PAPER

THE EFFECT OF THE ADDITION OF WATER, SOY PROTEIN, INULIN, AND MALTODEXTRIN ON THE QUALITY OF DOUGH AND GLUTEN-FREE BREADS

M.A. PRZYBYSZ and E. DŁUŻEWSKA*
Department of Food Technology, Faculty of Food Sciences, Warsaw University of Life Sciences, Nowoursynowska 166 ST, 02-787 Warsaw
*E-mail address: elzbieta_dluzewska@sggw.pl

ABSTRACT

The main aim of the study was to improve the textural properties of dough and the physicochemical properties of gluten-free breads derived from mixtures. The mixtures contained hydroxypropyl cellulose, soy protein isolate, inulin, and maltodextrin. During experiments the amount of water in dough was changed in the range from 80 to 100 g of the total weight of the mixtures. The textural properties of gluten-free dough (TPA's test) were measured. Bread volume, porosity, moisture, and hardness of crumb in the obtained breads were determined.
The obtained results show that the best positive impact on the textural properties of the gluten-free dough has the addition of 0.5 g/100 g of hydroxypropyl cellulose, 5.0 g/100 g of soy protein isolate, and 10.0 g/100 g of maltodextrin, with 100 g of water/100 g mixture. The results also suggest that water content is strongly associated with bread staling. Despite differences in their sensory properties, the breads were accepted by consumers.

Keywords: hydrocolloids, soy protein, inulin, maltodextrin, gluten-free bread, bread quality

1. INTRODUCTION

Coeliac disease (gluten sensitive enteropathy) is a chronic gluten intolerance. So far, the only effective way of the coeliac disease treatment was to follow the strict restrictions of a gluten-free diet.

The food that fulfills the gluten-free standards differs unfavorably from the regular food in terms of sensory quality. Such food usually has a lower nutritional value and its production process causes several technological problems (MOHAMMADI *et al.*, 2014).

In a typical bread production process, during the process of dough kneading, gluten-free flour with water cannot create the elastic structure of the dough. Gluten-free dough weakly keeps carbon dioxide during the process of growing and baking, which results in a small volume of bread (RAKKAR, 2007; PACIULLI *et al.*, 2016). The lack of gluten, which is responsible, among others, for the dough flexibility, makes gluten-free breads smaller (in volume) with an adverse taste, unpleasant smell and worse structure (MIR *et al.*, 2016). The crumb of such bread tends to crumble, and the process of staling is very fast (FURLAN *et al.*, 2015). The specificity of gluten-free ingredients does not allow to enrich the dough with adequate quantities of water, which could ensure the proper level of moisture. Hence, the gluten-free breads, especially those produced with a large addition of raw starch, tend to lose their freshness very fast. In such case, the bread with very good properties after baking concerning its moisture, cohesion and cutting, crumbles and becomes dry on the next day (GALLAGHER *et al*., 2003).

Because of the elimination of gluten, which is the most important ingredient in the production process of traditional bread responsible for the bread structure-forming, for gluten-free breads it is necessary to use hydrocolloids with the ability to bind water, which serve in a similar way as gluten in wheat dough (MANCEBO *et al*., 2015; MIR *et al*., 2016). Polysaccharide hydrocolloids such as xanthan gum, guar gum, pectin, cellulose, and their mixtures are often used as structure-forming components in gluten-free bread concentrates (AHLBORN *et al.*, 2005; SCIARINI *et al.*, 2010; MASURE *et al.*, 2016). Moreover, several scientists (CATO *et al.*, 2004; SIVARAMAKRISHNAN *et al.*, 2004; ONYANGO *et al.*, 2009) use different types of modified cellulose as a structure forming factor. The substantial disposal of a nutritional value in this type of food, however, caused the necessity to find such additives that combine structure-forming and active prohealth features. Such replacement may be represented by inulin or soy proteins. In combination with hydrocolloids and maltodextrin they can create breads similar to the ones that contain gluten in terms of both physicochemical and sensory features.

Inulin is an oligosaccharide belonging to fructans. What is important, the molecules of fructose in inulin are linked by β-2-1 glycoside bind (GUARNER, 2007). It appears that inulin, in addition to the numerous prohealth properties, can also be used as a texture-making factor – that stems from its capacity for absorbing water and for gelation, and also from its ability to create emulsions and condensation (BROWN and TUOHY, 2006; ZIOBRO *et al.*, 2013). The trials to enrich gluten-free bread by inulin have been carried out by GALLAGHER *et al.* (2003).

The main feature of maltodextrin is the value of its glucose equivalent DE (i. e. dextrose equivalent), which indicates the percentage of reductable sugars, expressed as glucose, calculated for a dry product. By the term maltodextrin, one can understand starch hydrolysates with DE below 20. Maltodextrin, due to its attractive rheological properties, is widely used in food processing (WITCZAK *et al.*, 2010).

Water plays an important role in the physical and chemical changes that occur during the production process of dough and bread. Depending on the amount of the added water the various quality characteristics of dough (CHIN *et al.*, 2005; HERA *et al.*, 2014) and bread (OSELLA *et al.*, 2007) can be affected. Hence, the aim of our work was to assess the textural properties of dough and gluten-free breads obtained with the addition of the structure-forming additives and different amounts of water added to the dough. It is worth noting that many research on the influence of formulation, including water content, on the quality of gluten-free dough and breads were carried out. But still gluten-free commercial breads are not as good as traditional breads. Thus, it is necessary to conduct further research.

2. MATERIALS AND METHODS

2.1. Preparation of mixtures

Mixtures contained 100g of dry dough ingredients. The mixtures of gluten-free breads were produced from corn flour and rice flour used in the ratio of 1:2. In each sample, the gluten-free mixture had the same quantity of yeast, salt, and sugar. As structure-forming additives, hydroxypropyl cellulose - HPC (Klucel, type M CS), soy protein isolate - SPI (795), maltodextrin (DE 16, Jaskulski Aromas JAR), and inulin (HPX, Hortimex) were used (Table 1). The first sample contained only HPC, while the next samples were enriched by SPI, inulin, and maltodextrin. Accordingly, we introduced the following sample codes: HPC; HPC-SPI; HPC-SPI-I; HPC-SPI-M. Our samples were chosen basing on preliminary results.

Table 1. The composition of the gluten-free bread mixture.

Additives	Content (g/100 g) Sample code			
	HPC	HPC-SPI	HPC-SPI-I	HPC-SPI-M
Corn flour	30.2	28.5	25.2	25.2
Rice flour	60.3	57.0	50.3	50.3
Yeast instant	2.4			
Sugar	5.1			
Salt	1.5			
Hydroxypropyl cellulose	0.5			
Soy protein isolate	–	5.0	5.0	5.0
Maltodextrin	–	–	–	10.0
Inulin	–	–	10.0	–

2.2. Bread baking

The amount of water in the dough was 80, 90 and 100 g with 100 g of the mixture. Firstly, the dough was mixed in a mixer for 5 minutes, and, then, it was kept for 30 min in a plastic bowl in the temperature of 40°C. Subsequently, after 30 minutes, the dough was moved into shaped bowls where the fermentation process was continued for the next 10 minutes until the optimum volume was reached. Baking was carried out in the combi-streamer oven by UNOX (type XBC, model XBC 404) for 23 min in 175°C on the third level of vaporization. The breads were cooled down to the ambient air temperature. Specifically, they were packed into plastic bags that remained open and, in order to make measurements, were kept in the room temperature for two days. Two breads were produced from one mixture. Six repetitions were made for each measurement.

2.3. Texture of gluten-free dough

The determination of the texture of gluten-free dough (test TPA-Texture Profile Analysis) was done using texture Analyzer TA-XT2 (Stable Micro System) connected to the PC. Raw dough samples were placed in glass vessels in the form of cylinders of 60 mm in diameter and 30 mm in height. The dough was double compressed to 1/3 of the height of the sample using a cylindrical head with an attachment in the shape of cylinder of 25 mm in diameter. The value of pressure used to compress the sample was equal to 250 N. The speed of measurement was equal to the speed of the head - 1 mm s^{-1}. During the study, curves in a force-shift of the stem system were obtained. On their basis, such features as hardness, cohesiveness, springiness, gumminess, and adhesiveness were specified. The TPA test was performed immediately after the mixer dough kneading had been completed.

The hardness is defined as the maximum value of the force needed to deform the dough during the first squeezing. The cohesiveness is defined as a ratio of the work needed to reach the point of hardness for the first compress to the work needed to reach the point of hardness for the second compress. The springiness is the difference between the distance at the point of bearing and the distance at the point of contact during the second cycle test. The gumminess is the product of the hardness of the first cycle and the cohesiveness. The adhesiveness is the area over the negative part of return force between the point of relaxation and the point of loss of contact (Stable Micro System, 1997).

2.4. Analysis of gluten-free breads

2.4.1 Physicochemical properties

The rapeseed displacement method 10-05 was applied to measure the bread volume. The Sa - Wa apparatus, produced by Sadkiewicz Instruments, was used to measure bread volume. The approved method 44-15A (AACC International, 2000) was applied to determine the bread moisture. The porosity of bread crumb was assessed in the same way as in, for example, ROMANKIEWICZ *et al.* (2017). It was performed by determination of the differences between the volumes of uncompressed and compressed crumb, which was devoiced of pores by kneading. The 27 cm^3 volume cylinders were cut from the bread crumb and were kneaded. Next, they were immersed in oil (edible oil was poured into cylinders up to a volume of 30 cm^3) in order to determine the volume. The height / diameter ratio (H/D ratio) was determined as well.

2.4.2 Textural properties

The crumb hardness was measured using texture Analyzer TA-XT2 (Stable Micro System, 1997). Twenty-millimeter thick slices were cut from the center of the analyzed loaves. Then, the slices, were compressed and relaxed. As previously, the cylindrical head with the attachment in the shape of a cylinder of a diameter of 25 mm was used. During the measurements, the speed of movement of the head was 1 mm s^{-1} and the sample was penetrated to the depth of 9 mm with the force of 250 N. We studied the moisture and the hardness of crumb 24 and 48 hours after baking.

2.4.3 Sensory assessment of gluten-free bread

Consumer quality assessment was performed using hedonic rating scale (100 mm - subsequently adopted as 100 arbitrary units). The boundary markings were from "very undesirable" (0 units) to "very desirable" (100 units). A team of 40 trained panelists conducted the sensory evaluation of the breads. The quality assessment was determined separately for each bread. The assessment was performed during several sessions, where each time 6 samples were evaluated. Based on the scores of the evaluation panel mean values were calculated (BARYŁKO-PIKIELNA, 1975).

2.4.4 Statistical analysis

All tests were performed at least in three replicates. The statistical analysis of the obtained data was performed applying Statgraphics Plus. The differences between the means were based on one-way ANOVA. The significance level (α) was set to 0.05 and the multiple comparisons of the means were conducted using Tukey's HSD test.

3. RESULTS AND DISCUSSION

3.1. Analysis of textural properties of gluten-free dough (TPA's test)

Table 2 presents the results of the textural features analysis of the gluten-free dough. The statistical analysis shows that the textural properties of the dough depend significantly on the amount of water addition, as well as on the type of structure forming additives (the results of two-way ANOVA may be obtained from the authors upon request). An increase of water amount, no matter what type of structure-forming additive was used, caused a significant decrease of the dough hardness, gumminess and adhesiveness. However, no significant impact of the amount of water on the springiness and cohesiveness of the dough was observed. The analysis of the impact of structure-forming additives on the textural properties indicates that a simultaneous use of HPC and SPI leads to an increase of the dough hardness, a significant increase of its gumminess and adhesiveness with 80 g and 90 g of water addition per 100 g of the mixture respectively, and a small decrease of its cohesiveness. The springiness of the dough samples, with and without the SPI addition, was on the same level for the same water addition respectively in whole analyzed range. One can conclude that the introduction of SPI into the gluten-free dough had no positive impact on the textural properties of the analyzed dough samples, but it is important to remember that the SPI additive significantly increased the amount of protein in the gluten-free bread, and, in consequence, increased its nutritional value.
There are a number of publications showing that the properties of mixtures of some biopolymers can be significantly different from the properties of individual components (MOHAMMADI *et al.*, 2014; DIOWKSZ *et al.*, 2009). The usage of polysaccharides composition allows to observe new functional properties or to change the rheological properties of food products (DIOWKSZ *et al.*, 2009). The phenomenon may be observed during the creation of the ternary systems of protein-polysaccharide-water. Depending on the proportion of the mixed ingredients, their structure, molecular weight, and the nature of the specific polysaccharides and proteins, distinct properties of mixtures, often beneficial, can be noticed. It is the case of, for instance, solubility, viscosity, susceptibility to an action of enzymes, gelation, denaturing temperature (MIR *et al.*, 2016).

Table 2. The parameter values of the texture of gluten-free dough with different addition of water.

Sample code	Amount of added water (g/ 100 g mixture)	Texture parameters				
		Hardness (N) $\bar{x}$ ±SD	Cohesiveness (-) $\bar{x}$ ±SD	Springiness (mm) $\bar{x}$ ±SD	Gumminess (N) $\bar{x}$ ±SD	Adhesiveness (N·mm) $\bar{x}$ ±SD
HPC	80	0.434±0.015^{c}	0.675±0.049^{a}	9.637±0.068^{a}	0.294±0.031^{b}	0.932±0.121^{c}
	90	0.220±0.017^{b}	0.710±0.073^{a}	9.252±0.330^{a}	0.157±0.022^{a}	0.353±0.044^{b}
	100	0.162±0.013^{a}	0.730±0.052^{a}	9.522±0.036^{a}	0.117±0.005^{a}	0.167±0.039^{a}
HPC-SPI	80	1.118±0.021^{c}	0.651±0.007^{a}	9.663±0.029^{b}	0.728±0.014^{c}	3.205±0.040^{c}
	90	0.474±0,044^{b}	0.660±0.027^{a}	9.587±0.033^{b}	0.313±0.032^{b}	1.141±0.170^{b}
	100	0.245±0.027^{a}	0.646±0.023^{a}	9.458±0.084^{a}	0.158±0.012^{a}	0.398±0.091^{a}
HPC-SPI-I	80	0.485±0.070^{c}	0.798±0.038^{a}	9.741±0.030^{a}	0.388±0.064^{c}	1.272±0.301^{c}
	90	0.287±0.077^{b}	0.800±0.088^{a}	9.762±0.053^{a}	0.226±0.040^{b}	0.548±0.317^{b}
	100	0.154±0.007^{a}	0.811±0.064^{a}	9.959±0.035^{b}	0.125±0.012^{a}	0.040±0.019^{a}
HPC-SPI-M	80	0.342±0.014^{c}	0.579±0.016^{ab}	9.818±0.055^{a}	0.198±0.004^{c}	0.248±0.027^{c}
	90	0.222±0.016^{b}	0.638±0.044^{b}	9.879±0.081^{ab}	0.141±0.004^{b}	0.075±0.047^{b}
	100	0.132±0.010^{a}	0.543±0.038^{a}	9.975±0.016^{b}	0.072±0.005^{a}	0.050±0.001^{a}

HPC - Hydroxypropyl cellulose, SPI - Soy protein isolate.

$\bar{x}$ - mean value / SD – standard deviation.

mean values denoted by different superscripts (a) to (c) in the same column for the same addition differ significantly from each other (α = 0.05).

It was found out that the best effect on the textural properties of the gluten-free dough had the addition of the mixture of HPC, SPI and maltodextrin. Thus, the dough obtained using the mixture of these additives had the highest springiness and the lowest hardness, gumminess and adhesiveness. The best effect of these compounds was noticed for the highest level of water addition. The addition of inulin instead of maltodextrin enables obtaining the most compact dough for each amount of water. The lowest rates can be noted for the dough containing the mixture of HPC and SPI for each amount of water, which were characterized by the highest level of hardness, gumminess and adhesiveness. DIOWKSZ *et al.* (2009) evaluated the impact of the enrichment of gluten-free bread by fibre creams of different composition on the rheological properties of the gluten-free dough. The authors argued that the use of lupin fibre with addition of inulin favorably reduced the hardness of the cream. The addition of inulin to lupin fibre substantially changed the rheological properties of the mixture. The significant influence of inulin on the quality of the gluten-free dough was not noticed, probably because of its small addition in relation to the total weight of the dough (from 1-3 %) and the properties of the dough were determined by lupin fibre or soy fibre (from 17-20 %). WITCZAK *et al.* (2010) claim that the rheological properties of gluten-free dough may be modified by the addition of maltodextrin, which weakens its structure and increases its ability of deformation. The dough with the addition of inulin is less flexible and more viscous. As a result, the addition of inulin is followed by the decrease in water amount. This effect is associated with the ability of inulin to form gels. The macromolecules of inulin zones are present in the cross-linked form and therefore they hold large quantities of water. During the folding of gel molecules, water is hold and does not bind (CAPRILES and AREAS 2013; ZIOBRO *et al.*, 2013; TSATSARAGKOU *et al.*, 2016).

3.2. Analysis of physicochemical properties of gluten-free breads

The properties of the porous 3D structure of crumb and the resulting volume of bread are next to the taste and smell basic features of the bread quality (DIOWKSZ *et al.,* 2009). The research shows that the volume of the gluten-free bread was differentiated not only in terms of structure-forming additives but also with reference to the amount of water addition, which also results from the different absorption capacity of the applied additives. On the basis of the obtained results (Fig. 1A), it was found out that the best influence on the volume of the gluten-free bread has the addition of the mixture of HPC and SPI and 100 g of water per 100 g of the mixture. The addition of SPI to the bread containing only HPC caused the increase of the volume of bread with 90 and 100 g of water per 100 g of the mixture. Further extension of the recipe to include inulin, only in the case of the bread with the addition of 90 g of water per 100 g of the mixture (which amounted to 178 cm^3/100 g of the product), remitted the increase of its volume. The replacement of inulin by maltodextrin proved beneficial only for 80 g of water per 100 g of the mixture, when the volume grew for the bread with the mixture of HPC and SPI with an increase of water content from 80 to 100 g per 100 g of the mixture. In the case of the bread containing only HPC and the bread with the addition of inulin and maltodextrin with the increase of water content in the mixture in the range from 80 to 90 g - the volume increased, while beyond 90 g/100 g of the mixture the volume decreased. The volume of the bread with the addition of HPC baked with 100 g of water/100 g of the mixture was higher in comparison to the volume of the bread with 80 g of water addition in relation to the weight of the mixture.

The research confirmed the earlier observations on the favorable impact of soy protein or milk additions on the appearance of the loaf – particularly, the increase of its volume and the extension of its freshness time (GALLAGHER *et al.,* 2003; GALLAGHER *et al.,* 2004; GAMBUŚ *et al.* 2007). Similar observations were made by RANHORTA *et al.* (1975) in their studies. They found not only the increase of the value of nutrition, but also the improvement in the characteristics of the final properties of the gluten-free breads baked on the basis of gluten-free wheat starch and soy protein isolates. The usage of maltodextrin with different glucose equivalents – DE (3.6, 15.3, 18.3, and 21.8) in the gluten-free bread production process has been widely discussed. WITCZAK *et al.* (2010) demonstrated that the maltodextrins with high DE, especially equal to 18.0 and 21.8, positively affected the size of a loaf, while the maltodextrins with low DE reduced the volume of bread and caused the deterioration of its quality. The higher volume of the loaves prepared with the addition of the maltodextrin with higher DE derives probably from the increasing number of low molecule carbohydrates that can be used by yeast during fermentation.

The analysis of the results of the gluten-free bread crumb porosity (Fig. 1B) shows that the bread with the mixture of HPC and SPI with 100 g of the addition of water per 100 g of the mixture had the largest volume, and, moreover, the largest crumb porosity (47.7 %). Generally, the addition of SPI increases the porosity (only the porosity of the bread with 80 g of water addition per 100 g of the mixture did not change, which could have been caused by too small amount of water - soy protein isolates have good properties of water absorption). The addition of inulin had beneficial aspects for the bread with 80 and 90 g of water per 100 g of the mixture. However, a higher value of the porosity can be obtained by the use of maltodextrin instead of inulin. The addition of maltodextrin to the recipe proved to be effective in the case of the bread with 80 to 90 g of water addition/100 g of the mixture, because for the water addition of 100 g the porosity was slightly lower than in the bread with the largest value of this parameter among all analyzed samples.

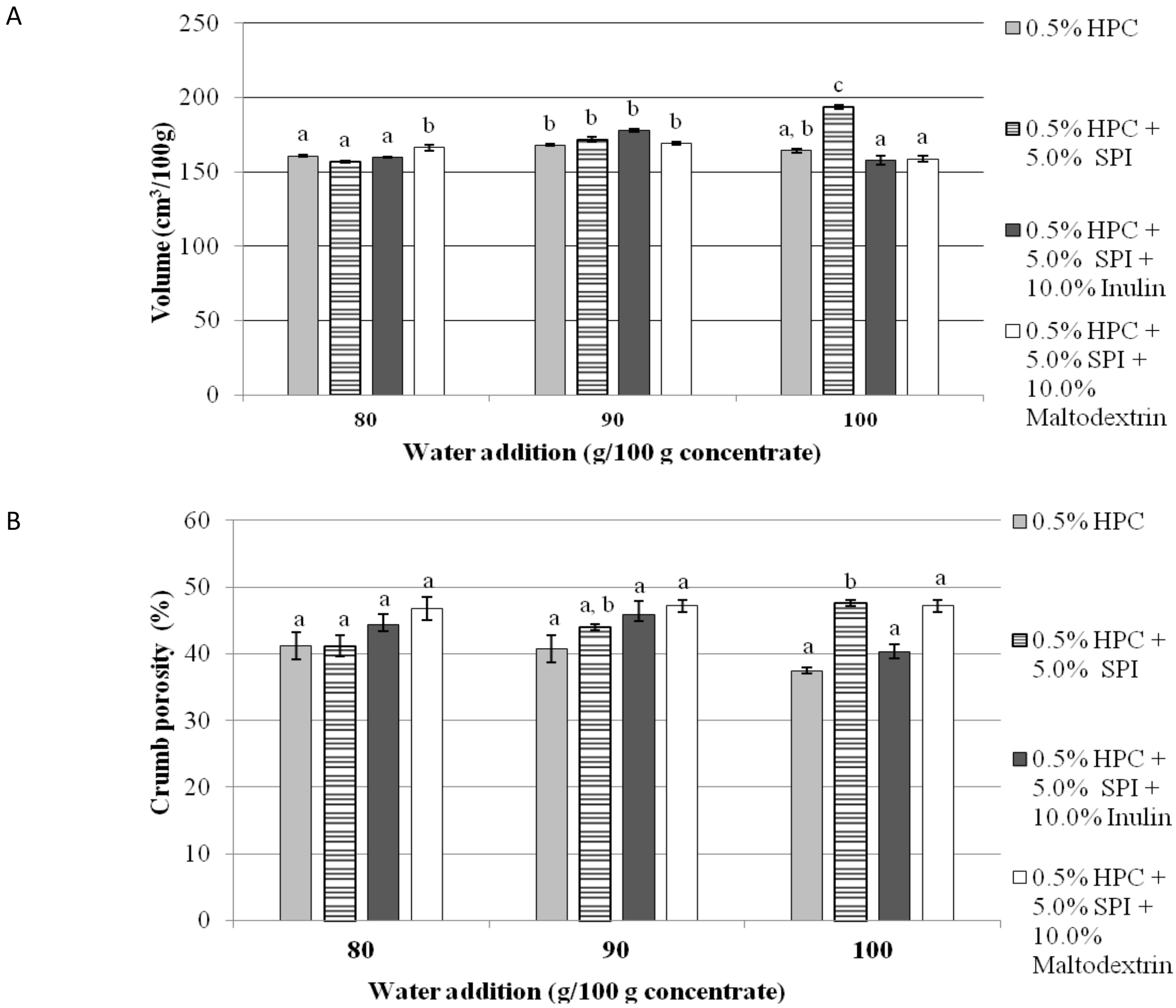

Figure 1. The physicochemical properties of gluten-free breads: A. Volume, B. Crumb porosity.
HPC - Hydroxypropyl cellulose, SPI - Soy protein isolate.
(a) to (c) – mean values denoted by different superscripts for the same addition differ significantly from each other (α = 0.05).

The porosity value of the bread with only HPC decreased with the increase of the water content in the dough, while an inverse relationship was noted for the bread containing the mixture of HPC and SPI. For the bread with the addition of inulin and maltodextrin, the porosity increased together with the increase of water content in the range from 80 to 90 g per 100 g of the mixture.
In order to examine the process of ageing, the gluten-free breads were kept in open plastic bags in the room temperature for two following days. The moisture of crumb was measured after 24 and 48 hours of storage. The research showed that the moisture of the crumb, for all samples of the bread, decreased with the addition of water to the dough during the whole storage time (Table 3). The addition of SPI, on the one hand, alleviated the crumb moisture after 24 hours of baking, and, on the other hand, it caused the loss of moisture changes during its storage in comparison with the crumb moisture of the bread without the addition of SPI. Considering both the impact of the addition of inulin and maltodextrin, it was found out that more advantageous is the use of inulin is more advantageous. The addition of inulin for each level of water addition allowed to obtain the

largest crumb moisture after 24 h of storage for all the analyzed bread samples. Moreover, the bread with its addition preferably retained moisture during the whole period of storage.
The increase in the crumb moisture for the breads with the addition of HPC, the mixture of HPC and SPI, and the mixture of HPC, SPI and inulin was observed during its storage time, as opposed to the breads with the mixture of HPC, SPI and maltodextrin, for which the minimal decrease of moisture or its absence was observed.

Table 3. Physicochemical properties of gluten-free bread after 24 and 48 h storage.

No of sample	Type and amount of addition (g/ 100 g)		Amount of water addition (g/ 100 g mixture)	Crumb moisture (%) $\bar{x}$ ±SD		Crumb hardness (N) $\bar{x}$ ±SD	
				After 24 hours	After 48 hours	After 24 hours	After 48 hours
1	HPC	0.5	80	52.8±0.2^{c}	53.8±0.4$^{c'}$	22.78±6.93^{a}	30.48±8.72$^{a'}$
			90	50.4±0.2^{b}	51.1±0.1$^{b'}$	20.41±4.04^{a}	24.74±5.88$^{a'}$
			100	48.6±0.5^{a}	49.3±0.3$^{a'}$	19.88±2.25^{a}	22.39±1.81$^{a'}$
2	HPC SPI	0.5 5.0	80	51.8±0.0^{c}	52.0±0.2$^{c'}$	28.56±3.86^{b}	33.75±4.91$^{b'}$
			90	49.7±0.2^{b}	50.1±0.4$^{b'}$	15.40±4.16^{a}	20.76±6.44$^{a'}$
			100	47.2±0.1^{a}	47.6±0.1$^{a'}$	11.64±1.97^{a}	14.81±2.61$^{a'}$
3	HPC SPI Inulin	0.5 5.0 10.0	80	52.8±0.1^{c}	52.8±0.0$^{c'}$	30.34±4.07^{b}	36.09±4.81$^{b'}$
			90	50.6±0.3^{b}	50.7±0.2$^{b'}$	19.19±3.13^{a}	24.07±2.56$^{a'}$
			100	48.8±0.2^{a}	49.1±0.6$^{a'}$	22.70±6.97^{ab}	29.06±7.81$^{a'b'}$
4	HPC SPI Maltodextrin	0.5 5.0 10.0	80	52.6±0.2^{c}	52.2±0.2$^{c'}$	20.28±3.88^{a}	25.22±2.19$^{a'}$
			90	50.4±0.2^{b}	50.0±0.1$^{b'}$	19.63±5.02^{a}	23.07±5.04$^{a'}$
			100	47.9±0.4^{a}	47.9±0.2$^{a'}$	14.25±5.53^{a}	17.74±5.17$^{a'}$

HPC - Hydroxypropyl cellulose, SPI - Soy protein isolate.
$\bar{x}$ - mean value / SD – standard deviation.
mean values denoted by different superscripts (a) to (c) / (a′) to (c′) in the same column for the same addition differ significantly from each other (α = 0.05).

3.3. Analysis of textural properties of gluten-free breads

The crumb hardness is one of the most obvious manifestations of bread staling. The crumb of the gluten-free breads hardens rapidly due to the starch content higher than in regular breads, as the starch components – amylose and amylopectin – retro gradate (RONDA and ROOS, 2011). The amount of water in the bread is also important in the process of bread staling. But this process is not caused by the loss of the water amount. It may be partly caused by the migration of moisture from the crumb to the crust. In addition, the water content and its activity can affect the degree of recrystallization of the starch (RONDA and ROOS, 2011). The crumb hardness in all examined breads increased during their storage. The addition of SPI to the bread containing HPC reduced the hardness of the bread with the 90 and 100 g of water per 100 g of the mixture after 24 h storage time (these breads were characterized by the lowest values of the hardness among all analyzed samples), but the addition of SPI increased the process of bread staling in all analyzed breads. Considering the addition of inulin and maltodextrin, it can be concluded that the addition of inulin proved to be disadvantageous (for the bread with 80 and 100 g of water addition to 100 g of the mixture largest values of the hardness 24 h after baking can be noticed). The research has shown that better results were guaranteed by the addition of maltodextrin than inulin. This addition allows you to obtain not only smaller values of the crumb hardness during the whole period of storage, but also can reduce the rate of adverse changes. The crumb hardness of the breads containing only HPC, HPC and SPI and the breads containing maltodextrin decreased together with increasing the content of water added to the dough. Throughout the period of storage, the value of the crumb hardness for the breads with the addition of inulin decreased with the increase of water content in the range from 80 to 90 g/100 g of the mixture. However, the further growth of the amount of water resulted in the increase of the hardness value after 24 and 48 h of storage. The desired effect of extension of the consumption freshness of breads associated with addition of soy protein, and different fractions of dietary fibre (including inulin) have been widely observed (CROCKETT *et al.,* 2011; Martinez *et al.,* 2014; TSATSARAGKOU *et al.,* 2016). HAGER *et al.* (2011) explored the impact of the addition of inulin and oat beta glucan on the quality of wheat and gluten-free bread. According to the authors, the inulin, although interesting from a nutritional point of view, has little use in the production of bread, both wheat and gluten-free, because its addition causes the increase in crumb hardness as well as the increase of staling. The use of a mixture of 5% to 8% inulin, fructo-oligosaccharides and flour from the chicory, for all applied doses, reduces the speed of the crumb hardness within three days of storage (KORUS *et al.*, 2006). This confirms the earlier observations concerning new functional properties of the mixtures of some biopolymers.

The changes of the physiochemical parameters of gluten-free breads due to different addition of water were investigated by a number of authors. For example, YAZAR *et al.* (2017) studied the nonlinear rheological properties of the gluten-free bread dough samples prepared using the optimum water absorption levels. Among others, they showed that the optimal addition of water depends on the ingredients included in the formulation of the gluten-free dough. 110%, 90%, 85%, and 160% water levels were found as optimal for rice, buckwheat, quinoa, and soy flour, respectively.

The evaluation of the panelist score concerning the gluten-free breads (Fig. 2) showed that they were accepted by consumers. The largest degree of consumer demand (49.4 j.u.) gained the bread with the mixture of HPC, SPI, and maltodextrin, with 100 g of water per 100 g of the mixture. The received samples of the gluten-free breads are shown in Fig. 3.

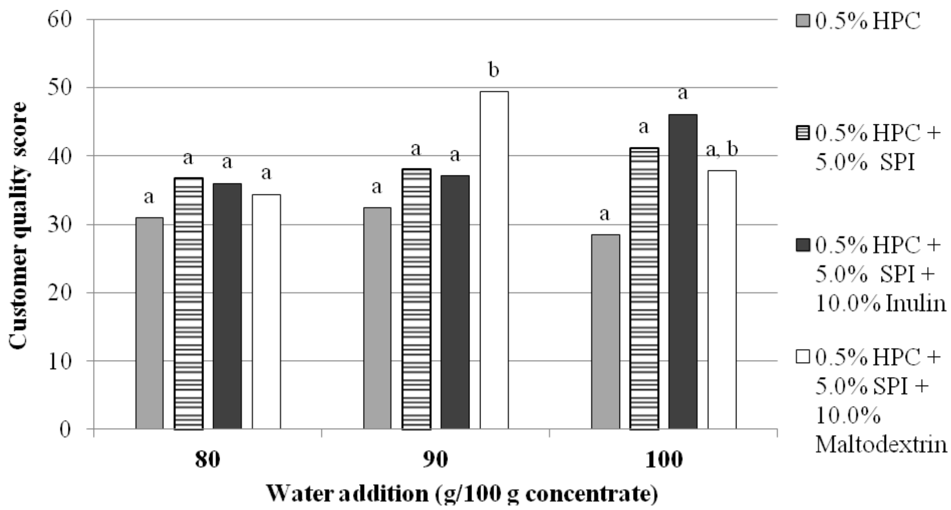

Figure 2. Quality assessment of consumer demand on gluten-free breads.
HPC - Hydroxypropyl cellulose, SPI - Soy protein isolate.
(a) to (b) – mean values denoted by different superscripts for the same addition differ significantly from each other (α = 0.05).

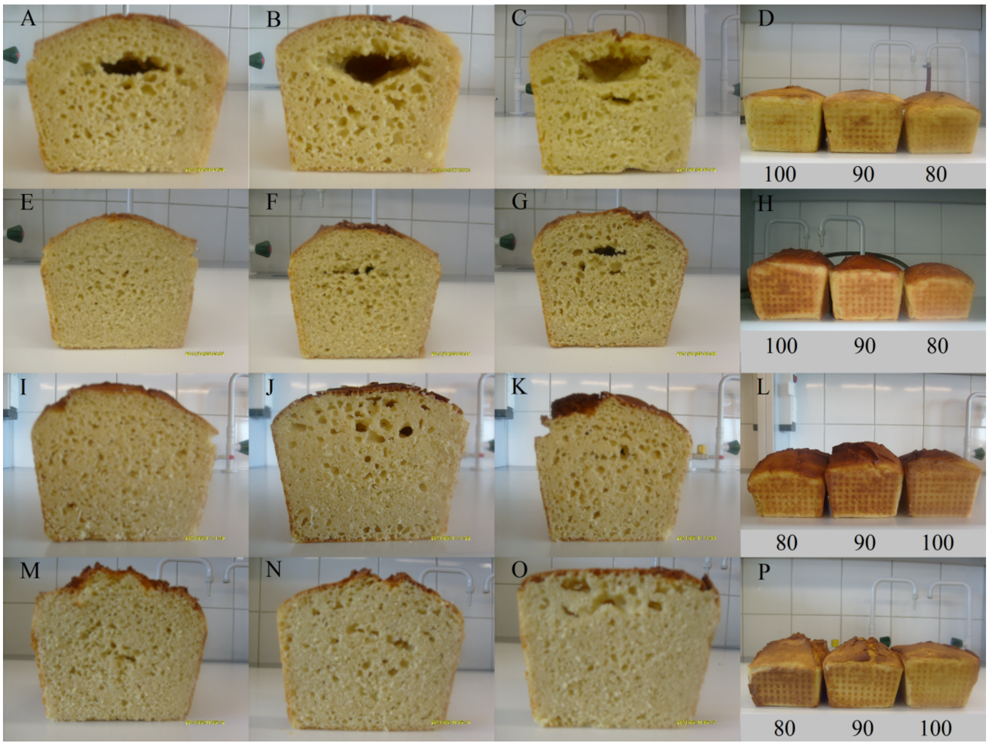

Figure 3. Gluten-free bread with addition: HPC and 80 (A), 90 (B), 100 (C) g W/100 g mixture, a general statement (D); HPC, SPI and 80 (E), 90 (F), 100 (G) g W/100 g mixture, a general statement (H); HPC, SPI, I and 80 (I), 90 (J), 100 (K) g W/100 g mixture, a general statement (L); HPC, SPI, M and 80 (M), 90 (N), 100 (O) g W/100 g mixture, a general statement (P). HPC - hydroxypropyl cellulose, SPI - soy protein isolate, I - inulin, M – maltodextrin, W – water.

The breads with the single addition of HPC (Fig. 3 A, B, C, D) have the lowest assessment due to the inadequate structure of their crumb, their specific aroma and yellow colour. The breads with the addition of inulin are darker and have roasted skins (Fig. 3 I, J, K, L), which is confirmed by the literature (GALLAGHER *et al.*, 2004). The browning of the skins of the gluten-free breads containing inulin is related to the partial hydrolysis of polysaccharides present in the powder of the inulin, which occurs during baking. It leads to a strong Maillard reaction, and, in consequence, the products are darker. This is a desired effect, because gluten-free breads are much lighter than wheat breads.

4. CONCLUSIONS

Summing up, firstly, the hardest and the gumminess gluten-free dough with the largest adhesiveness for each level of water addition was observed using the mixture of hydroxypropyl cellulose and soy protein isolate. The addition of maltodextrin had a positive impact on the textural properties of the gluten-free dough. In particular, it improved the springiness and reduced the hardness, gumminess and adhesiveness of the gluten-free dough. The textural properties of the gluten-free dough varied depending on the amount of water added to the dough.

Secondly, the most significant improvement of the quality of the gluten-free breads was observed when the mixture containing hydroxypropyl cellulose and soy protein isolate with the addition of 100 g of water was used. The sample had not only the largest volume, the highest porosity and the smallest crumb hardness, but also the highest level of freshness during the whole storage test.

Thirdly, on the one hand, the addition of the mixture consisting of hydroxypropyl cellulose, soy protein isolate and inulin to the gluten-free bread increased and maintained the proper crumb moisture during its storage, but, on the other hand, it increased the crumb texture hardness.

Our results showed that the best formulation among the analyzed in this study is the one composed of 0.5 g of hydroxypropyl cellulose, 5.0 g of soy protein isolate, and 10.0 g of maltodextrin on 100 g of the mixture, with 100 g of water. The breads prepared from this formulation reached the highest level of consumer demand. The breads had the largest volume, and, moreover, the highest crumb porosity. Also the dough had the highest springiness and the lowest hardness, gumminess and adhesiveness. The research showed that better results were guaranteed by the addition of maltodextrin than inulin.

Considering the fact that commercial gluten-free breads have usually lower nutritional value than the traditional ones, it should be emphasized that the addition of soy proteins not only favorably affects the texture of gluten-free breads, but also increases their nutritional value. Also the research confirmed the earlier observations on the favorable impact of soy proteins on the appearance of a loaf – particularly, the increase of its volume and the extension of its freshness time.

REFERENCES

AACC International 2000. Approved methods of the American Association of Cereal Chemists, 10th ed. Methods 10-05 and 44-15A. The Association, St. Paul, MN.

Ahlborn G.J., Pike O.A., Hendrix S.B., Hess W.M. and Huber C.S. 2005. Sensory, mechanical and microscopic evaluation of staling in low-protein and gluten-free breads. Cereal Chem. 82:328-335.

Baryłko-Pikielna N. 1975. Zarys analizy sensorycznej żywności. WNT, Warsaw (in Polish).

Brown D.T. and Tuohy K.M. 2006. Inulin: a prebiotic functional food ingredient. Food Sci. Technol. Bulletin: Functional Foods, 3(4):31-46.

Capriles V.D. and Areas J.A. 2013. Effects of prebiotic inulin-type fructans on structure, quality, sensory acceptance and glycemic response of gluten-free breads. Food Funct. 4:104-110.

Cato L., Gan J.J., Rafael L.G.B. and Small D.M. 2004. Gluten free breads using rice flour and hydrocolloid gums. Food Aust. 56(3):75-78.

Chin N.L., Campbell G.M. and Thompson F. 2005. Characterization of bread dough with different densities, salt contents and water levels using microwave power transmission measurements. J. Food Eng. 70:211-217.

Crockett R., Ie P. and Vodovotz Y. 2011. Effects of soy protein isolate and egg white solids on the physicochemical properties of gluten-free bread. Food Chem. 129:84-91.

Diowksz A., Sucharzewska D. and Ambroziak W. 2009. Function of dietary fibre in forming functional properties of gluten free dough and bread. Żywność. Nauka. Technologia. Jakość 2 (63):83-93 (in Polish).

Furlan L.T.R., Padilla A.P. and Campderros M.E. 2015. Improvement of gluten-free bread properties by the incorporation of bovine plasma proteins and different saccharides into the matrix. Food Chem, 2015, 170, 257-264.

Gallagher E., Gormley T.R. and Arendt E.K. 2003. Crust and crumb characteristics of gluten free breads. J. Food Eng. 56:153-161.

Gallagher E., Gormley T.R. and Arendt E.K. 2004. Recent advances in the formulation of gluten – free cereal-based products. Trends Food Sci. Technol. 15:143-152.

Guarner F. 2007. Studies with inulin – type fructans on intestinal infections, permeability, and inflammation. J. Nutr. 137:2568-2571.

Hager A.S., Ryan L.A.M., Schwab C., Ganzle M.G., O'Doherty J.V. and Arendt E.K. 2011. Influence of the soluble fibres inulin and oat β-glucan on quality of dough and bread. Eur. Food Res. Technol. 232:405-413.

Hera E., Rosell C.M. and Gomez M. 2014. Effect of water content and flour particle size on gluten-free bread quality and digestibility. Food Chem. 151:526-531.

Korus J., Grzelak K., Achremowicz K. and Sabat R. 2006. Influence of prebiotic additions on the quality of gluten-free bread and on the content of inulin and fructooligosaccharides. Food Sci. Technol. Int. 12:489-495.

Mancebo C.M., Miguel M.A.S., Martinez M.M. and Gómez M. 2015. Optimisation of rheological properties of gluten-free doughs with HPMC, psyllium and different levels of water. J. Cereal Sci. 61:8-15.

Martinez M.M., Diaz A. and Gómez M. 2014. Effect of different microstructural features of soluble and insoluble fibres on gluten-free dough rheology and bread-making. J. Food Eng. 142:49-56.

Masure H.G., Fierens E. and Delcour J.A. 2016. Current and forward looking experimental approaches in gluten-free bread making research. J. Cereal Sci. 67:92-111.

Mir S.A., Shah M.A., Naik H.R. and Zargar I.A. 2016. Influence of hydrocolloids on dough handling and technological properties of gluten-free breads. Trends Food Sci. Tech., 51: 49-57.

Mohammadi M., Sadeghnia N., Azizi M-H., Neyestani T-R. and Mortazavian A.M. 2014. Development of gluten-free flat bread using hydrocolloids: Xanthan and CMC. J. Ind. Eng. Chem. 20:1812-1818.

Onyango C., Unbehend G. and Lindhauer M.G. 2009. Effect of cellulose-derivatives and emulsifiers on creep-recovery and crumb properties of gluten-free bread prepared from sorghum and gelatinised cassava starch. Food Res. Int. 42:949-955.

Osella C.A., Sanchez H.D. and Torre M.A. 2007. Effect of dough water content and mixing conditions on energy imparted to dough and bread quality. Cereal Foods World 52(2):70-73.

Paciulli M., Rinaldi M., Cirlini M., Scazzina F. and Chiavaro E. 2016. Chestnut flour addition in commercial gluten-free bread: A shelf-life study. LWT – Food Sci. Technol. 70:88-95.

Rakkar P.S. Development of a gluten-free commercial bread. Thesis Scholarly Commons. AUT University, 2007.

Ranhorta G.S., Loewe R.J. and Puyat L.V. 1975. Preparation and fortification of soy-fortified gluten-free bread. J. Food Sci. 40:62-64.

Romankiewicz D., Hassoon W.H., Cacak-Pietrzak G., Sobczyk M., Wirkowska-Wojdyła M., Ceglińska A. and Dziki D. 2017. The effect of chia seeds (*salvia hispanica* l.) addition on quality and nutritional value of wheat bread, J. of Food Quality, Hindawi 2017:1-7.

Ronda F., Roos Y.H. 2011. Staling of fresh and frozen gluten-free bread. J. Cereal Sci. 53:340-346.

Sciarini L.S., Ribotta P.D., Leon A.E. and Perez G.T. 2010. Effect of hydrocolloids on gluten-free batter properties and bread quality. Int. J. Food Sci. Technol. 45:2306-2312.

Sivaramakrishnan H.P., Senge B., Chattopadhyay P.K. 2004 Rheological properties of rice dough for making rice bread. J. Food Eng. 62(9):37-45.

Stable Micro System. 1997. User guide. Texture expert for Windows. Stable Micro System, Godalming, UK.

Tsatsaragkou K., Protonotariou S. and Mandala I. 2016. Structural role of fibre addition to increase knowledge of non-gluten bread. J. Cereal Sci. 67:58-67.

Witczak M., Korus J., Ziobro R. and Juszczak L. 2010. The effects of maltodextrins on gluten – free dough and quality of bread. J. Food Eng. 96:258-265.

Yazar G., Duvarci O., Tavman S. and Kokini J.L. 2017 Non-linear rheological behavior of gluten-free flour doughs and correlations of LAOS parameters with gluten-free bread properties. J. Cereal Sci. 74:28-36.

Ziobro R., Korus J., Juszczak L. and Witczak T. 2013 Influence of inulin on physical characteristics and staling rate of gluten-free bread. J. Food Eng. 116:21-27.

Paper Received November 20, 2017 Accepted June 5, 2018