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Physical characteristics and nutritional composition of gluten-free bread with share of freeze-dried red potatoes

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ABSTRACT
The aim of the study was to compare nutritional composition and physical properties of gluten-free bread samples with a 5% addition of freeze-dried red potatoes (variety: Blue Star, Magenta Love, Violeta), in order to check the suitability for nutritional enrichment of such products. It was observed that the use of potato variety Magenta Love resulted in the most beneficial nutritional quality of gluten-free bread (especially high content of insoluble fibre), and its best physical properties (high volume, low hardness, good cohesiveness), which were reflected in the highest consumer acceptance of this product. The use of freeze-dried red potatoes could be recommended as an innovative way to enrich gluten-free products in nutrients and improve their technological quality.

Características físicas y composición nutricional del pan sin gluten que contiene papas rojas liofilizadas

RESUMEN
El presente estudio se orientó a comparar la composición nutricional y las propiedades físicas de muestras de pan sin gluten adicionadas con 5% de papas rojas liofilizadas de tres variedades: Blue Star, Magenta Love, Violeta. En este sentido, con el fin de valorar su idoneidad en términos del enriquecimiento nutricional de estos productos. Se observó que a partir de la adición de la variedad de papa Magenta Love se obtuvo el pan sin gluten con la calidad nutricional más beneficiosa, constatándose un contenido especialmente elevado de fibra insoluble en el mismo. Además, este presentó óptimas propiedades físicas (alto volumen, poca dureza, buena cohesión), lo cual se vio reflejado en que registró las más altas calificaciones entre los consumidores. Por lo que se concluye que puede recomendarse el uso de papas rojas liofilizadas como forma innovadora de enriquecer el valor nutritivo de productos sin gluten y mejorar su calidad tecnológica.

Introduction

Celiac disease (CD) is a disorder manifested as permanent intolerance to gluten, more specifically to the prolamin fraction of wheat (gliadin), rye (secalin) and barley (hordein) (Capriles & Áreás, 2014; Dizlek & Ozer, 2016; Hamer, 2005; McGough & Cummings, 2005; Sollid & Lundin, 2008), that affects approximately 1% of the world population and has a growing trend. According to the guidelines of European Society for Pediatric Gastroenterology, Hepatology, and Nutrition (ESPGHAN) (Husby et al., 2012), CD is characterised by the presence of variable combination of gluten-dependent clinical manifestations, CD-specific antibodies, HLA-DQ2 or HLA-DQ8 haplotypes and enteropathy. Gliadin as an antigen forms immunological complexes in epithelium, which induce aggregation of lymphocytes, and in consequence lead to the damage of the villi in small intestine. As a result, nutrients such as amino acids, lipids, carbohydrates, minerals and vitamins could not be properly absorbed. Their deficiencies could be accompanied by slower physical and mental development, rachitis, osteoporosis, anaemia and limited mental development, rachitis, osteoporosis, anaemia and limited effect, a risk of mineral deficiencies and digestive problems caused by lack of dietary fibre could be expected in persons adhering to gluten-free diet (Rodrigo, 2006). To eliminate such problems, a continuous research on gluten-free bread nutritional enrichment has been done in recent years. Among the most commonly used raw materials, there are flours from gluten-free cereals and pseudocereals such as buckwheat, amaranth and maize as well as tubers such as a cassava (Dizlek, 2015; Mariotti, Lucisano, Ambrogina Pagani, & Ng, 2009; Pasqualone et al., 2010; Witczak, Ziobro, Juszczak, & Korus, 2016). It seems that also potato-based preparations, which have not yet been applied in gluten-free bread, could be valuable components of such formulations, as they contain high-quality protein, dietary fibre, minerals and vitamin C. Especially interesting are red potato

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varieties because of their antioxidant potential, and high level of carotenoids (Burlingame, Mouillé, & Charrondière, 2009; Ji, Zhang, Li, & Li, 2015; Rady & Guyer, 2015). Gluten-free bread with an addition of red potato could extend the portfolio of such bakery products, and provide the consumers with nutritionally valuable constituents. Because the use of fresh potatoes might be difficult from technological point of view, application of freeze-dried preparations seems to be the best option. We could assume that freeze-drying minimally changes nutritional value of plant material. In practice it could be expensive, but this type of drying reflects maximum benefits, which could be obtained for selected plant material in food technology. Prior to their launching on the market, the new products with an addition of freeze-dried red potatoes should be positively evaluated by the consumers in terms of their appearance (volume, colour, shape) and other sensory properties (smell and taste), as well as texture and structure. At the same time, they should reveal high nutritional value (Dwyer et al., 2014; Świeca, Gawlik-Dziki, Dziki, Baraniak, & Czyż, 2013). These steps are essential in studies aimed at releasing new food products (Pasqualone, Bianco, & Paradiso, 2013), and are particularly important in presence of CD due to the total dependence on gluten-free diet that renders any sensorial and nutritional alteration able to affect health and quality of life of patients.

The aim of the study was analysing the contents of nutritionally important compounds and dietary fibre in gluten-free bread containing 5% of freeze-dried red potatoes of three varieties (Blue Star, Magenta Love and Violeta). This evaluation was accompanied with an analysis of physical properties (colour, crumb texture, porosity, etc.) and consumer acceptance of the products. The final aim of the study was to choose red potato variety which would have the best effect on the product (content of nutritional components, dietary fibre, texture and physical properties, sensory assessment) when applied in the form of freeze-dried preparation.

Materials and methods

Materials

Potatoes of varieties Magenta Love, Blue Star and Violeta were grown in the year 2014 in a field nursery at the Department of Environmental Protection and Organic Farming in Spišská Belá (Slovakia). The potatoes were freeze-dried for 40 h in a laboratory grinder Grindomix GM200 (Retsch GmbH & Co, Haan, Germany), so as to pass through a sieve with 100 μm mesh, and used for the production of gluten-free bread, which were further analysed. In this publication (in the Tables and Figures), the following abbreviations were used:

- BS; ML; V – freeze-dried red potatoes variety: Blue Star, Magenta Love, Violeta, respectively; Control – control bread;
- GFB+5BS; GFB+5ML; GFB+5V – gluten-free bread with share of freeze-dried red potatoes (variety: Blue Star, Magenta Love and Violeta, respectively).

The following analyses were performed on samples of freeze-dried red potatoes: the content of nutritional components, the content of dietary fibre, the content of micro- and macro-elements. Gluten-free breads with share of freeze-dried red potatoes were evaluated in terms of the content of nutritional components, the content of dietary fibre, the content of micro- and macro-elements, as well as physical characteristics and sensory evaluation.

Methods

Bread preparation

Formulation of gluten-free bread includes the following of raw materials: 400 g maize starch (Bezzgluten, Poland), 100 g potato starch (Pepees S.A., Poland), 8.3 g guar gum (Lotus Gums & Chemicals, India), 8.3 g pectin (Pektowin, Poland), 25 g freeze-dried yeast Saf-instant (S.I. Lesaffre, France), 10 g sucrose, 8.3 g salt, 15 g oil, 517 ml water (control sample). Gluten-free breads with a share of freeze-dried red potatoes consisted of the same ingredients but part of both starches equal to 5% of their initial amount was replaced with freeze-dried preparations of three varieties of red potatoes. All the ingredients were mixed 8 min (Laboratory Spiral Mixer SP12, Diosa, Germany). The dough was transferred for 15 min into a fermentation chamber (temperature 35°C, humidity 80%), re-mixed for 1 min and weighed pieces of dough (250 g) were put into greased pans. Final fermentation under the above-mentioned conditions was continued for 20 min. The loaves were baked in an oven MIWE Condo type CO 2 0608 (MIWE GmbH, Germany) for 30 min temperature 230°C. Two batches of 6 loaves were acquired. The loaves were cooled at room temperature, packed in polyethylene bags and stored under ambient conditions (temperature 22 ± 2°C, humidity 64%) for further analyses.

Bread volume and crumb structure

Bread volume and height were measured with the use of Volcan Profiler (Stable Micro Systems, England). In order to determine crumb structure parameters, the slices from the internal part of each loaf (thickness 1 cm) were scanned by Plustek S-12 desktop scanner. The registered images were analysed with the help of ImageJ software v. 1.44c (Abrámoff, Magalhães, & Ram, 2004), evaluating porosity, i.e. area of gas cells divided by area of bread slice, cell density, i.e. number of pores per 1 cm², and percentage of pores >5 mm diameter (Gonzales-Barron & Butler, 2006).

Analysis of crumb colour

Crumb colour was analysed by instrumental method in CIE (International Commission on Illumination, 2004) L*a*b* system. Determination of reflectance in CIE system was done using Konica MINOLTA CM-3500d at an angle 10°, with a slit width 30 mm. Samples were put in Petri dishes with a diameter 55 mm. The measurement allowed determination of the following parameters: L* – luminance (L* = 0 black, L* = 100 white), a* – the intensity of green (a* < 0) or red (a* > 0), b* – the intensity of blue (b* < 0) or yellow (b*> 0). Each sample was analysed in 4 replicates. Colour differences (ΔE*ab) between individual samples were calculated as follows: ΔE*ab = [(ΔL*)² + (Δa*)² + (Δb*)²]½ (International Commission on Illumination, 2004).

Texture profile analysis (TPA) of bread crumb

TPA of bread crumb of one loaf from each batch was performed, using texture analyser TA-XT2plus (Stable Micro Systems, England), according to standard programme, at the compression rate 5 mm/s. Sample of bread crumb, taken from the centre of the loaf with a height 2 cm (and
diameter 1.5 cm) was pressed to reach 50% deformation by a P/20 aluminium cylinder probe with a diameter 2 cm, in two cycles with a 5 s delay. Two independent measurements were done for each loaf. The resulting hardness, and cohesiveness of the crumb were used as indicators of textural changes during storage. The calculations were performed using the attached software Texture Exponent (Stable Micro Systems, England). The analysis was performed after 2, 24 and 48 h after baking.

Sensory evaluation

Sensory evaluation was carried out according to Polish Standard (PN-ISO 8589, 1998) by a group of 12 panelists who considered the following characteristics of the product: appearance, crust colour and thickness, crumb elasticity and porosity, smell and taste. Analyses were done in a laboratory designed and equipped with respect to PN-ISO 8589 (1998). The method was based on the acceptance analysis of encoded bread samples on the 7-point scale, where 0 means “extremely dislike”, and 6, “extremely like”.

Chemical evaluation

Content of basic nutritional components (protein, ash, reducing sugars, soluble carbohydrates) was performed by the method of Association of Official Analytical Chemists (AOAC) (2006), and content of non-starch polysaccharides, i.e. total, soluble and insoluble dietary fibre, by the method 32-07 of American Association of Cereal Chemists (AACC) (2012). Content of micro- and macro-elements was determined as follows: one gram of the sample was digested in 1:1 mixture of HNO₃ and redistilled water. The digestion continued for 55 min in a closed vessel, high-pressure microwave digester (MARS X-press, USA). After cooling to room temperature, the mixture was filtered using Munktell filter paper (grade 390.84 g/m², Germany) and diluted to 50 ml with distilled water. The extracts were subsequently analysed for Cd, Pb, Cu, Zn, Co, Cr, Ni, Mn and Fe, using fast sequential atomic absorption spectrophotometer Varian model AA 240 FS (Varian Ltd., Mulgrave, Australia) after selecting the various wavelengths at which the heavy metals are tested following due calibration process (Cd – 228.8 nm, Pb – 217.0 nm, Cu – 324.8 nm, Zn – 213.9 nm, Co – 240.7 nm, Cr – 357.9 nm, Ni – 232.0 nm, Mn – 279.5 nm, Fe – 241.8 nm).

Statistical analysis

The experimental data were subjected to analysis of variance (Duncan’s test), at the confidence level of 0.05, by the use of software Statistica v. 8.0 (Statsoft, Inc., Tulsa, OK, USA). All measurements were done at least in duplicate.

Results and discussion

Characteristics of freeze-dried preparations of three varieties of red potatoes, used in gluten-free bread formulation

Freeze-dried preparations of red potato varieties were analysed in terms of their nutritional composition and content of dietary fibre. It was observed that among the analysed freeze-dried preparations, lyophilised potatoes of variety Magenta Love displayed the highest content of protein, reducing sugars and soluble carbohydrates, while Blue Star exhibited the highest contents of ash (Table 1). Among the analysed micro- and macro-elements, Fe, Ca, Mg and P were found in largest amounts in freeze-dried Violeta variety, while Mn, Zn and Cu, as well as Cr in Magenta Love variety (Table 2).

Taking into account the content of dietary fibre, freeze-dried potatoes of variety Violeta contained the highest level of its insoluble fraction, 17.6% more than Blue Star, and 54% more than Magenta Love. Similar tendency could also be observed for soluble and total dietary fibre (Table 3). Although there are no available data about contents of nutritional components and dietary fibre in freeze-dried red potatoes, the measured values are in agreement with reports on other types of raw potatoes (Burlingame et al., 2009; Ji et al., 2015; Rady & Gayer, 2015).

The effect of potato variety on physical properties of gluten-free bread and its sensory evaluation

An analysis of physical properties of bread is necessary for its successful introduction on the market. It should cover all the properties which could affect consumer’s acceptance, namely its appearance, structure, texture and sensory features. In case of the addition of freeze-dried red potatoes to gluten-free bread, there is an obvious effect on colour. Thus it was analysed first.

It could be observed that crumb of gluten-free bread with an addition of freeze-dried red potatoes of Blue Star and Violeta varieties was significantly darker than control, while the use of Magenta Love variety has no statistically significant effect on the value of L* (Table 4). The replacement of 5% of starch with freeze-dried red potatoes of all varieties caused an increase of redness, which could be seen by an increase in a* values from negative to positive. The smallest influence of such replacement on a* of bread was observed for Blue Star preparation, while the largest was observed for Magenta Love. The values were comparable with those measured after an addition of 5–10% defatted strawberry seeds to gluten-free bread (Korus et al., 2012). The share of yellowness (b* > 0) of the crumb decreased significantly for all analysed samples of gluten-free bread with an addition of freeze-dried red potatoes in comparison to control, and the values were also comparable with those reported for gluten-free bread with an addition of defatted blackcurrant seeds (Korus et al., 2012). No statistically significant changes could be observed for b* parameter between crumbs with different red potato varieties.

Colour difference could be interpreted as follows: 0 < ΔE* < 1, the differences are not detectable by a standard observer; 1 < ΔE* < 2, only an experienced observer could detect the change; 2 < ΔE* < 3.5, inexperienced observer

| Samples | Protein | Ash | Reducing sugars | Soluble carbohydrates |
|---------|---------|-----|-----------------|----------------------|
| BS      | 56.70 ± 1.00* | 52.80 ± 0.00* | 22.00 ± 0.20* | 36.20 ± 0.50* |
| ML      | 87.80 ± 0.10* | 50.10 ± 0.70* | 37.20 ± 0.20* | 102.90 ± 0.70* |
| V       | 76.60 ± 0.30* | 49.80 ± 0.30* | 23.40 ± 0.40* | 41.50 ± 0.30* |

Different letters in column denote mean values that statistically differ one from another (Duncan test, at α = 0.05%).

BS: ML: V = freeze-dried red potatoes variety: Blue Star, Magenta Love, Violeta, respectively (the same abbreviations apply for Tables 2 and 3).

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Table 3. Content of dietary fibre (g/kg) in freeze-dried red potatoes.

| Samples  | Insoluble fraction of dietary fibre | Soluble fraction of dietary fibre | Total dietary fibre |
|----------|-----------------------------------|----------------------------------|---------------------|
| BS       | 51.20 ± 0.10                      | 18.70 ± 0.10                     | 69.90 ± 0.80        |
| ML       | 39.00 ± 0.10                      | 24.00 ± 0.20                     | 63.00 ± 1.00        |
| V        | 60.20 ± 0.20                      | 27.40 ± 0.20                     | 87.60 ± 0.00        |

Different letters in column denote mean values that statistically differ one from another (Duncan test, at α = 0.05 ±).

Las distintas letras en la columna indican valores medios que difieren estadísticamente entre sí (Prueba Duncan, a = 0.05 ±).

### Table 4. Colour of gluten-free bread with share of freeze-dried red potatoes.

| Samples                  | L  | a   | b   | ΔE  |
|--------------------------|----|-----|-----|-----|
| Control                  | 74.82 ± 0.61   | -0.91 ± 0.19  | 15.18 ± 0.76  | -   |
| GFB + SBS                | 69.85 ± 0.51   | 1.07 ± 0.18   | 13.11 ± 0.63  | 5.77 ± 0.73  |
| GFB + SML                | 73.86 ± 0.72   | 2.83 ± 0.03   | 12.99 ± 0.19  | 4.57 ± 0.33  |
| GFB + V                  | 69.61 ± 0.26   | 2.29 ± 0.04   | 13.02 ± 0.08  | 6.53 ± 0.50  |

Different letters in column denote mean values that statistically differ one from another (Duncan test, at α = 0.05 ±).

Control – control bread; GFB+SBS; GFB+SML; GFB+V – gluten-free bread with share of freeze-dried red potatoes (variety: Blue Star, Magenta Love, Violeta, respectively). (Same abbreviations apply for Tables 5 and 6).

Las distintas letras en la columna indican valores medios que difieren estadísticamente entre sí (Prueba Duncan, a = 0.05 ±).

### Table 2. Content of micro- and macro-elements (mg/kg) in freeze-dried red potatoes.

| Elements | Samples | Mg  | Ca  | K   | Na  | Fe | Cu  | Zn  | Mn  | Ni  | Co  | Cr  | Pb  | Cd  | Ni  | P  |
|----------|---------|-----|-----|-----|-----|----|-----|-----|-----|-----|-----|-----|-----|-----|----|---|
| BS       | 9.00 ± 0.25 | 18.5 ± 0.25 | 517 ± 0.25 | 51.20 ± 0.25 | 24.00 ± 0.25 | 0.60 ± 0.25 | 0.10 ± 0.25 | 0.09 ± 0.25 | 6.60 ± 0.25 | 6.52 ± 0.25 | 11.20 ± 0.25 | 0.80 ± 0.25 | 4.70 ± 0.25 | 0.90 ± 0.25 | 12.40 ± 0.25 |
| ML       | 9.00 ± 0.25 | 18.5 ± 0.25 | 517 ± 0.25 | 51.20 ± 0.25 | 24.00 ± 0.25 | 0.60 ± 0.25 | 0.10 ± 0.25 | 0.09 ± 0.25 | 6.60 ± 0.25 | 6.52 ± 0.25 | 11.20 ± 0.25 | 0.80 ± 0.25 | 4.70 ± 0.25 | 0.90 ± 0.25 | 12.40 ± 0.25 |
| V        | 9.00 ± 0.25 | 18.5 ± 0.25 | 517 ± 0.25 | 51.20 ± 0.25 | 24.00 ± 0.25 | 0.60 ± 0.25 | 0.10 ± 0.25 | 0.09 ± 0.25 | 6.60 ± 0.25 | 6.52 ± 0.25 | 11.20 ± 0.25 | 0.80 ± 0.25 | 4.70 ± 0.25 | 0.90 ± 0.25 | 12.40 ± 0.25 |

Different letters in column denote mean values that statistically differ one from another (Duncan test, at α = 0.05 ±).

Las distintas letras en la columna indican valores medios que difieren estadísticamente entre sí (Prueba Duncan, a = 0.05 ±).

could see the change; 3.5 < ΔE* < 5, anyone could see the difference; ΔE* > 5, there are two different colours (Rogowska, 2015). The data collected in Table 4 indicate that colour of the samples in which 5% of starch was replaced with freeze-dried red potatoes deviated highly from control. In the case of breads containing Blue Star and Violeta preparations, the difference ΔE* exceeded 5, which means that the colours were different. The change after an addition of Magenta Love preparation was smaller than 5, which means that one could describe the colours as similar, but the differences could be easily detected, though not so big as in two other cases. The value of ΔE* in the case of bread containing freeze-dried Magenta Love preparations differed significantly from samples with Blue Star and Violeta varieties (ΔE*Magenta Love-Blue Star and ΔE*Magenta Love-Violeta equalled 4.43, 4.31, respectively), and the difference was evident for any observer. The colour of bread with an addition of freeze-dried Blue Star and Violeta potato varieties was comparable (ΔE*Blue Star-Violeta = 1.39) and the difference could be detected only by an experienced observer.

The influence of freeze-dried red potatoes on bread volume depended on their variety (Table 5). A decrease could be observed after an addition of freeze-dried red potatoes variety Blue Star, while both other preparations resulted in an increase of bread volume, although in the case of Violeta it was not statistically significant in comparison to control. These changes were accompanied with respective alterations of the number of pores (Table 5), but not with the porosity, which was slightly but significantly reduced only in the case of Magenta Love addition in comparison to control. The changes in volume were also
corresponding to a number of large pores, which were more frequent when the number of total pores and bread volume were smaller (Table 5).

Similar observations could be found for texture parameters monitored during storage (Figures 1 and 2). On the day of baking, the crumb of the most compact bread, obtained by adding of freeze-dried potatoes variety Blue Star, exhibited significantly higher hardness, than all other samples, which were not significantly different from each other. It also remained harder than the others for the whole storage period; however, the difference between it and the control was less noticeable (Figure 1). Freeze-dried potatoes of both other varieties (Magenta Love and Violeta) had a strong positive effect on gluten-free bread hardness during storage, and despite the observed changes in density and pore structure, the reduction of crumb hardness was comparable for them. After the second day of storage, hardness of the samples with Magenta Love and Violeta equalled 67% and 76% of control, respectively. The differences in bread hardness after their supplementation with freeze-dried potatoes followed the changes in volume of the loaves. The volume of gluten-free bread with an addition of freeze-dried red potatoes variety Blue Star was smaller in comparison with other additions, which in turn reflected its less porous structure. More compact structure caused faster reorientation and binding of starch molecules, which enhanced its retrogradation, one of the main causes of staling (Krog, Olesen, Toernaes, & Joensson, 1989).

Crumb cohesiveness was affected in a similar way. On the day of baking, only an addition of freeze-dried potatoes variety Violeta resulted in a statistically significant increase of this texture parameter, but during storage the sample was comparable with control. The best cohesiveness after 1 or 2 days of storage could be found for gluten-free bread with an addition of freeze-dried red potatoes variety Magenta Love, and the worst for the sample with Blue Star (Figure 2).

In the studies of Ziobro, Gumul, Korus, and Korus (2016) concerning the enrichment of gluten-free bread with amaranth, buckwheat and maize flours, a significant decrease of hardness on the day of baking and during 2 days of storage (in comparison to control) was observed, at the same time, no increase in cohesiveness could be measured, except for buckwheat flour. Similarly, in the research of Korus et al. (2012) on gluten-free bread with defatted strawberry and blackcurrant seeds (5–15%), a decrease in bread hardness in comparison to control could be observed on the day of baking and after 1 day of storage. A diminishing tendency in hardness of gluten-free bread with pseudocereals, as compared to control was also reported by Alvarez-Jubete, Auty, Arendt, and

| Samples       | Volume (ml) | Specific volume (ml/g) | Number of pores | Porosity (%) | Number of pores/cm² | Pores >5 mm (%) |
|---------------|-------------|------------------------|----------------|--------------|---------------------|----------------
| Control       | 610 ± 18ab  | 2.96 ± 0.08b           | 1017 ± 95b     | 0.424 ± 0.013b | 3.653 ± 0.347b     | 0.118 ± 0.017b |
| GFB+5BS       | 550 ± 15a   | 2.61 ± 0.07a           | 665 ± 48b      | 0.428 ± 0.007b | 2.666 ± 0.155a     | 0.173 ± 0.018a |
| GFB+5ML       | 750 ± 59c   | 3.56 ± 0.29c           | 1408 ± 200c    | 0.401 ± 0.019c | 4.779 ± 0.701c     | 0.075 ± 0.023c |
| GFB+5V        | 630 ± 33d   | 3.19 ± 0.16d           | 1046 ± 123d    | 0.423 ± 0.016d | 3.605 ± 0.470d     | 0.125 ± 0.030d |

Different letters in column denote mean values that statistically differ one from another (Duncan test, at α = 0.05±). Las distintas letras en la columna indican valores medios que difieren estadísticamente entre sí (Prueba Duncan, α = 0.05±).

Figure 1. Changes in crumb hardness of gluten-free bread during storage (Control – control bread, GFB+5BS – gluten-free bread with 5% freeze-dried red potatoes variety Blue Star, GFB+5ML – gluten-free bread with 5% freeze-dried red potatoes variety Magenta Love, GFB+5V – gluten-free bread with 5% freeze-dried red potatoes variety Violeta).

Figura 1. Cambios en la dureza de la miga del pan sin gluten durante su almacenamiento (Control – pan de control, GFB+5BS – pan sin gluten adicionado con 5% de papas rojas liofilizadas de la variedad Blue Star, GFB+5ML – pan sin gluten adicionado con 5% de papas rojas liofilizadas de la variedad Magenta Love, GFB+5V – pan sin gluten adicionado con 5% de papas rojas liofilizadas de la variedad Violeta).

Table 5. Physical properties of gluten-free bread with share of freeze-dried red potatoes.

Tabla 5. Propiedades físicas del pan sin gluten que contiene papas rojas liofilizadas.
Gallagher (2010a). On the other hand, the results of Capriles, Santos, & Aréas (2015) on gluten-free bread with various additives (for example, 65% unripe banana flour + 23% potato starch + 12% rice flour; 64% whole buckwheat flour + 36% potato starch; 75% whole chickpea flour + 25% potato starch) demonstrated that the hardness on the day of baking was on the constant level in comparison to control.

It seems that the changes observed for gluten-free bread physical parameters could be explained by slight changes in chemical composition. It is especially possible that both quantity and quality of protein could be decisive factors, as the amount of protein in Blue Star variety was the lowest, and in Magenta Love the highest, similarly to the volume of respective bread (Tables 1 and 5). Emulsifying effect of protein could be a reason of increased number of pores, as it was described by Demirkesen, Sumru, and Sahin (2013). On the other hand, a significant decrease in the level of fat could be responsible for deterioration of crumb structure after an addition of freeze-dried red potatoes variety Blue Star (Tables 5 and 6). The influence of both factors may be complex, because lipid–protein interactions are important for bread volume (Rogers, Zeleznak, Lai, & Hoseney, 1988).

It was found that, among the analysed bread samples with freeze-dried red potatoes, the best sensory scores were given to bread with an addition of freeze-dried Magenta Love variety, because of its good appearance, crust colour and thickness, crumb elasticity, smell and taste (Figure 3). It is not surprising, taking into account the benefits resulting from the application of freeze-dried potatoes variety Magenta Love in gluten-free bread, which were evident in the results of texture analysis (Figures 1 and 2). A decrease of hardness and an increase of cohesiveness had a positive impact on bread quality, and thus on the consumer acceptance of the final product.

In the study of Korus et al. (2012) concerning the impact of defatted strawberry and blackcurrant seeds (5–15%) on sensory evaluation of gluten-free bread, it was observed that an increase in their amount deteriorated sensory assessment. Only 5% level of addition allowed to obtain better scores. The samples with 5% defatted blackcurrant seeds were improved in terms of taste and smell, and those with 5% defatted strawberry seeds gained better scores in taste, appearance and colour in comparison to all other samples, including control. In the studies of Capriles et al. (2015) on gluten-free bread with various additives (for example, 65% unripe banana flour + 23% potato starch + 12% rice flour; 64% whole buckwheat flour + 36% potato starch; 75% whole chickpea flour + 25% potato starch), it was found that the additives did not deteriorate the results of sensory evaluation. Similarly, in the studies of Álvarez-Jubete et al. (2010a) on gluten-free bread with pseudocereals, it was observed that the additives did not change bread acceptability in a significant way. In the current study, the most acceptable was the bread with freeze-dried potatoes, variety Magenta Love, and the least – one with freeze-dried potatoes, variety Blue Star.

The effect of potato variety on the content of nutritional constituents and dietary fibre in gluten-free bread with an addition of freeze-dried red potatoes

As it was mentioned in the introduction, gluten-free bread usually exhibits much lower nutritional value than traditional cereal products, containing less dietary fibre, protein and microelements (Korus, Witczak, Ziбро, & Juszczak, 2015; Nanditha & Prabhasankar, 2008; Thompson, 2000). This is the reason to enrich it with gluten-free components of high nutritional quality. Such enrichment seems to be especially important, taking into account the risk of inadequate supply of microelements and prolonged constipation induced by inadequate amounts of dietary fibre (Rodrigo, 2006).

The content of nutritional constituents and dietary fibre in gluten-free bread containing freeze-dried preparations of the applied varieties of red potatoes were collected in Table 6. It could be observed that all gluten-free bread samples containing...
freeze-dried red potatoes exhibit statistically higher content of protein (by 14.4% on average), ash (14.4%) and reducing sugars (5%) in comparison to control, while the contents of starch and fat are decreased by 1.8% and 18.5%, respectively.

Taking into account the amounts of micro- and macro-elements, the use of freeze-dried red potatoes resulted in increased contents of Fe, Mn, Cu, K, Mg and P in gluten-free bread samples, as compared to control (Table 7). The highest contents of Fe and Mn were found after an application of freeze-dried preparation of Blue Star potato variety, which could be explained by high quantity of Mn in the preparation (Tables 2 and 7). At the same time, samples with an addition of freeze-dried red potatoes exhibited low levels of heavy metals (Co, Ni, Cr, Pb, Cd), as they varied between 0.06 to 1.5 mg/kg. In the study of Matos-Segura and Rosell (2011) comparing 11 types of commercial gluten-free bread, the level of ash was on average level of 2.94 g/100 g d.m., and according to the authors, the content of ash depended on the level of added salt. In our study the content of salt was constant, so the increase in ash content was due only to the addition of freeze-dried red potatoes in gluten-free formulation, as it was mentioned earlier.

The increase in protein levels together with elevated contents of minerals (mainly Fe, Cu, Mn) in gluten-free bread with freeze-dried red potatoes (Tables 6 and 7) is especially valuable, as such products are often deficient in these constituents, which has a negative effect on development, growth and physical condition of celiacs, especially children (Thompson, 2000; Witczak et al., 2016; Ziobro, Witczak, Juszczak, & Korus, 2013).

Taking into account that potato protein has high biological value and contains sufficient amounts of all essential amino acids in contrast to cereal proteins which are deficient in lysine, it could be suggested that the enrichment of gluten-free bread with freeze-dried preparations of red potatoes has stronger influence on its nutritional quality than an equivalent addition of cereal protein. Biological value of potato protein is comparable with egg white and other animal proteins, and significantly higher than pea, wheat or rice proteins. It is regarded as the best source of lysine of plant origin (Desborough, 1985; Eppendorfer & Eggum, 1994; Pełska et al., 2013).

In the case of micro- and macro-elements, the application of freeze-dried red potatoes caused a significant increase in Fe (by 350% on average), Mn (500%) and Cu (35%) in gluten-free breads in comparison to control (Table 7). This large increment is very important, because of mineral deficiencies in typical gluten-free diets. While in a traditional diet the

Table 6. Content of nutritional compounds and dietary fibre (g/kg) in gluten-free bread with share of freeze-dried red potatoes.

| Samples   | Protein | Fat  | Ash   | Reducing sugars | Starch | Insoluble fraction of dietary fibre | Soluble fraction of dietary fibre | Total dietary fibre |
|-----------|---------|------|-------|----------------|--------|-----------------------------------|----------------------------------|---------------------|
| Control   | 18.30 ± 0.00a | 42.20 ± 1.30b | 20.30 ± 0.50b | 1.80 ± 0.10b | 917.3 ± 0.10b | 21.00 ± 0.80a | 10.5 ± 0.20a | 31.50 ± 0.50a |
| GFB+5BS   | 18.80 ± 0.40ab | 32.90 ± 0.20ab | 22.80 ± 1.70ab | 0.80 ± 0.20ab | 900.7 ± 2.30ab | 41.90 ± 0.10b | 34.2 ± 0.30ab | 76.10 ± 0.20ab |
| GFB+5ML   | 22.10 ± 0.10ab | 35.00 ± 0.60ab | 23.40 ± 0.10ab | 2.60 ± 0.10ab | 900.6 ± 0.40ab | 45.60 ± 0.10ab | 33.9 ± 0.00ab | 79.50 ± 2.10ab |
| GFB+5V    | 21.90 ± 0.80ab | 35.30 ± 1.00ab | 23.50 ± 0.10ab | 2.30 ± 0.10ab | 901.1 ± 0.20ab | 41.40 ± 0.20b | 34.8 ± 0.40ab | 76.30 ± 0.50b |

Different letters in column denote mean values that statistically differ one from another (Duncan test, at α = 0.05±).

Las distintas letras en la columna indican valores medios que difieren estadísticamente entre sí (Prueba Duncan, α = 0.05±).

Figure 3. Sensory assessment of gluten-free bread (Control – control bread, GFB+5BS – gluten-free bread with 5% freeze-dried red potatoes variety Blue Star, GFB+5ML – gluten-free bread with 5% freeze-dried red potatoes variety Magenta Love, GFB+5V – gluten-free bread with 5% freeze-dried red potatoes variety Violeta).

Figura 3. Valoración sensorial del pan sin gluten. (Control – pan de control, GFB+5BS – pan sin gluten adicionado con 5% de papas rojas liofilizadas de la variedad Blue Star, GFB+5ML – pan sin gluten adicionado con 5% de papas rojas liofilizadas de la variedad Magenta Love, GFB+5V – pan sin gluten adicionado con 5% de papas rojas liofilizadas de la variedad Violeta).
microelements are present in wholemeal products and breakfast cereals, these product types have to be avoided by celiacs. Therefore, the possibility to enrich gluten-free bread with minerals (Cu, Fe, Mn, Mg) by incorporation of red potatoes seems to be worth of interest for gluten-free food producers.

The addition of freeze-dried red potatoes to gluten-free bread formulation resulted in an increase of contents of insoluble dietary fibre in the product, on average by 105% in comparison to control, and the highest change could be found after an application of Magenta Love variety. The contents of soluble and total fibre in gluten-free bread with an addition of freeze-dried red potatoes grew in the range 222–231% and 141–152%, respectively, in comparison to control, regardless of the applied potato variety (Table 6). Such a change seems to be important, taking into account hypocholesterolaemic, hypoglycaemic and anti-cancer properties of soluble dietary fibre (Esposito et al., 2005), and its deficiencies in gluten-free products, resulting in digestive problems. The use of freeze-dried red potatoes could be a good way to overcome these deficiencies, and cause health improvement of celiacs.

Substantial part of published results on gluten-free bread is focused on their enrichment with gluten-free flours: amaranth, buckwheat and maize. In the studies of Alvarez-Jubete et al. (2009, 2010b) it was observed that the level of protein, Ca, Mg, Zn, Fe and vitamin E in gluten-free bread could be elevated by an application of pseudocereal flours. There are fewer studies on the effects of other plant raw materials on nutritional quality of gluten-free bread. Korus et al. (2012) analysed the influence of 5–15% defatted blackcurrant seeds and defatted strawberry seeds on quality of gluten-free bread. The authors observed that such an addition increases the level of protein up to 80% in the case of blackcurrant seeds and up to 60% in the case of strawberry seeds in comparison to control. Another study showed that the replacement of 20–60% of starch in bread recipe with debittered acorn flour caused an increase in protein content by 37–105%, and in dietary fibre by 76–220% (Korus et al., 2015). In the study of Tsatsaragkou, Gounaropoulos, and Mandala (2014) on the enrichment of rice-based gluten-free bread with 15% addition of carob germ, it was found that the increase in protein content could reach 8.4%. The content of dietary fibre could be increased by an addition of 5–15% defatted blackcurrant seeds or defatted strawberry seeds by 45–74 and 54–87.1 g/kg, respectively (Korus et al., 2012). The results presented here demonstrate that similar effect could be obtained by using only 5% addition of freeze-dried red potatoes, as they provide 76.1–79.5 g/kg total dietary fibre in gluten-free bread (Table 6). If we compare it with daily requirements for fibre, which is estimated to be 25 g for women and 38 g for men (Anonymous, 2008), one can observe that such bakery products is an important source of this constituent in a diet of celiacs.

Summarising, the applied 5% level of addition of freeze-dried red potatoes significantly increased the contents of high-quality protein, minerals and all fractions of dietary fibre, which indicates that these products could be an interesting choice for people with gluten intolerance.

| Table 7. Content of micro- and macro-elements (mg/kg) in gluten-free bread with share of freeze-dried red potatoes. |
| Samples | Fe | Mn | Mg | Ca | K | P | Cr | Co | Ni | Pb | Cu | Zn | Cd | Mn | Mg |
|---------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Control | 3.60 ± 1.03 | 0.10 ± 0.05 | 0.70 ± 0.10 | 0.76 ± 0.27 | 111 ± 13 | 666 ± 13 | ND 0.06 ± 0.00 | 926 ± 43 | 0.50 ± 0.00 | 1.00 ± 0.13 | 1.00 ± 0.13 | 0.30 ± 0.02 | 1.30 ± 0.03 | 5.50 ± 0.40 | ND 0.05± |
| GFB+5BS | 27.90 ± 2.34 | 0.10 ± 0.05 | 0.70 ± 0.10 | 0.76 ± 0.27 | 111 ± 13 | 666 ± 13 | ND 0.06 ± 0.00 | 926 ± 43 | 0.50 ± 0.00 | 1.00 ± 0.13 | 1.00 ± 0.13 | 0.30 ± 0.02 | 1.30 ± 0.03 | 5.50 ± 0.40 | ND 0.05± |
| GFB+5ML | 1.60 ± 1.06 | 0.10 ± 0.05 | 0.70 ± 0.10 | 0.76 ± 0.27 | 111 ± 13 | 666 ± 13 | ND 0.06 ± 0.00 | 926 ± 43 | 0.50 ± 0.00 | 1.00 ± 0.13 | 1.00 ± 0.13 | 0.30 ± 0.02 | 1.30 ± 0.03 | 5.50 ± 0.40 | ND 0.05± |

Different letters in column denote mean values that statistically differ one from another (Duncan test, at α = 0.05±).

**not determined.

La distintas letras en la columna indican valores medios que difieren estadísticamente entre sí (Prueba Duncan, a = 0.05±).
Conclusions

It was observed that addition of freeze-dried red potatoes significantly improves the level of protein (with high biological quality), minerals and dietary fibre in comparison to control. The influence of different potato varieties on physical and sensory properties of gluten-free bread is non-uniform (and could be detrimental).

Summarising, among the analysed gluten-free bread samples with an addition of freeze-dried red potatoes, the best results could be obtained by using variety Magenta Love, which provided high levels of protein, ash, together with the largest amounts of reducing sugars and insoluble dietary fibre (with bulking and anti-cancerogenig properties). Nutritional improvement was in this case accompanied by positive sensory changes, including its appearance, crust colour and thickness, crumb elasticity, smell and taste. The application of freeze-dried red potatoe variety Magenta Love allowed to obtain gluten-free bread with the highest volume, lowest hardness and significantly improve cohesiveness in comparison to other samples, both on the day of baking and during storage. It might be suggested that supplementation of gluten-free bread with such an addition results in an innovative product that could extend the portfolio of bread available for people with CD.

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Conflict of interest

The authors declare that they have no conflict of interest.

Compliance with ethics requirements

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

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