Swelling index

The swelling index was measured as described by Singh (**Singh *et al.* 2017**). 0.5 g flour was weighed in a pre–weighed 15 ml centrifuge tube, and 15 ml distilled water was added. Flour was dispersed using a vortex mixer. The tubes were immersed in a 90 °C water bath for 30 minutes, with occasional stirring to prevent lump formation. After 30 minutes, the tubes were removed, cooled down for 20 minutes at room temperature, and centrifuged at 3000 rpm for 25 minutes. The supernatant was removed, and the weight of the swollen wet samples was taken.

Bread making process

Bread development was done in the Food Innovation Center of the University of Debrecen, according to Marston (2016), with some modifications (**Marston *et al.* 2016**). The base sorghum bread recipe was the following: sorghum flour (140 g), potato starch (60 g), sunflower lecithin (4 g), granulated sugar (2 g), salt (2 g), skimmed milk powder (2 g), active dried yeast (4 g), and tap water. The recipe was modified by adding psyllium husk flour at 5; 7.5; and 10%. Bread batches of all variations were done with and without dry heat pre–treatment in duplicate. Dry ingredients were homogenised using a kitchen robot (KitchenAid Artisan Mixer, KitchenAid Hungary, Budapest, Hungary) with mixer heading on medium speed until all ingredients were homogenised, then approximately 330–350 ml amount of lukewarm water was added and blended on medium speed for 30 seconds. Kneading was performed for another 60 seconds by hand. Before leavening, the dough was split into two equal parts and shaped. Then it was put in a fermentation cabin (F-608, FM INDUSTRIAL Lucena, Spain at 35 °C for 30–40 minutes until the dough height reaches around 4.5 cm. The exact weight of the bread was taken before leavening. After proofing, the surface of the bread was sprayed with sugar water, and cuts were made using a knife to enable water evaporation during baking. The doughs were placed in a convection oven (RXB 610 SMART, FM INDUSTRIAL Lucena, Spain)with the following parameters: 220 °C, humidity 95%, 10 minutes, 220 °C, humidity 50%, 25 minutes, 180 °C, humidity 30%, 20 minutes. After baking, the breads were left to cool for 1 hour at room temperature before being packaged into airtight plastic bags.

Baking quality of bread

After cooling for 1 hour, the weight of whole bread was measured along with bread volumes using rape seed displacement method. Specific volumes of bread were measured by dividing bread volume by total weight. Bread dimensions (length height, and width) were measured with a ruler at their centre lines, respectively. The formal ratio was also evaluated by dividing the width by the length of the bread. According to regulations, the acceptable formal ratio of bread products is below 2.2. The bread were sliced using a bread cutter, and a texture profile analysis (TPA) was performed using a TA–XT2 (Stable Micro System, Godalming, United Kingdom) texture analyser. For TPA, the centre two slices were used to avoid differences in size and shape as much as possible. Bread firmness was measured using a 10 mm diameter cylinder probe attached to a 5 kg mass load cell. Pre–and pro–test speeds were adjusted to 1 mm sec^{-1} and 10 mm sec^{-1} ,respectively. The test speed was set at 0.50 mm sec^{-1}, until a maximum distance of 5 mm was reached, and the probe was held for 30 s. The force affecting the slice was measured on a computer. Aside from bread firmness, the springiness of the bread crumbs was also evaluated, using the force values from the previous firmness test for calculation. Springiness was calculated by dividing the end force by the maximum force exerted on the slices. Springiness values were given as a percentage.

Sensory evaluation

A small-scale sensory evaluation was done to analyse the acceptance and consumer value of sorghum bread with twenty untrained people aged 18–54. There were nine males and 11 females among the participants. The participants were given a pre–screening questionnaire to obtain data about age, gender, eating and consuming habits, possible food-related allergies or intolerances. Bread were cut into small pieces on a plastic plate and labelled with numbers before being given to the participants. Samples were evaluated using an 8–point hedonic scale (8=Like extremely, 7=Like very much, 6=Like moderately, 5=Like lightly, 4=Neither like or dislike, 3=Dislike moderately, 2= Dislike very much, 1=Dislike extremely) to determine the acceptance and likeability of the prepared bread. Five attributes were evaluated this way: appearance, odour, texture, flavour, and overall general impression.

Statistical design and analysis

Data were analysed by analysis of variance (Oneway–ANOVA), with Tukey test using SPSS statistic software (version 24). Graphs and charts were made using Microsoft Excel (Microsoft Office Professional Plus 2016). Bar graphs present analytical results with averages and their standard deviations and significant differences using GraphPad Prism 8 (Dotmatics, Bishop's Stortford, United Kingdom). Results of the sensory analysis are represented by the radar chart using Microsoft Excel (Microsoft Office Professional Plus 2016, Microsoft, Albuquerque, USA)

RESULTS AND DISCUSSION

Functional properties of sorghum flours

Flours' water and oil absorption capacities are fundamental in product development and determining product quality. In our research, it was found that sorghum flours have a higher level of water absorption ability than other gluten-free flour sources like oat or millet, but even wheat flour (Figure 1). The highest level of water absorption capacity was measured for the oven–and freeze–dried samples. They could absorb 1.5 folds of their amount, but this is mainly due to the loss of water during the drying procedure. Regarding oil absorption, sorghum flours appeared to be similar to other flours with oven–heated flours showing the highest level of oil absorption capacities at 86%. Overall, sorghum flour has a considerable potential as a gluten-free flour due to its beneficial ability to bind a higher amount of water compared to other alternatives like millet or rye presented in this research, and this ability can be influenced by physical modifications, which can improve the dough mixing stage of bread making. Oladunmoye et al. (2010) evaluated the WAC values of wheat, cassava, maise and cowpea flour, and cassava flour had the highest level of WAC with 221%, while maise also had 168% water absorbing capacity. (**Oladunmoye *et al.* 2010**) In our research, the oven-dried samples showed similar values to the maise flours in terms of WAC. Similar results to our research were found in the study by Trappey et al (2014) with 120–140 % WAC values depending on particle size distribution (**Trappey *et al.* 2014**).

The addition of fibre to the flour improved further the water absorption capacities. Flours supplemented with 10% fibre (w/w%) had the highest values, but there were no significant differences between flours with 7,5 and 10 % fibre content. Heat treatment had a slight effect on water absorption values, and flour with 10% added fibre had the highest values. Oil absorption capacities didn't show significant differences between different flour mixtures.

In the case of the swelling index (SI), sorghum flour showed a slightly lower SI than rye and wheat flour with 5.90, 6.37, 6.60, and 6.436 g $g^{-1,}$ respectively (Figure 2).

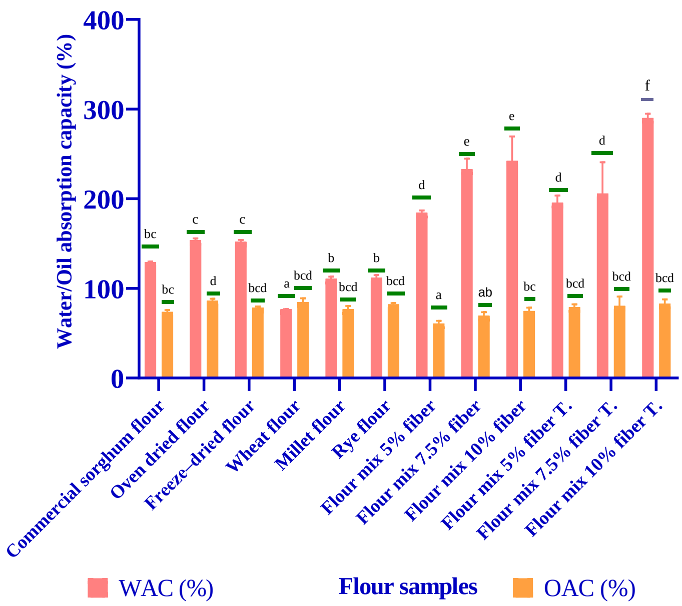

Figure 1 Water and oil absorption capacities of flours. Different letters above columns present significant statistical differences

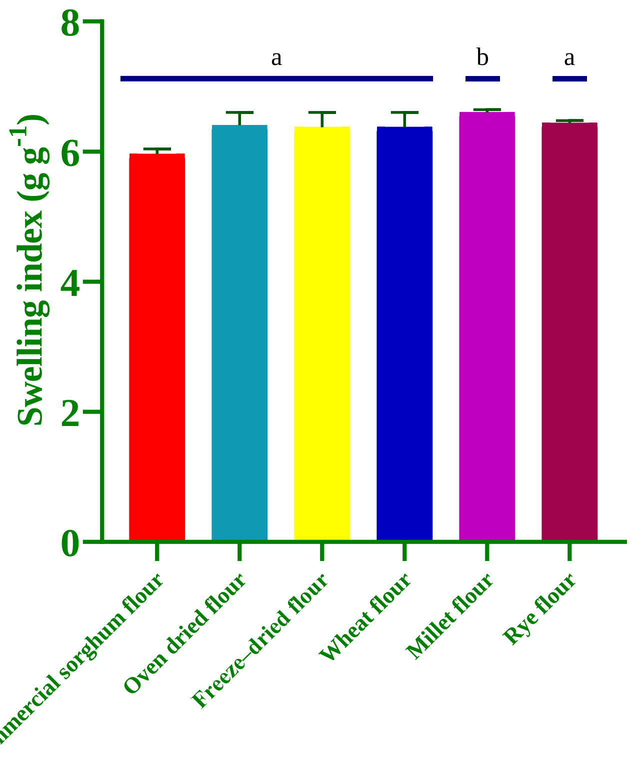

Figure 2 Swelling power of flours. Different letters above columns present significant statistical differences

Characteristics of sorghum bread

Sorghum bread prototypes can be seen in Figure 3. Bread with fibre addition have visibly larger volume and dense crumb structure, but an improvement in colour can be observed compared to the control bread. Control bread without psyllium husk had a much darker crust colour with the present baking parameters. Control samples had a visibly crumblier and more porous crumb structure compared to bread with fibre content. This result proves that dietary fibres have a crucial impact on the functional properties of dough and bread. Aside from the documented health benefits of dietary fibres, they also improve the water absorption and ge-forming ability of gluten-free flours, thus improving their structure, increasing specific volume and resulting in a softer crumb. As gluten-free bread usually has a fairly weak structural integrity, these texture changes can help improve the quality of our gluten-free products. (**Tsatsaragkou *et al.* 2016; Abdullah *et al.* 2021; Torbica *et al.* 2022**).

Bread were evaluated for their specific characteristics and quality. Results can be seen in Figure 4, and Figure 5. Overall, sorghum bread, with the addition of even a small, 5% amount of fibre had a significantly higher volume and denser crumb compared to the control bread with 518 and 420 $cm^{3,}$ respectively. However, there were no differences between bread with different fibre content. Similar tendencies were found by Marston et al (2014) but without fibre addition. Heat-treated breads had higher volume, cell number per area, and a higher acceptability score compared to control breads (**Marston *et al*. 2016**) These findings suggest that fibres have an upper limit on how much they can increase the stability of the dough, and without a proper protein network the gas-holding ability of doughs is limited.

The baking loss and formal ratio of bread were also analysed. The baking loss increased slightly in bread with psyllium husk by 3% compared to control bread, but dry heat treatment caused a 5% decrease in all fibre-containing bread. Thus starch gelatinisation together with fibres could have helped reduce water loss during baking. The formal ratio is the ratio between the width and height of breads, and it is an important rating quality in baking industry. We found no statistical differences in the formal ratios of our sorghum bread, and the values comply with the relevant regulations (Codex Alimentarius Hungaricus, regulation 1–3/16–1) used in the industry, which states that the formal ratios upper limit is at 2.2 value.

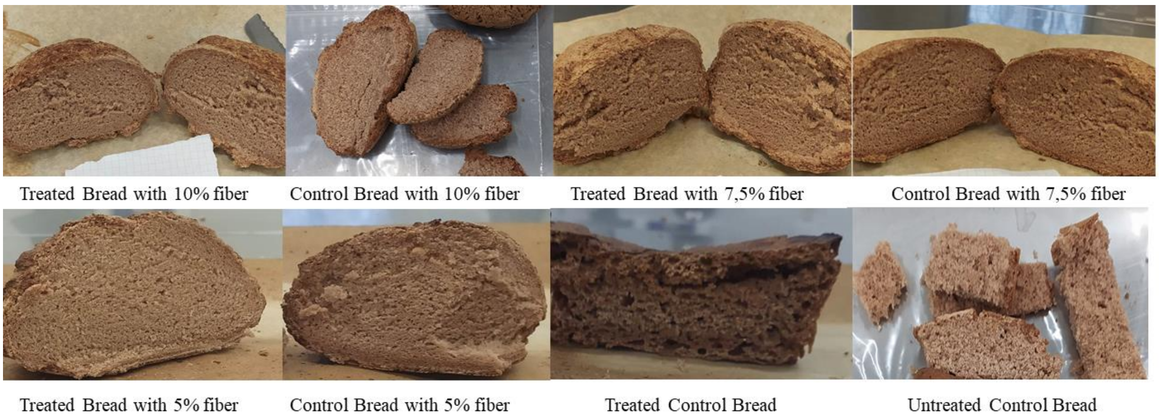

Figure 3 Bread prototypes made from sorghum flour and psyllium husk

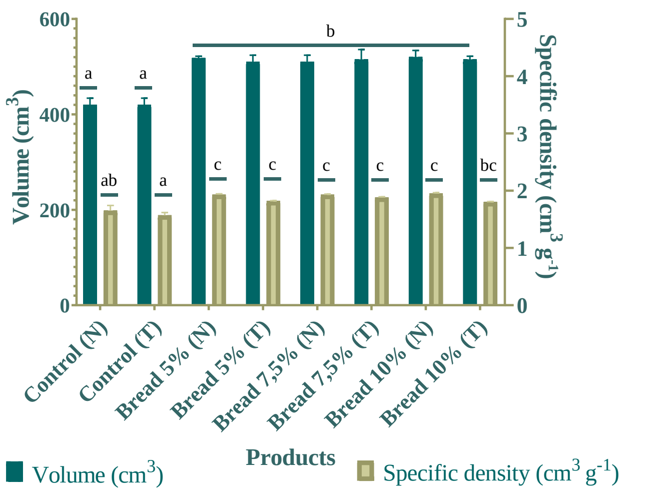

Figure 4 Bread volume and specific density of sorghum breads. Different letters above columns present significant statistical differences. N= Non–treated, T= Treated

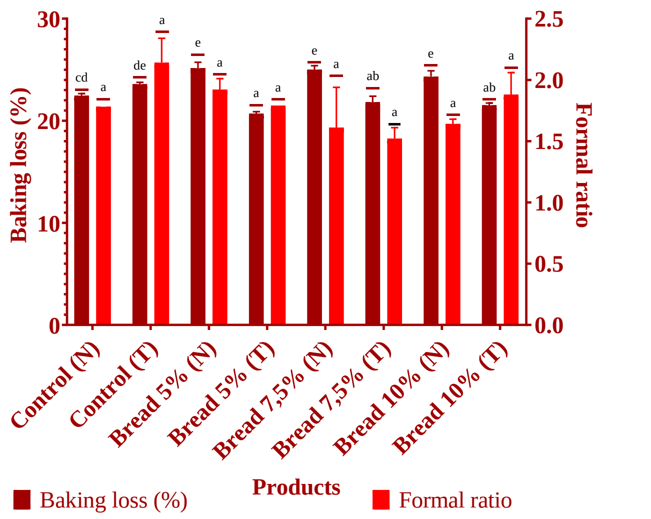

Figure 5 Baking loss and the formal ratio of sorghum bread products. Different letters above columns present significant statistical differences. N= Non–treated, T= Treated

Rheological properties of bread

Fibre addition and starch modification processes have a major impact on the structural properties of bread, bakery products and other food matrices. Figure 6 graphically shows the firmness and springiness measured during the texture profile analysis on bread. Firmness was expressed as the force applied in grams, while springiness was expressed as a percentage value. Due to the fibre added to the dough, which increases the water absorbing ability of the batter, firmness increased significantly in the case of untreated sorghum bread from 80.78 g to as high as 209.96 g, and springiness increased in both untreated and treated samples above 60%. Although heat treatment alone resulted in a much harder bread crumb, fibre addition alleviated this increase, causing a decrease in firmness values. Treated control bread had the lowest springiness of all samples, with only 43% on the baking day, which improved with increased fibre supplementation. This improvement is attributable to the excellent water-binding ability of fibres, and it can improve the overall quality of bread. In the same time, this increased moisture content can lead to a shorter shelf life as well. After 48 hour long storage, the hardness of the bread increased in all cases. Control breads in both groups showed the highest increase with six–and fourfold increase in values (Table 1.). Similar tendencies about psyllium husk were found in the research by Fratelli et al. (2021) where the findigs showed that added psyllium fibre can decrease loaf firmness by as much as 75% over a 72 h storage period with high acceptability scores during sensory evaluation. Therefore, fibre addition can delay the bread stalling procedure due to improved water-holding abilities (**Fratelli *et al.* 2021**).

Table 1 Texture analysis profile of sorghum bread products

Sample	Firmness g g^{-1}		Springiness (%)	
	Day 1	Day 2	Day 1	Day 2
Control (C)	80.78±18.36^{a}	514.74±113.76^{b}	55.34±3.98^{b}	48.03±5.8^{a}
Control (T)	392.68±85.16^{d}	1614.64±362.22^{d}	43.12±2.08^{a}	42.41±8.49^{a}
B5 (C)	215.05±15.57^{b}	510.81±69.44^{b}	65.49±2.56^{c}	60.19±3.48^{b}
B5 (T)	290.73±68.69^{c}	759.94±135.85^{c}	63.53±2.71^{c}	59.69±4.02^{b}
B7.5 (C)	145.66±42.82^{b}	308.71±79.38^{ab}	66.83±3.83^{c}	65.27±2.37^{b}
B7.5 (T)	151.04±39.01^{b}	255.87±67.10^{a}	68.11±3.61^{c}	64.66±4.16^{b}
B10 (C)	209.09±20.72^{b}	455.53±96.91^{ab}	65.83±4.84^{c}	60.99±5.30^{b}
B10 (T)	152.61±32.25^{b}	396.29±101.36^{ab}	68.43±4.58^{c}	63.08±4.63^{b}

Legend: C=untreated control, T= treated flour. Values with different letters in a column indicate significant differences at the 95% probability level

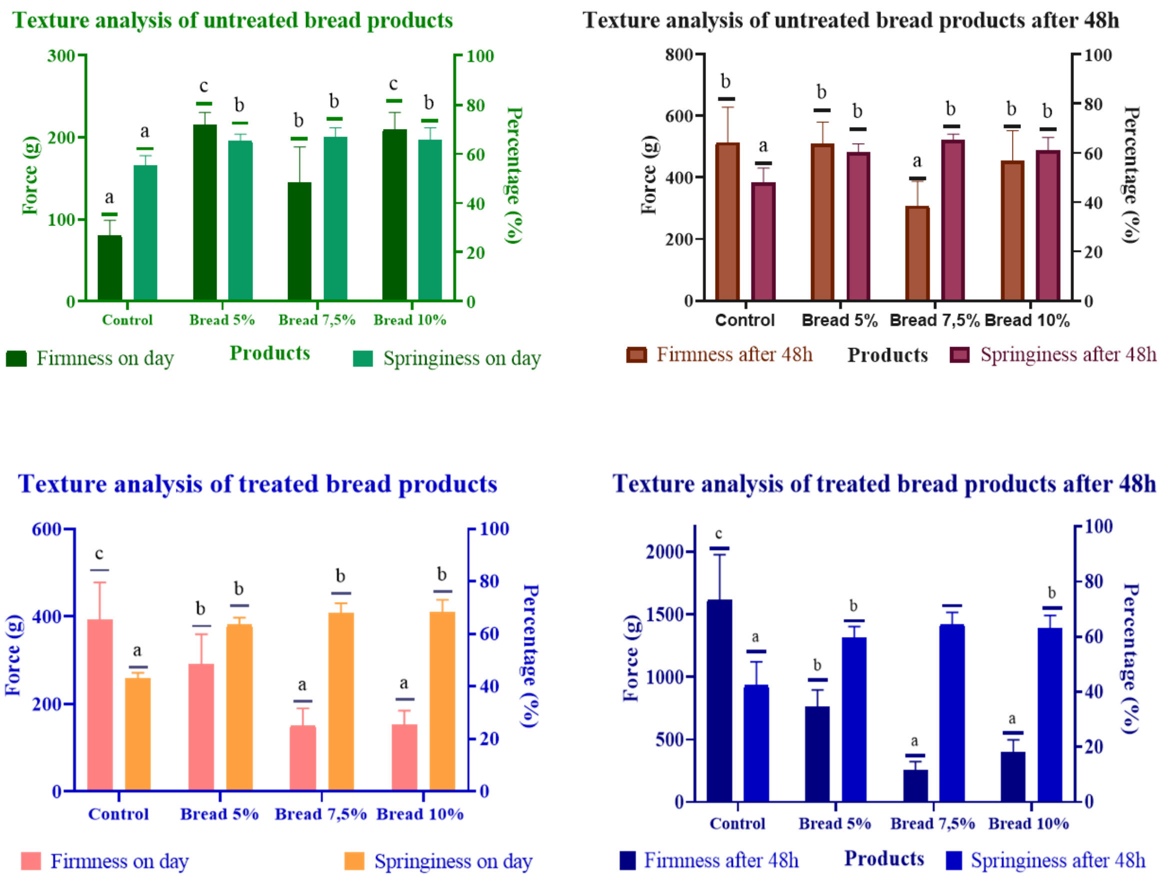

Figure 6 Texture analysis profile of sorghum bread products. Columns of matching variables with the same letters are not statistically different ($p<0.05$)

Fibre addition decreased this rate of increase, due to its water-binding ability, with only a twofold increase. According to these results, heat treatment had a positive effect on the storability of bread, compared to the untreated control sample. There were no significant differences between fibre ratios in terms of springiness, and the products with 7.5% added psyllium husk proved to have the optimal texture for consumption.

Sensory evaluation

Organoleptic properties are value-determining aspects of food, and they are highly important for the evaluation of novel food products. Among the presented samples, untrained tasters found bread with 7.5 and 10% psyllium husk addition had the best sensory characteristics, with an average from five to seven points between the variables. Texture and appearance scores showed the biggest differences between samples, with the control sample (T) having the lowest average score of 3.64 and 4.0 for appearance and texture, respectively. According to the tasters, bread with 7.5 and 10% fibre content had appropriate and desirable appearance and scent considering their gluten–free characteristics, and some of the testers expressed their liking to the mild astringent taste, which was otherwise moderately disliked in most cases. The final sensory evaluation scores can be seen in Figure 7. Heat treatment had a slight effect on the taste of the bread. Participants mentioned that pre–treated sorghum bread were less astringent and bitter compared to control ones, which is backed up by evidence from other researchs as well. Sharanagat et al. (2022) mentioned an increase in acceptability scores and an improvement in taste.(**Sharanagat *et al.* 2022**)

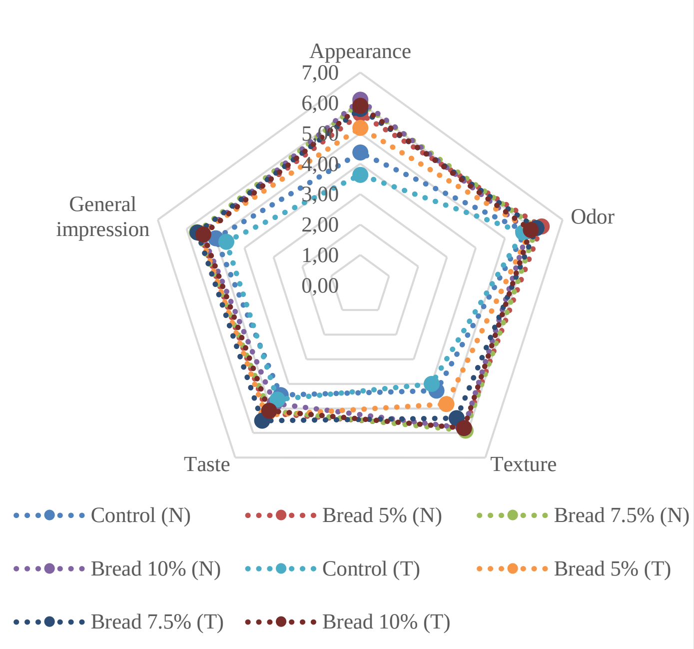

Figure 7 Sensory evaluation of sorghum bread products. *Bread 5% = Bread with 5 % psyllium husk, Bread 7,5%= Bread with 7,5% psyllium husk, Bread 10%= Bread with 10% psyllium husk. N=non–treated, T=Treated*

CONCLUSION

Physical treatments (heat) and its effect on functional properties of sorghum flours were evaluated in this study in addition to gluten–free bakery product development with associated rheological measurements. Water absorbing capacities of sorghum flours exceeded the values measured in the case of other gluten–free and gluten-containing flours, with a 153% WAC value of heat-treated sorghum flour at the top. Gluten–free bread were developed using psyllium husk as a fibre source with three different ratios (5,7.5, 10%) and their quality and rheological properties were measured. Fibre addition, together with heat treatment, improved bread volume and shape, together with their storability, however heat treatment also decreased some of the rheological characteristics, like the springiness of the final products. Overall, heat treatment has a controversial effect on product quality, and it is necessary to further optimise and investigate its usability in food processing. Bread made with 7.5 and 10% psyllium husk proved to be the most appropriate during sensory evaluation, but concerns arise about after–taste and higher production costs. Thus, further improvements are required.

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