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Effect of sourdough addition on rice based gluten-free formulation: rheological properties of dough and bread quality

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RESEARCH ARTICLE

Abstract

Today, the consumers suffering from celiac disease have increasingly been demanding high quality and health beneficial bakery products. The bakery industry, therefore, needs scientific data regarding dough properties and final product quality for gluten-free formulations. In this study the effects of rice sourdough on gluten-free bread quality were examined. A gluten-free bread formulation was prepared based on rice flour and corn starch along with different levels (10, 20, and 30%) of rice sourdough. In all cases, the value of elastic modulus, G', was higher than that of the viscous modulus, G''. Bread volumes were negatively affected by the addition of sourdough. The textural hardness value increased as a result of storage in all bread samples, but sourdough addition resulted in a decrease in hardness values of the bread samples on the first and third days of the storage. During storage, the springiness and cohesiveness values decreased whereas the chewiness values increased. As a result of storage, the colour of the crust was lightened, and the redness and yellowness values decreased. The results of the study suggest that the use of sourdough is beneficial in prolonging the shelf-life of rice flour-based gluten-free bread.

Keywords: celiac disease, gluten-free, texture profile analysis, dynamic rheology, rice flour

1. Introduction

Food allergies and hypersensitivities are generally the result of a reaction of the immune system to certain foods or food components, especially protein. Recently, the number of chronic health problems caused by food allergies has increased (O'Neill, 2010), and celiac disease has become one of the most common food intolerances in the world (Di Cagno *et al.*, 2004). Celiac disease is an enteropathy caused by an immune system disorder through the consumption of cereal prolamin proteins by genetically susceptible individuals (De Angelis *et al.*, 2006) and it affects about 1-2% of the world's population (Cabrera-Chávez and Calderón de la Barca, 2010; Moroni *et al.*, 2009). The basic method of treatment for celiac disease is a life-long gluten-free diet and the consumption of only gluten-free products (Aydoğdu and Tümgör, 2005; Thompson, 2001).

Gluten protein complex is composed of glutenin and gliadin fractions and is responsible for the viscoelastic properties of dough (İşleroğlu *et al.*, 2009) leading to expanded bakery products. The crumb structure and volume of a product develop as a result of the denaturation of gluten proteins and stabilise during baking (O'Neill, 2010). Gluten also contributes to the appearance and crumb structure of many bakery products. Therefore the absence of gluten is a major problem for bakery products. Gluten-free products on the market are generally low in quality especially in terms of taste and aroma (Gallagher *et al.*, 2004).

Sourdough is a mixture of water and flour fermented with lactic acid bacteria (LAB) and yeasts, which determine its characteristics in terms of acid production, aroma and leavening (Moroni *et al.*, 2009). There is considerable consensus with regard to the positive effects of sourdough addition for bread production, including improvements in bread volume and crumb structure, flavour, nutritional value and shelf-life (Arendt *et al.*, 2007). The use of LAB in sourdough breads has been reported to affect the rheological properties of dough and final characteristics of the breads (Gül *et al.*, 2005). Therefore, the use of sourdough is thought to provide positive effect on gluten-free bread quality. This study aims to produce high-quality gluten-free sourdough bread based on rice flour and to determine the effects of sourdough addition on dough rheology and gluten-free bread quality.

2. Materials and methods

Materials

Rice flour (moisture content 12.17%, protein 6.84% and ash 0.59%), corn starch (moisture content 9.8%, protein 5.53% and ash 0.51%), fresh baker's yeast, baking powder, hydrogenated vegetable fat, salt and sugar were purchased from local markets. Xanthan gum (Tekkim Chem. Ltd., Istanbul, Turkey), pectin (Berk Chem, Istanbul, Turkey), fungal α-amylase and hemicellulose (Ataer Ltd., Istanbul, Turkey) were also used.

Preparation of rice sourdough

Rice sourdough was prepared with traditional method as follows: on the 1st day, 100 g of rice flour, 150 g of tap water and 3 g of chickpea (with the idea of enrichment to microflora) were mixed in a glass bowl with a wooden spoon. The mixture was covered and left to rest for two days at 30 °C in an incubator. On the 3rd day, 100 g of rice flour and 100 g of tap water were added to the previous mixture and left to rest for one day at 30 °C. On the 4th day, 100 g of rice flour and 100 g of tap water were again added to the mixture and this was left to rest for one day at 30 °C. On the 5th day, after the rice sourdough reached a pH value of 3.8-4.0, it was stored at 4 °C and fed with 100 g of rice flour and 100 g of tap water every three days.

Gluten-free bread formulations

The batter recipe was 100 g gluten-free flour (70 g rice flour and 30 g corn starch), 5 g baking powder, 4.5 g salt, 3 g sugar, 1 g xanthan gum, 1 g pectin, 0.05 g α-amylase, 0.05 g hemicellulose, 10 g hydrogenated fat, 10 g fresh yeast, and 250 ml water. The rice sourdough was added at 10, 20 and 30% of gluten-free flour weight. The proportion of dry matter and water were provided approximately equal (w/w) for all bread formulations.

The dry ingredients were mixed for 1 min using a mixer (KitchenAid Classic, St. Joseph, MI, USA) at a speed of 1. Sugar solution was prepared with the given amount sugar and warm water in the formulation. Fresh yeasts were activated by suspending them in the sugar solution for a period of 20 min. The sourdough was added to the activated yeast and then added to the dry ingredients together with the fat and mixed at a speed of 2 for 10 min. 250 g batter was poured into baking tins and placed in a proofer for 40 min at 40 °C. The loaves were baked in an oven (Unox®, Cadoneghe, Italy) at 230 °C for 15 min. They were then cooled to room temperature for 2 h. Breads were stored in polyethylene bags for 24 and 72 h after baking.

Dynamic rheology

The rheological properties of the gluten-free dough samples were determined using a strain/stress controlled rheometer (Rheostress 1; Thermo-Haake, Karlsruhe, Germany) equipped with a temperature-control unit (K15; Thermo-Haake). The measuring system consisted of parallel plate geometry (35 mm diameter, 1 mm gap). The rheological measurements were performed at 30 °C. Dough samples were prepared without the addition of yeast and rested for 10 min. A sample of 1.1 ml of the gluten-free dough was applied to the lower plate of the rheometer with an injector and the probe was lowered to a gap width of 1 mm. The sample border was then covered immediately with a thin layer of silicone oil to prevent drying.

Stress sweeps at a frequency of 1 Hz were carried out to determine the linear viscoelastic region from 0.1 to 10 Pa. Frequency sweep tests were performed within a frequency range of 0.1-10 Hz at 0.3 Pa to determine the storage modulus (G') and loss modulus (G'') as a function of frequency. Five measurements were carried out and averaged.

Bread properties

Loaf volume was measured by the rapeseed displacement method (AACC, 2001). Loaf weight was recorded and loaf specific volume (ml/g) was calculated. The moisture of gluten-free bread samples was measured following a procedure based on the AACC method (AACC, 1999) after 2, 24 and 72 h post baking. Texture profile analysis (TPA) was performed 2 h after baking using a texture analyser (TA. XT Plus; Stable Micro Systems, Godalming, UK) equipped with a 5-kg load cell and a 50 mm aluminium cylindrical probe. The pre-test, test and post-test speeds were 1, 1.7 and 10 mm/s, respectively, and compression was set at 40%. Two loaves were used for each analysis. The loaves were sliced using an electrical bread knife to obtain uniform slices of 25 mm thickness. TPA analysis was repeated 24 and 72 h after baking (days 1 and 3, respectively). Crust and crumb colour were measured using a Minolta colour measuring device (CR-400; Konica-Minolta, Tokyo, Japan) and results were expressed using the L*, a*, b* colour scale.

Statistical analysis

The results were expressed as means ± standard deviation. Statistical significant differences between the mean values were evaluated with Tukey multiple comparison test using SPSS 17.0.1 (SPSS Inc., Chicago, IL, USA) at $P<0.05$.

3. Results and discussion

Dynamic rheology

The mechanical spectra of the gluten-free dough samples are presented in Figure 1. Storage and loss moduli increased with frequency. The rheological behaviour of control and 10% (G10) sourdough containing samples were identical to 20% (G20) and 30% (G30) sourdough containing samples. While the storage modulus of the samples linearly increased, a marked increase after 1 Hz was observed for loss moduli. In all cases G' was higher than G'' indicating the prevalence of elastic features over viscous ones. Similar results were reported in different gluten-free rice dough enriched with protein isolate (Marco and Rosell, 2008) and low lactose dairy ingredients (Nunes *et al.*, 2009b). The usage of xanthan gum, β-glucan and pectin strengthened the structure of rice flour-based dough as indicated by higher G’ values (Lazaridou *et al.*, 2007). Lorenzo *et al.* (2009) reported that the elastic modulus of hydrocolloid containing gluten-free dough was higher than the viscous modulus and the values for both parameters were similar to each other with increase in frequency. Sivaramakrishnan *et al.* (2004) compared the rice flour-based dough samples with wheat dough, and proved that all the samples were more elastic and 1.5% and 3% hydroxypropyl methyl cellulose added rice flour dough showed similar rheological features to wheat dough. In a study investigating the effects of resistant starch, both the elastic and viscous moduli of gluten-free dough increased with frequency and it was reported that elastic properties were more dominant than viscous properties (Korus *et al.*, 2009). Pruska-Kędzior *et al.* (2008) reported that gluten-free dough exhibited more elastic behaviour, and both viscous and elastic moduli increased with frequency. The elastic modulus of gluten-free dough produced by rice flour and buckwheat flours was higher than the viscous modulus in all frequency ranges (1-10 Hz). Only a slight increase with frequency was observed implying typical gel-like behaviour (Torbica *et al.*, 2010). After fermentation of gluten-free dough at 30 °C for 30 min the G’ values were higher than the G'' values indicating solid-like behaviour (Renzetti *et al.*, 2008).

The rheological properties of gluten-free dough observed in this study were similar to the results of previous studies mentioned above. When the level of pectin and xanthan in the gluten-free dough was constant, increasing amounts of rice sourdough led to proportional reduction in the rate of hydrocolloids. And this could be the reason of lower G’ and G'' values of G20 and G30 dough when compared to those of control and G10 dough.

Specific volume

Control bread had the highest volume, and a statistically significant ($P<0.05$) reduction in bread volume with increase in the level of sourdough was recorded. The specific volume of control, G10, G20 and G30 breads were 1.98, 1.86, 1.77 and 1.68 ml/g, respectively. In gluten-free sorghum bread produced by the method of chemical acidification and sourdough, while sourdough and the control group had the highest specific volume, the chemically acidified breads had the lowest (Schober *et al.*, 2007). Similarly, Pruska-Kędzior *et al.* (2008) observed that the specific volume of gluten-free breads produced with two-step fermentation

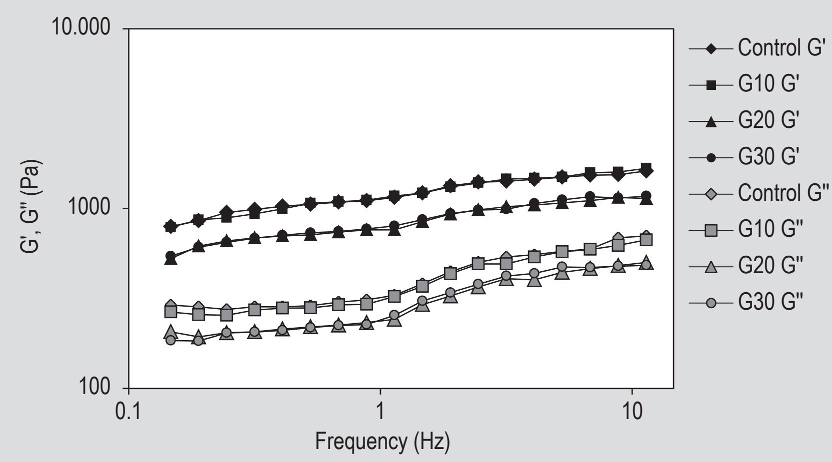

Figure 1. Storage (G') and loss (G'') moduli of gluten-free dough samples. Values are means (n=5). Control = gluten-free control bread; G10 = gluten-free bread containing 10% sourdough; G20 = gluten-free bread containing 20% sourdough; G30 = gluten-free bread containing 30% sourdough.

was higher. In contrast, Moore *et al.* (2007) reported that sourdough did not increase gluten-free bread volume due to the absence of gluten network.

The possible causes of the negative impact of sourdough on volume may be as follows: while the amount of sourdough increased, the ratio of baking powder, yeast, pectin, xanthan gum, and enzymes were reduced in the formulation; also, the impact of LAB developing in the sourdough on volume may have been reduced due to the absence of gluten network.

Moisture content

The moisture content decreased depending on storage time. A high level of moisture loss was determined in control bread. The addition of sourdough resulted in a reduction in the water loss of the samples during storage.

It is known that bread with high moisture content stay fresher compared to those with lesser moisture content (Gallagher *et al.*, 2003). This study indicated a decrease in the level of moisture during the storage of bread as a result of the staling effect. The addition of sourdough caused less water loss in bread during storage. Thus, use of sourdough in gluten-free bread is likely to affect the staling behaviour of bread. Similarly, the moisture content of gluten-free breads based on rice flour and corn starch was 47.42 and 45.27%, on the 1st and 3rd day, respectively The moisture content of bread samples supplemented with wheat, corn, oats and barley fibre was reported in the range of 49.53-53.42% on the 1st day and 46.30-50.76% on the 3rd day (Sabanis *et al.*, 2009). The 2, 24, 72 and 120 h after production of rice based gluten-free bread moisture contents were determined 46.38, 46.84, 45.29 and 45.12%, respectively. The loss of moisture specified as 97.3% in gluten-free bread (Thompson, 2009).

Textural properties

The hardness values of gluten-free samples are given in Figure 2A. G30 bread with the highest sourdough level had the maximum hardness value after 2 h, while the G10 and G20 bread had the lowest hardness value. Gluten-free bread with sourdough did not differ significantly (P>0.05) between 24 and 72 h and they were softer than the control. The hardness of all samples gradually increased during storage. Gluten-free bread containing 10% and 20% sourdough had higher crumb softness than the control samples, but the addition of 30% sourdough caused quite a hard crumb. The hardness values of the sourdough bread remained constant during storage and appeared softer when compared with the control bread. The hardness values of all the bread samples were significantly increased during storage due to staling effect. The results obtained from the hardness tests seem to be largely related to the moisture content of bread. Similarly, Sabanis *et al.* (2008) reported that the hardness of samples produced with a gluten-free flour mixture increased significantly during 2 and 4 days

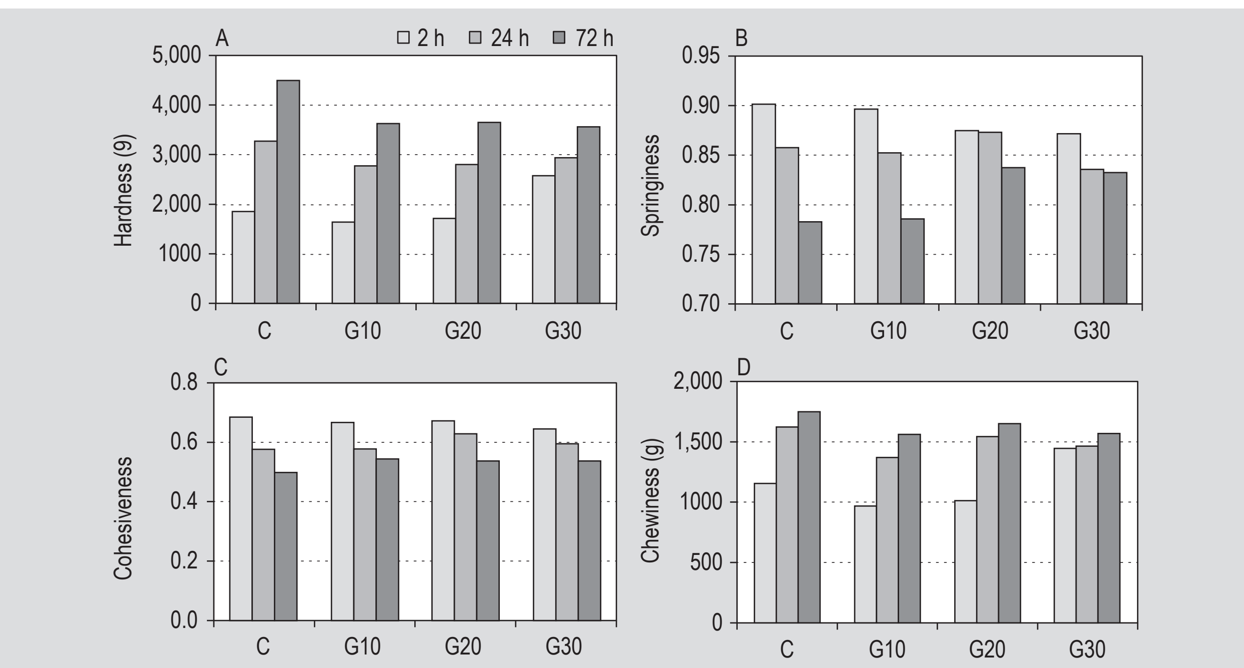

Figure 2. Texture profile analysis profile of the bread samples after 2, 24, 72 h post-baking: (A) crumb hardness; (B) crumb springiness; (C) crumb cohesiveness; (D) crumb chewiness. Data are averages of a duplicate test (n=5). C = gluten-free control bread; G10 = gluten-free bread containing 10% sourdough; G20 = gluten-free bread containing 20% sourdough; G30 = gluten-free bread containing 30% sourdough.

of storage. The hardness value of gluten-free bread with different hydrocolloids added significantly increased as a result of storage at 5 °C for 3 days (Lazaridou *et al.*, 2007). According to Nunes *et al.* (2009a) the hardness of gluten-free bread supplemented with emulsifier increased significantly during a 5 day storage period. There was no statistical difference in the hardness of gluten-free bread prepared with *Lactobacillus plantarum* 2115 KW, *L. plantarum* FST 1.11, and *Lactobacillus sanfranciscensis* TMW 1.52 strains compared with controls on the 1st (0) and 2nd day, but it was seen that they had a lower hardness value after the 5th day (Moore *et al.*, 2007). The hardness value of sorghum sourdough bread was reported to be similar with the control group and softer than chemically acidified bread (Alvarez-Jubete *et al.*, 2010). A study investigating the effect of LAB on the hardness value of wheat bread found that the hardness of all bread samples increased during 144 h storage depending on the type of starter used. However, bread containing *Lactobacillus hilgardii* S32 with endoxylanase and pentosans had the lowest hardness value (Corsetti *et al.*, 2000).

According to the results of the present study, the most significant reduction in springiness value due to staling was observed for control bread (shown in Figure 2B). G10 and G20 bread lost their springiness more slowly than other samples. Even when the springiness of the bread remained the same after 2 and 72 h, G30 bread had the lowest value of 0.836 and G20 bread had the highest value of 0.874 (data not shown). Control and G10 bread had similar springiness values. The springiness value of corn starch based gluten-free bread was reported to decrease during storage of 48 h (Korus *et al.*, 2009). Witczak *et al.* (2010) investigated the effect of maltodextrins on gluten-free bread containing corn and potato starch and found that bread springiness values did not change in themselves, and were not affected by 1 and 2 day storage periods.

As shown in Figure 2C, the most notable point for the cohesiveness values of bread was gradual decline during storage. Reducing crumb cohesiveness indicate a weakened bread structure (Schober *et al.*, 2005). The most significant decrease in cohesiveness occurred in the control bread. While G20 bread had the highest cohesiveness after 2 and 24 h, after 72 h the difference was insignificant (P>0.05) among the samples. In general, G10 and G20 bread that had the lowest chewiness value of all were similar to each other. Although the cohesiveness of G30 bread was not affected by a 3 day storage period, the other bread's values at 24 h and 72 h were higher than those of fresh samples. Korus *et al.* (2009) demonstrated a decrease in the cohesiveness value of corn starch-based gluten-free control bread during 48 h storage.

While the chewiness of gluten-free samples increased significantly between 2 and 24 h, there was no increase at 72 h (Figure 2D). G10 and G20 bread had the lowest values throughout. No statistically significant difference was observed among samples at 3 days. The chewiness value of G30 bread was not changed by a 3 day storage period.

Crumb and crust colour

The L*, a*, and b* values for the crust and crumb colour of all bread samples are summarised in Figure 3. The addition of sourdough did not affect the colour parameters of bread significantly. The colour values of the bread samples were influenced by storage. According to the results, the L* value of the control bread crust increased consistently with storage. The L* values of G10, G20 and G30 bread 2 h after baking were lower than those of other days, in other words, the colour darkened. This can be explained by starch retrogradation occurs on the surface of the bread, and increasing the moisture content of the bread crust with water migration from crumb to crust during staling (Majzoobi *et*

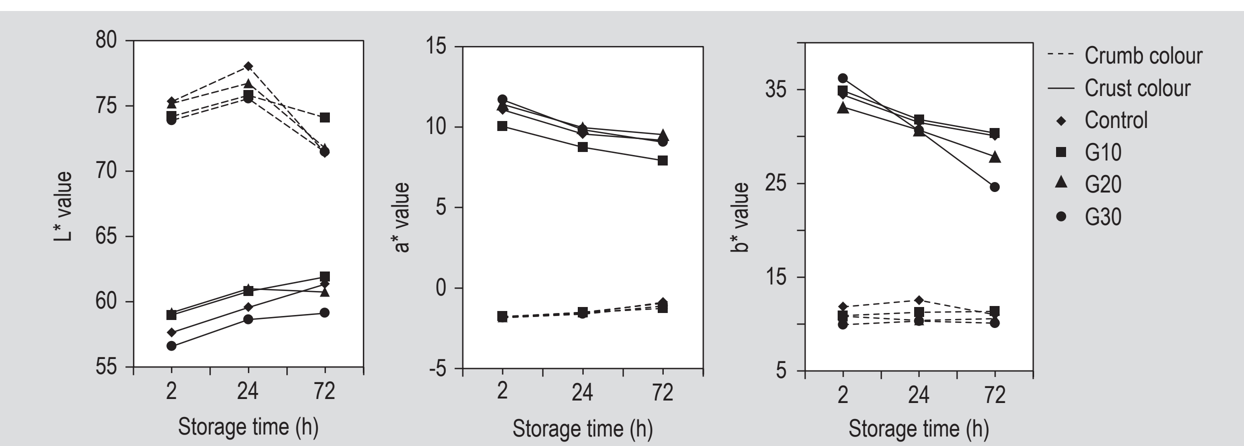

Figure 3. Effect of sourdough addition on crust and crumb colour of gluten-free breads. Data are averages of a duplicate test (n=5). Control = gluten-free control bread; G10 = gluten-free bread containing 10% sourdough; G20 = gluten-free bread containing 20% sourdough; G30 = gluten-free bread containing 30% sourdough.

al., 2011). This case was slightly different for crumb. The L * value of control, G20 and G30 bread crumb increased 2 h after baking until 24 h; however it decreased at the end of 72 h. Although the same trend was partly observed for G10 bread, the changes were statistically identical (P>0.05). The crust colour of G30 bread during all storage times was the lowest. The redness value of fresh bread crust was the highest and a significant decrease occurred after 24 h storage. The a* values of bread crumbs were all negative, which means that there was no red hue for the crumb. The difference in a* values of bread crumb 2 and 24 h after baking, a statistically significant (P<0.05) difference, was observed after 72 h. In contrast to the crust of the bread, crumb redness increased gradually during storage. The b * value of bread crust gradually decreased during storage. G30 bread had the lowest b * value during storage.

In the literature, the colour values for gluten-free bread samples vary extensively possibly due to different formulation, baking temperature and time. The L* values of rice flour based gluten-free bread crusts obtained from a formulation using specific proportions of buckwheat, quinoa, amaranth, and potato starch, were reported in ranges from 69.7 to 51.4 (Alvarez-Jubete *et al.*, 2010). Sabanis *et al.* (2009) found that the L*, a* and b* values of corn starch and rice flour-based control gluten-free bread were 71.82, 7.02 and 31.02 in crust; likewise they were 72.93, -2.38, and 5.69, respectively, in crumb. Moore *et al.* (2007) reported no significant difference for the colour values of gluten-free bread samples produced from LAB added formulation.

4. Conclusions

In this study, rice sourdough was developed by natural fermentation and was added in specific proportions to a gluten-free bread formulation. The most important contribution of the addition of sourdough on the quality of gluten-free bread was its reducing the staling effect as a result of development in crumb moisture content and textural properties. Consequently, the use of sourdough was shown to be beneficial in prolonging the shelf-life of gluten-free bread which normally goes stale after a short time. However, it was also noted that an increase in the amount of sourdough in gluten-free bread leads to a decrease in specific volumes. In terms of achieving improvements in the both volume and flavour, incorporation of sourdough into whole formulation instead of its addition only, might be followed as another strategy. The use of starter may be preferred instead of spontaneous fermentation in making gluten-free sourdough with rice flour. Thus, bread quality can be improved in the desired direction with selecting the proper microbial species.

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