Broccoli by-product as an attractive ingredient of gluten-free mini sponge cakes: evaluation of batter viscosity and characteristics of the final product

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ABSTRACT

The nutritional improvement of gluten free foods is still a challenge, because celiac patients are looking for foods similar to gluten containing foods but providing the supplements they need for ameliorating their deficiencies. This study aimed to assess the influence of broccoli leaf powder (BLP) of previously confirmed nutraceutical properties on batter viscosity, technological characteristics and sensory quality of gluten-free mini sponge cake (GFS). BLP (2.5%, 5, 7.5 %; w/w) was incorporated into GFS formulation by replacing an equivalent amount of starches. BLP decreased significantly ($p < 0.05$) the viscosity of experimental batters and increased the instrumental firmness of GFS. Nevertheless, elasticity, crustiness, mastication and adhesiveness of broccoli GFS were similar to the control GFS. GFS with 2.5% BLP was characterized by attractive green colour, small size and proper distribution of pores, and was distinguished for its desirable sensory quality, although a slight cabbage aroma and taste were perceived. As a conclusion, BLP addition should not exceed moderate amounts to preserve good quality and palatability of GFS.

Keywords

Broccoli leaves; gluten-free; confectionary products; batter consistency; technological properties; sensory quality

1. Introduction

Recent years have witnessed an exponential growth of the gluten-free (GF) market which has become one of the most profitable segments of the food industry. This dynamic growth is the result of the increasing detection of a spectrum of gluten-related disorders (Sapone et al., 2012), in particular coeliac disease (CD). For those patients, GF products are the cornerstone of therapy because the elimination of gluten from the daily diet is still the only available and effective therapeutic method. A growing number of patients/consumers expect continuous improvement in the nutritional value and palatability of GF products. The enhancement of the quality of GF foods should be of fundamental interest to producers who are faced with a growing demand for products of the type. Therefore, studies aiming to improve the quality and nutritional value of GF products are of great importance.

In comparison with conventional wheat dough, GF batter is less cohesive and flexible, more viscous and difficult to handle. Moreover, GF baked products are characterised by lower technological quality, in particular by firm and crumbling texture, unattractive colour, faster staling, and poorer consumer acceptance (Drabińska, Rosell, & Krupa-Kozak, 2018; Drabińska, Zieliński, & Krupa-Kozak, 2016; Gallagher, Gormley, & Arendt, 2004). GF products are also characterised by insufficient nutrients content (Saturni, Ferretti, & Bacchetti, 2010; T. Thompson, 1999; Tricia Thompson, Dennis, Higgins, Lee, & Sharrett, 2005; Matos and Rosell, 2011). However, numerous studies have demonstrated that the technological and sensory properties and the nutritional value of GF products can be improved by applying natural GF cereals (millet, sorghum), pseudocereals (buckwheat, amaranth, quinoa) (Alvarez-Jubete, Auty, Arendt, & Gallagher, 2009; Capriles & Arêas, 2014; Krupa-Kozak, Wronkowska, & Soral-Śmietana, 2011), and proteins of animal and vegetable origin (Krupa-Kozak, Baczek, & Rosell, 2013; Nunes, Ryan, & Arendt, 2009).

Sponge cake, muffins and biscuits are widely consumed around the world as breakfast or evening snacks. These confectionary products are particularly popular among children and adolescents on account of their taste and spongy texture. The quality of cakes is determined by balanced formulae, batter aeration, stability of liquid batters in the early stage of baking and the thermal-setting stage (Cauvain, 2003). In the production of GF cakes, wheat flour has to be replaced with GF flours. Rice flour is the principal ingredient of GF muffins and cakes (Marco & Rosell, 2008b; Turabi, Sumnu, & Sahin, 2008a). Other approaches of GF cake production involve the application of corn and potato starches (Ronda & Roos, 2011). However, the use of alternative ingredients in the production of GF cake remains rare (Majzoobi, Poor, Jamalian, & Farahnaky, 2016; Talens, Álvarez-Sabatel, Rios, & Rodríguez, 2017). By-products from fruit and vegetable processing could be incorporated into GF products as a low-cost source of nutrients and functional ingredients (O'Shea, Arendt, & Gallagher, 2014). Hemp seed oil press-cake and decaffeinated green tea leaves have been used to improve the antioxidant properties and nutritional value of GF crackers (Radočaj, Dimić, & Tsao, 2014). Majzoobi et al. (2016) demonstrated that carrot pomace powder (up to 30%) had a positive effect on the quality of batter and the acceptability of GF sponge cake. In a recent study by Talens et al. (2017), a microwave-dried orange by-product was incorporated into the GF formulation to produce muffins characterised by an attractive colour, flavour and texture.

Brassica vegetables, including broccoli, are a good source of proteins, dietary fibre and bioactive compounds, in particular polyphenols which contribute to the prevention of diseases associated with oxidative stress, such as cardiovascular and neurodegenerative diseases and cancer (Scalbert, Manach, Morand, Rémésy, & Jiménez, 2005; Zhang et al., 2011). Cruciferous vegetables also contain glucosinolates with chemopreventive properties (Higdon, Delage, Williams, & Dashwood, 2007). Several studies have demonstrated that broccoli by-products, in particular leaves, have similar chemical composition to broccoli florets (Campas-Baypoli et al., 2009; Domínguez-Perles, Martínez-Ballesta, Carvajal, García-Viguera, & Moreno, 2010), which suggests that these materials could be valuable functional food additives. In our previous study (Drabińska, Ciska, Szmatowicz, & Krupa-Kozak, 2017), broccoli leaf powder (BLP) obtained in laboratory conditions was determined as an ingredient of a high antioxidant capacity and characterised by a high content of biologically active glucosinolates. Moreover, the use of BLP in the production of GF mini sponge cakes (GFS) significantly increased their antioxidant capacity, while the glucosinolate content of GFS was higher than expected, which suggests the presence of a synergistic interaction between these bioactive compounds and the food matrix. In view of our previous findings, the objective of the present study was to assess the impact of BLP on batter viscosity characteristics, technological parameters and sensory attributes of experimental GFS.

2. Materials and Methods

2.1. Preparation of broccoli leaf powder

Preparation of a broccoli leaf powder (BLP) was described previously (Drabińska et al., 2017). Briefly, mature leaves of broccoli (*Brassica oleracea* L. var. italica cv. Sebastian) without damage were washed and blanched in hot water for 1 min to inactivate enzymes hydrolysing biologically active compounds. Afterwards, blanched leaf blades without petioles and main midribs were freeze-dried and ground to obtain powder of particle size ≤ 0.60 mm. The powder was stored in a tightly closed container for further application in experimental gluten-free mini sponge cake (GFS) formulation.

2.2. Preparation of experimental gluten-free mini sponge cakes

Potato (30.6%) and corn (7.8%) starches, egg (43%), sugar (14%), sunflower oil (3.7%), salt (0.2%) and gluten-free baking powder (0.7%) were the main ingredients of a control GF mini sponge cake (GFS) formulation (Drabińska et al., 2017). BLP was incorporated into GFS in the following proportions: B1 – 2.5%, B2 – 5%, B3 – 7.5% (w/w) by replacing an equivalent amount of potato and corn starches in the control formulation. To prepare the GFS, egg white and salt were mixed for 2 min at a high speed to form foam in a stainless steel bowl using a planetary mixer KitchenAid Professional K45SS (KitchenAid Europa, Inc, Brussels, Belgium). Then, egg yolk and sugar were added and vigorous mixing was continued for another 3 min. Finally, starches, baking powder and oil were added, and all the ingredients were mixed at a low speed for 3 min to obtain smooth homogenous batter. Batter portions of 30 g was dosed into a paper mould (50 mm diameter x 35 mm high). Twelve moulds were arranged in three rows each of four mini sponge cakes on a baking tray and baked at 180 °C for 25 min in electric oven (SVEBA DAHLEN, AB model DC-21, Sweden). Baked GFSs were left to cool at room temperature for 1 h, then were packed in a clip-on polyethylene bags and analysed at the day of preparation. Products of two independent batches were analysed.

2.3. Pasting characteristic

The pasting behaviour of GFS batter was evaluated using a Rapid Visco-Analyser (RVA-4800; Perten Instruments, Madrid, Spain). A batter sample (8 g) was dispersed in 12 mL of distilled water. Suspensions were stirred thoroughly at 600 rpm for 1 min at 30 °C. Then, the temperature raised to 95 °C at a rate of 12 °C/min. The sample was maintained at 95 °C for 30 s, cooled to 50 °C at a rate of 12 °C/min and finally maintained at 50 °C for 2 min. The peak temperature (P_{temp}, °C), peak viscosity (PV, cP), hot paste viscosity (HPV; cP), cold paste (final) viscosity (CPV; cP), breakdown (PV-HPV; cP) and setback (CPV-HPV; cP) were recorded. The experiments were conducted in duplicate.

2.4. Physical parameters and instrumental colour analysis

In order to determine the physical parameters of GFSs, weight (using a digital balance), volume and surface area (using 3D NextEngine Scanner; NextEngine, Inc., Santa Monica, USA) were determined. Weight loss was calculated as the percentage of the ratio between weight of batter in the mould and the weight of the cake after baking, whereas a specific volume was calculated as the ratio of volume and weight. The instrumental measurement of colour of crumb and crust of experimental GFSs was evaluated using a HunterLab ColorFlex (Hunter Associates Laboratory, Inc, Virginia, USA), and the results were expressed in accordance with the CIELAB system. The parameters determined were L^* (L^* = 0 (black) and L^* = 100 (white)), a^* ($-a^*$ = greenness and $+a^*$ = redness), and b^* ($-b^*$ = blueness and $+b^*$ = yellowness). Values were the mean of twelve replicates.

2.5. Instrumental texture analysis

Textural properties of experimental GFSs were assessed on the day of preparation. Firmness and springiness were determined using TA.HD Plus Texture Analyser (Stable Micro Systems Ltd., UK) equipped with 5 kg load cell. Values obtained were the mean of six replicates. The GFS samples were removed from clip-on polyethylene bag just prior to testing to retain moisture. To standardise the procedure, the GFS were cut horizontally at the height of the mould to form a flat surface, the upper part was discarded and the 2 cm-high lower part were analysed. Sample was placed centrally under AACC 36 mm cylinder probe with radius (P/36R). The GFS sample was compressed at a constant rate of 1.0 mm/s at a distance of 5 mm. Probe holds at this distance for 30 seconds and then withdraws from the sample and returns to its starting position. Each kind of GFSs was tested in six replications. In this experiment, firmness was defined as the force in grams, required to compress the sample at maximum distance (5 mm). To determine springiness, the force after 30 seconds was recorded (F_{30} sec), divided by the force at maximum distance (F_{max}) and multiplied by 100%:

$$Springiness = (F_{30}/F_{max}) \times 100\%$$

2.6. Sensory analysis

2.6.1. Sensory methods and evaluation conditions

Sensory characteristics of the experimental GFS were determined using a quantitative descriptive analysis (QDA) (Lawless & Heymann, 2010). Prior to the analysis, vocabularies of the sensory attributes were developed by the panel in a round-table session, using a standardised procedure (ISO/DIS, 1998). Fifteen attributes were evaluated: porosity (pore collocation and dimension), aroma (sponge cake, sweet, cabbage), taste (sponge cake, sweet, cabbage, aftertaste), texture by finger (elasticity, crustiness) and texture by mouth fell (mastication, adhesiveness) and overall quality (overall appearance and palatability). The panellists evaluated the intensity perceived for each sensory attribute on unstructured graphical scales. The scales were 10 cm long and verbally anchored at each end, and the results were converted to numerical values (from 0 to 10 units) by a computer. The samples of experimental GFS were coded with a three-digit number and presented to the panellists all together in random order in transparent plastic boxes. Mineral water was offered and suggested to drink between each sample evaluation. The assessments were carried out at a sensory laboratory room, which fulfils the requirements of the ISO standards (ISO, 1998). The results were collected using a computerised system ANALSENS (IAR&FRPAS, Olsztyn, Poland). GFSs were tested in two replications.

2.6.2. Sensory panel

Sensory assessments was carried out by the expert panel consisting of 6 members (5 females; 1 male) previously selected and trained according to ISO guidelines (ISO, 1993). Prior to their participation in the experiments, the panellists were trained on sensory descriptors for gluten-free sponge cake baked from commercial mix (Celiko S.A., Poznań, Poland) purchased in a local supermarket.

2.7. Statistical analysis

The results were processed by one-way analysis of variance (ANOVA). The significance of differences between the samples was determined by Fisher's Least Significant Difference (LSD) Post Hoc Test with $p < 0.05$ set as a significance point. To verify significant differences between the products in each sensory attribute the statistical analyses were performed using software FIZZ, Biosystemes version 2.47B, and XLSTAT Version 19.01. The Pearson correlation coefficient between rheological and technological parameters of the samples as well as the proteins content (Drabińska et al., 2017) were calculated. The same parameters were analysed using principal component analysis (PCA). All the analyses were performed in Statistica v. 12 software (StatSoft, USA).

3. Results and Discussion

Measurements of the apparent viscosity of batter with a RVA can provide valuable insights into the quality of the final product. In the cake-making process, starch is the key structure-forming component, and the addition of sugar and liquids modify the gelatinisation properties of starch and affects the subsequently formed crumb structure (Cauvain, 2003). The pasting characteristics of the experimental GFS batters are shown in Figure 1. In general, shapes of RVA plots obtained during mixing, pasting and gelling of experimental GFS batters composed of potato and corn starches did not differ meaningfully. During the initial mixing, a consistency of all experimental GFS batters was similarly low, but after a rapid increase in batter viscosity was observed during heating that led to the gelatinisation of starches and, ultimately, the rupture of starch granules when the maximum consistency was achieved. The experimental batters achieved the peak viscosity at similar temperature regardless of the presence of BLP in GFS formulation (Table 1), but the formulations containing BLP differed in viscosity relative to the control batter. The peak viscosity of all samples containing BLP was significantly ($p < 0.05$) lower than in the control batter, in particular in sample B3 containing the highest amount of BLP (Table 1). The immediate explanation for that reduction could be the starch dilution that is produced when replacing starch by BLP. To confirm that a batter without BLP and containing the amount of starches present in B3 were tested . Indeed, the replacement of starches, brought about a reduction in the maximum peak viscosity, but some additional reduction was observed, likely due to the BLP composition. Regarding the proteins content in BLP (Drabińska et al., 2017), the observed differences could be attributed in some extend to the thermal properties of proteins added with BLP as a correlation between the peak viscosity and proteins content was noted (R = - 0.65) (Figure 2). Results obtained in the present study correspond with a previous study by Wang et al. (2002), where a negative correlation between proteins content and peak viscosity was noted in rice flour. Moreover, Marco and Rosell (2008a) analysed the effect of different protein isolates (pea, soybean, egg albumen and whey proteins) on the rheological properties of rice flour dough and reported that pea, soybean and whey proteins promoted a decrease in peak viscosity. Breakdown viscosity is influenced by starch resistance to high temperature and shear stress (Marco & Rosell, 2008a). In samples with higher BLP content, a significant (p <0.05) decrease in breakdown viscosity was determined relative to the control batter (Table 1), which agree with starch dilution. In the last stage of RVA analysis when temperature decreased, the viscosity of GFS batters increased gradually, but significant differences in final viscosity were not detected. However, final viscosity resulting from starch dilution was much lower, thus BLP conferred additional viscosity during cooling. However, setback viscosity, the amplitude between final and hot paste viscosity, changed in response to BLP application. The highest setback was determined in sample B3 containing the highest amount of BLP (Table 1). The increase in viscosity during setback is typically associated with the crystallisation of amylose chains; however, in this case, it could also be affected by the reorganisation of denatured proteins from BLP (correlation between protein content and setback, $R = 0.89$). An analysis of changes in batter viscosity during heating-cooling cycles could provide important information about the baking properties and technological characteristics of GFS.

The physical and technological parameters of GFS are shown in Table 2. Visual differences between the control sample and broccoli GFS can also be observed in Figure 3. The analysis of physical properties revealed that the control GFS was characterised by the greatest weight loss and significantly ($p < 0.05$) higher specific volume and surface area than the GFS containing BLP (Table 2). Cakes with higher specific volume generally lose more water during baking because they have a greater surface area that comes into contact with air (Zhou & Therdthai, 2008). The occlusion of air cells in batter during mixing produces an aerated emulsion or foam which is converted to a semi-solid, porous and soft structure during baking. The final cake volume depends on air incorporation and retention, which is influenced by batter viscosity and the distribution of air cells inside the batter matrix (Edoura-Gaena, Allais, Trystram, & Gros, 2007; Turabi, Sumnu, & Sahin, 2008b). In the current study, the results of the statistical analysis revealed that specific volume and surface area were clearly dependent on batter viscosity, and a high positive correlation was noted with most RVA parameters (Figure 2). The application of BLP in the experimental formulations significantly ($p <0.05$) decreased the specific volume and surface area of baked GFS, but their specific gravity was nearly twice higher than in the control GFS. In conventional wheat cakes, the quality of flour, in particular its starch and protein content (Wilderjans, Luyts, Goesaert, Brijs, & Delcour, 2010) and the size of flour particles (Yamazaki & Donelson, 1972), directly influences the quality attributes of the final product. BLP was characterised by relatively large particles (≤ 0.60 mm) and a relatively high content of proteins and minerals (Drabińska et al., 2017). It might be that BLP compounds decrease the amount of water available for starch gelatinisation and interact with starch to weaken the structure and lower the quality of GFS.

The results of the instrumental texture analysis are shown in Table 2. The experimental GFS did not differ in springiness, however considerable variations in firmness were noted between the softest control GFS (572.5 g) and the significantly ($p < 0.05$) firmer GFS containing BLP (Table 2). Furthermore, a gradual increase in firmness was observed in broccoli GFS, ranging from 947.2 in B1 to 1505.7g in B3, which indicates that firmness depended on the quantity of BLP in the formulation. The firmness of the experimental GFS was affected by batter viscosity and revealed a strong negative correlation with peak (R = - 0.97) and breakdown (R = - 0.97) viscosity (Figure 2). Moreover, firmness increased with a rise in the specific gravity of cakes (R = 0.81) which was influenced by the amount of BLP in the formulation. In a study by Majzoobi et al (2016) investigating GF sponge cake with carrot pomace powder, high-density cakes were also characterised by harder texture. Therefore, the properties of the applied flours and ingredients, as well as physical properties of batter (viscosity) and cake (moisture content, density, volume) should be evaluated in the cake-making process because they considerably influence the textural properties and the quality of the final product (de la Hera, Martinez, Oliete, & Gómez, 2013; Talens et al., 2017).

The results of the instrumental colour analysis of the experimental GFS are shown in Table 2. The values of parameters L, a^* and b^* for the crust and crumb of the control sample were significantly ($p < 0.05$) different from those noted in the GFS with BLP. The crust and crumb of the control GFS were characterised by the highest lightness (69.61 and 81.20, respectively) and redness (11.99 and 4.83, respectively), but yellowness (positive *b** value) was significantly ($p < 0.05$) lower in comparison with the GFS containing BLP. As expected, due to its vivid green colour, BLP applied in formulation significantly influenced the colour of the final GFS (Table 2). In gluten-free cake containing carrot pomace powder colour changed from pale to slightly orange (due to a high beta-carotene content in carrot powder) however, these changes had a positive effect on the overall acceptability of the evaluated products (Majzoobi et al., 2016). In the present study, a significant ($p < 0.05$) decrease in crust and crumb lightness was related to BLP content (Table 2). Moreover, the crust and crumb of the experimental GFS containing BLP were also characterised by the highest values of greenness (parameter *a**) that increased gradually with a rise in the content of vividly green BLP. However, the yellowness of the crust and crumb decreased with an increase in the amount of BLP in the formulation. Pigmented ingredients (orange by-products) significantly influence the colour of the final product (Talens et al., 2017). The visual differences between the typically creamy control GFS and broccoli GFS (B1, B2, B3) of light-green colour can be seen at Figure 3.

The differences in firmness of the experimental GFS noted in the instrumental texture analysis (Table 2) were not perceived in sensory analysis conducted by expert's panel (Table 3). The results of texture analysis by QDA revealed that the elasticity, crustiness, mastication and adhesiveness of all broccoli GFS were comparable to the control GFS (Table 3). Moreover, the porosity of GFS with BLP, in particular the distribution and size of air bubbles, was similar to the porosity of the control GFS (Table 3). High-quality sponge cakes are characterised by a large number of small air bubbles rather than a small number of large bubbles (Sahi, 1994). In all experimental broccoli GFS, air bubbles were small (≤ 2) and homogeneously distributed that is a feature of a good quality of sponge cake. QDA revealed significant differences ($p < 0.05$) in colour, aroma and taste of the experimental GFS (Table 3). The control GFS was creamy and had a typical for sponge cake aroma and taste. Sample B1 containing the lowest amount of BLP was characterised by a light-green colour, while sponge cake aroma and sweet taste was masked by a slight cabbage aroma and aftertaste. As expected, in samples B2 and B3 with a higher content of BLP, cabbage aroma and taste were perceived as more intensive. The scores of overall quality, representing the general sensory acceptability, indicated however that the appearance and palatability of sample B1 was comparably high to that of the control GFS.

4. Conclusions

BLP obtained in laboratory conditions was applied as a component of GFS formulation. The results obtained indicated that BLP influenced the batter viscosity characteristics and selected technological and sensory parameters of final GFS. Sample containing the lowest amount of BLP (B1) was characterized by attractive green colour, proper size and distribution of pores, and was distinguished for its desirable sensory quality, although a slight cabbage aroma and taste were perceived. On the other hand, the results of the instrumental texture analysis and QDA suggested that BLP addition should not exceed moderate amounts to preserve good quality and palatability of GFS. As a conclusion, the adequate amount of experimental BLP could be an attractive novel ingredient suitable in GFS.

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Author Contributions

UKK and CMR conceived and designed the study; ND, AL, AA, and CF performed the experiments; TJ performed the texture analysis; AO performed the sensory analysis; UKK, CMR and ND analysed the data; UKK wrote the manuscript. All authors read and approved the final version of manuscript.

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Table 1 Effects of BLP on the RVA parameters of GFS batters

	Control	**B1**	**B2**	**B3**
Onset temperature (ºC)	64.3±0.1	64.5±0.5	64.3±0.1	65.3±0.4
Peak temperature (ºC)	76.7±0.7	77.9±0.1	79.2±2.4	77.1±0.9
PV (cP)	3947.5±16.3^{a}	3736.3±85.4^{b}	3652.0±72.3^{bc}	3535.0±89.6^{c}
HPV (cP)	1866.5±14.85	1796.0±36.4	1809.7±45.24	1725.3±61.8
Breakdown (cP)	2081.0±1.41^{a}	1940.3±54.3^{ab}	1842.3±27.6^{b}	1809.7±76.5^{b}
Final PV (cP)	2811.0±49.5	2722.0±47.7	2785.7±28.0	2769.0±49.1
Setback (cP)	944.5±64.4^{b}	926.0±30.6^{b}	976.0±19.0^{b}	1043.7±29.2^{a}

[a] Values followed by different letters in the same row are significantly different ($P < 0.05$).

Table 2. The effect of BLP on the physical and textural properties and the colour of GFS.

		Control	B1	B2	B3
Moisture (%)		33.73±0.23	33.63±0.42	33.60±0.03	33.23±0.75
Weight loss (%)		14.9±1.2	13.9±0.8	13.8±1.0	13.4±1.3
Specific volume (cm^3/g)		3.99 ± 0.06^{a}	2.56 ± 0.17^{b}	2.44 ± 0.07^{b}	2.50 ± 0.11^{b}
Surface area (cm^2)		113 ± 1^{a}	84 ± 2^{c}	83 ± 1^{bc}	88 ± 2^{b}
Specific gravity (g/cm^3)		0.25 ± 0.01^{b}	0.39 ± 0.03^{a}	0.41 ± 0.01^{a}	0.40 ± 0.02^{a}
Firmness (g)		572.5 ± 71.0^{c}	947.2 ± 127.7^{b}	1109.7 ± 109.4^{b}	1505.7 ± 87.3^{a}
Springiness (%)		54.1±1.4	56.1±1.6	54.7±2.2	55.4±1.6
Crust colour	L^*	69.61 ± 1.30^{a}	52.53 ± 3.99^{b}	44.38 ± 2.91^{c}	40.67 ± 0.26^{d}
	a^*	11.99 ± 0.26^{a}	-3.38 ± 1.33^{b}	-7.73 ± 2.39^{c}	-9.83 ± 2.44^{d}
	b^*	34.73 ± 0.43^{d}	40.18 ± 0.63^{a}	38.91 ± 1.65^{b}	37.65 ± 0.89^{c}
Crumb colour	L^*	81.20 ± 0.65^{a}	69.61 ± 1.47^{b}	47.42 ± 1.50^{c}	42.98 ± 0.49^{d}
	a^*	4.83 ± 0.35^{a}	-11.99 ± 4.40^{b}	-12.72 ± 0.34^{c}	-13.02 ± 0.09^{c}
	b^*	25.31 ± 0.42^{c}	41.04 ± 1.20^{a}	39.61 ± 0.35^{a}	34.73 ± 0.71^{b}

[a] Values followed by different letters in the same row are significantly different ($P < 0.05$).

Table 3. QDA sensory analysis of experimental GFS with BLP

		Control	B1	B2	B3
Colour	creamy colour	3.2 ± 0.8^{a}	0.0^{b}	0.0^{b}	0.0^{b}
	green colour	0.0^{d}	3.0 ± 1.0^{c}	5.7 ± 0.9^{b}	7.7 ± 1.3^{a}
Aroma	sponge cake	8.2 ± 1.3^{a}	4.8 ± 1.6^{b}	3.2 ± 1.8^{c}	2.2 ± 1.5^{c}
	sweet	6.3 ± 1.6^{a}	4.5 ± 1.2^{b}	3.3 ± 1.5^{bc}	3.0 ± 1.5^{c}
	cabbage	0.0^{d}	2.3 ± 0.9^{c}	3.6 ± 1.6^{b}	5.1 ± 1.9^{a}
Taste	sponge cake	8.2 ± 1.2^{a}	5.3 ± 1.7^{b}	4.5 ± 1.5^{bc}	3.7 ± 1.6^{c}
	sweet	5.2 ± 1.2^{a}	4.1 ± 1.0^{b}	4.0 ± 0.9^{b}	3.9 ± 0.9^{b}
	cabbage	0.0^{d}	1.6 ± 0.5^{c}	2.7 ± 0.8^{b}	3.8 ± 1.4^{a}
	aftertaste	1.7 ± 0.8^{c}	2.3 ± 0.7^{bc}	2.7 ± 0.8^{ab}	3.1 ± 1.1^{a}
Porosity	collocation	6.6±2.0	6.9±2.5	7.0±2.5	5.2±2.9
	dimension	2.0±0.9	1.6±0.7	1.7±0.5	1.9±0.6
Texture (by finger)	elasticity	6.4±1.7	4.9±2.9	4.6±2.9	4.3±2.9
	crustiness	1.7±1.1	2.1±1.4	2.3±1.6	2.7±1.7
Texture (mouth fell)	mastication	3.6±2.5	3.6±2.1	3.6±2.2	3.6±2.0
	adhesiveness	3.5±2.5	3.6±2.3	3.5±2.4	3.4±2.4
Overall quality		8.3 ± 1.0^{a}	6.8 ± 1.6^{ab}	6.1 ± 1.7^{b}	5.43 ± 1.7^{b}

[a] Values followed by different letters in the same row are significantly different ($P < 0.05$).

Figure captions:

Figure 1. Effect of BLP on the plots of viscometric profile recorded with the rapid viscoanalyzer

Figure 2. Principal components plot of physical and technological features of GFSs.

Figure 3. Example pictures of appearance, cross-section and 3D scans of experimental GFS with BLP.

Figure 1. Pasting properties of starches affected by broccoli leafs.

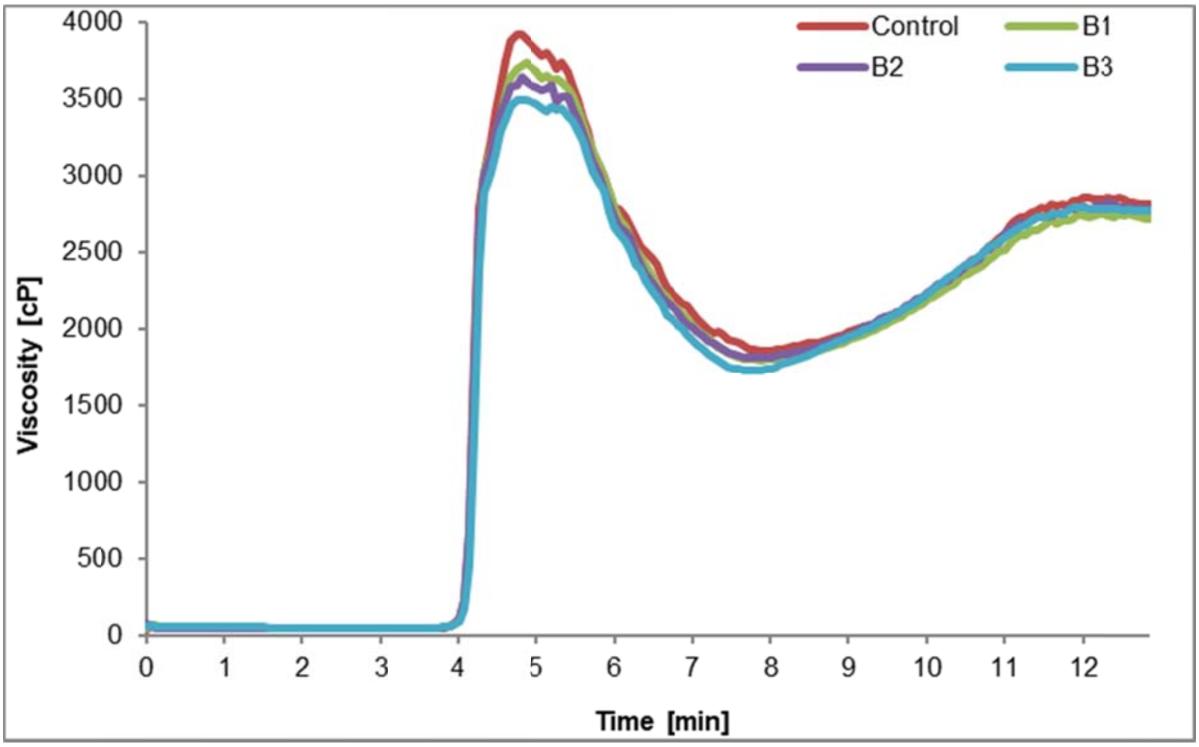
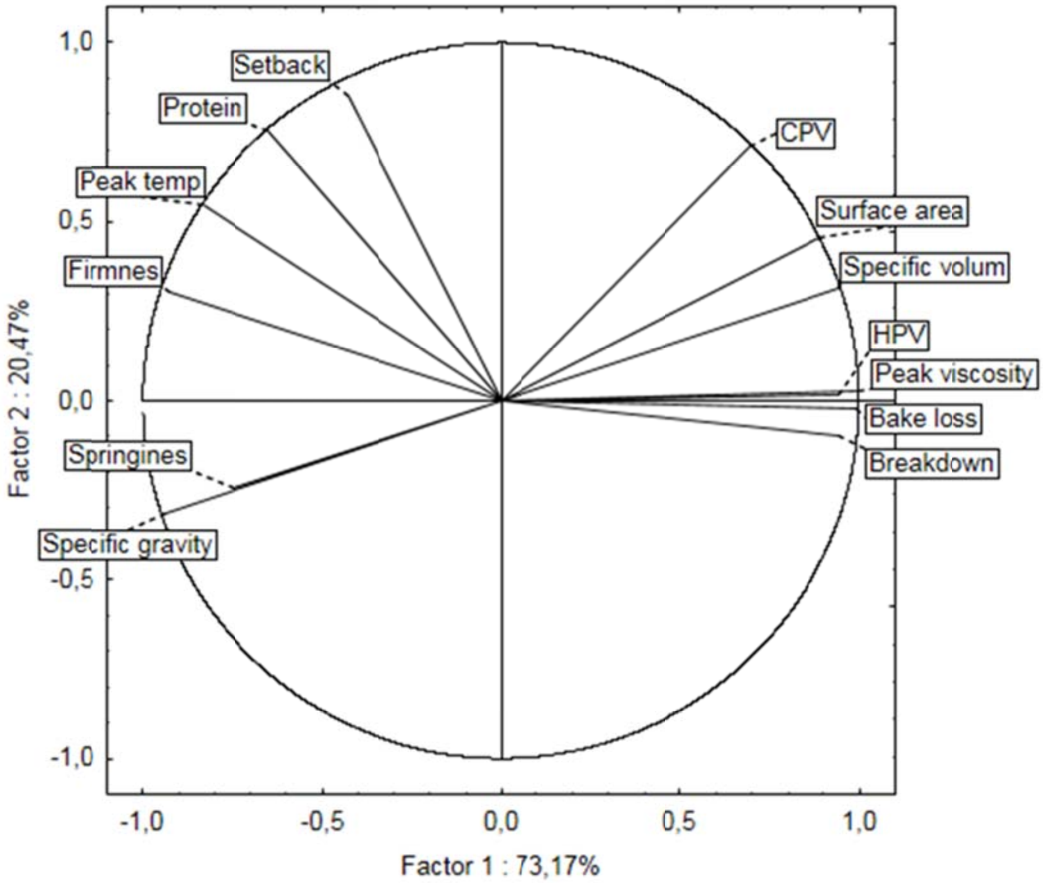


Figure 2.



Setback
Protein
Peak temp
Firmnes
Springines
Specific gravity
CPV
Surface area
Specific volum
HPV
Peak viscosity
Bake loss
Breakdown
1,0
0,5
0,0
-0,5
-1,0
-1,0
-0,5
0,0
0,5
1,0
Factor 2 : 20,47%
Factor 1 : 73,17%

Figure 3.