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Development of high-fibre biscuits using brewers' spent grain: Innovation in the bakery industry

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Abstract. The potential of reusing brewers' spent grain (BSG) as a high-fibre raw material for the bakery industry was investigated, focusing on product development, colour analysis, organoleptic analysis, and nutritional value development. Since BSG is a wet-state beer industry by-product, pre-treatment is always required. The BSG used in this research was a research by-product that was saved from being discarded, and its technological usability was evaluated for use in the development of biscuits. During product development, four different BSG-size fractions were used in combination with four enrichment levels (25%, 50%, 75%, and 100%). The enriched biscuits (EB) were subjected to colour and organoleptic analysis. The nutritional data of the biscuits (highlighting the fibre data) were compared with a control sample to test and evaluate their industrial feasibility. Sensory tests showed that biscuits enriched with 25% BSG performed best in all parameters. The BSG fortification enhanced the fibre content across all biscuit variants in comparison to the control sample. Colour analysis showed that BSG fortification consistently decreased the lightness values of the biscuits compared to the control.

Keywords and phrases: brewer's spent grain, innovative product development, functional foods, colour analysis, fibre enrichment, organoleptic evaluation

1. Introduction

Brewers' spent grain (BSG) is the largest by-product of the beer industry, accounting for 85% of the total solid by-products (*Kobelev et al.*, 2023). The production of 1 hL of beer generates about 20 kg of BSG, with about 40 million metric tonnes produced worldwide yearly (*Nocente et al.*, 2019; *Simon*, 2023). Brewers' spent grain, a waste from the beer industry, has valuable nutritional parameters such as low sugar content, high fibre (mainly hemicellulose, cellulose, lignin) and protein content (*Bachmann et al.*, 2022; *Chetrariu & Dabija*, 2023). BSG is a valuable source of bioactive compounds with health-promoting potential. Insoluble fibre helps to improve gastrointestinal health, regulate blood sugar levels and even reduce serum cholesterol (*Mussatto et al.*, 2006; *Lynch et al.*, 2016). Different types of fibre act through different mechanisms, so a varied intake of fibre is recommended (*Szűcs et al.*, 2016). In addition to fibre (30–70% dry weight), BSG provides a substantial amount of protein (15–30%), with essential amino acids like lysine and glutamine that contribute to muscle maintenance, immune defence, and digestive health (*Steiner et al.*, 2015). In addition, BSG is an abundant source of phenolic compounds (e.g. ferulic acid), which are also known for their antioxidant, anti-inflammatory, and anti-cancer properties; it also contains micronutrients (e.g. magnesium, phosphorus, zinc, and B vitamins), which also support its use as a functional food ingredient (*Waters et al.*, 2012; *McCarthy et al.*, 2013; *Nyhan et al.*, 2023). Due to their health-beneficial properties, BSG could become an integral part of the human diet in the future, integrating it into our diet healthily and sustainably (*Nagy & Diósi*, 2021; *Baiano et al.*, 2023).

The exploration of the potential of BSG from brewing has become a major focus of research into the use of by-products in recent years. These research studies have led to the development of several pilot products for the food industry. The most popular food products whose recipes have been reimagined with BSG are dry pasta, bread, and biscuit products (*Petrovic et al.*, 2017; *Shih et al.*, 2020; *Karlović et al.*, 2020; *Patrignani et al.*, 2021; *Yitayew et al.*, 2022). Biscuits as a snack product are enjoying remarkable popularity worldwide, which explains why their artisanal nature is increasingly being replaced by a science-based, well-mechanised industry (*Arepally et al.*, 2020).

A healthy and balanced diet with adequate physical activity is key to the proper functioning of the human organism and could prevent the development of metabolic syndrome (obesity and cardiovascular diseases) (*Finegold et al.*, 2013; *Willett et al.*, 2019). Keller's 2018 survey of Hungarian adult consumers ($n = 1563$) focused on understanding healthy eating styles (*Keller*, 2019). The hierarchical cluster analysis identified four main consumer groups: those who avoid unhealthy foods (20.3%), those who reject unhealthy foods (11.8%), those who are neutral (26.2%), and those who choose healthy foods (14.7%). This research highlights that the goal of all societies is to reduce overweight and obesity, in which appropriate, science-based education could be a key element.

For the food industry to produce healthy foods that support human health, as recommended by the WHO in its reports, forward-looking changes are needed (*WHO*, 2003; *WHO*, 2020; *Galanakis et al.*, 2021). One such change could be the recycling of valuable food by-products such as BSG. In addition to producing healthy food to feed a growing global population, sustainability is also becoming a focus for a growing number of conscious consumers (*Iqbal et al.*, 2021; *Nagaraj*, 2021; *Nagy et al.*, 2024). In the spirit of innovation and sustainable product development, we aim to investigate the reintroduction of BSG in the food industry through a prototype biscuit product, with a view to renewable environmental management.

2. Materials and methods

2.1. Product development

The product development was conducted at the Innovation Centre, Institute of Food Technology, Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, Hungary. We aimed to reimagine a popular Indian recipe and make it more sustainable by using BSG, as we added different proportions of BSG relative to the weight of flour. The BSG we used was a research by-product (from the Institute of Food Science, University of Debrecen), which we salvaged and processed for sustainability reasons. The collected wet BSG had a moisture content usually ranging between 75% and 85% by weight before drying and 9% after drying, which was safe to work with. Other ingredients in the recipe (baking powder, custard powder, margarine, milk, refined wheat flour – max. 0.60% (m/m) ash content –, sugar powder, vanilla sugar) were readily available components. The BSG treatment consisted of drying for 24 hours at 40–42 °C, then grinding using a Retsch (SR 200) rotor beater mill (rotor speed 8100 rpm) with a 1 mm sieve, as it is universally applicable to reduce the size of food and feed (*Fernlund et al.*, 2007; *Retsch*, 2015). This milled BSG was shifted with a laboratory hand sieve (250 µm) and distinguished between a part that remained above (d > 250 µm) and a part that fell through the sieve (d < 250 µm). There was another BSG treatment as we milled the BSG to coffee-grade fineness. By using different grinding methods, we were able to work with four different particle size fractions of BSG (n = 4). The biscuit enrichment was made at four fortification levels as follows: 25–100% in equal increments of 25%. A total of 16 enriched biscuits and one control sample (without BSG) were prepared (n = 17).

Table 1 shows the BSG codes by the processing steps and the enrichment levels used. The recipe was the same in all cases, only the proportions of BSG and wheat flour were changed. Once the biscuits had the right consistency, they were baked at 180 °C for 8 minutes after shaping.

Table 1. BSG codes by the processing steps and the used enrichment levels

BSG processing steps	**25% enrichment**	**50% enrichment**	**75% enrichment**	**100% enrichment**
Milling + Coffee Grinding	1/25	1/50	1/75	1/100
Milling + Shifting (250 µm <)	2A/25	2A/50	2A/75	2A/100
Milling + Shifting (250 µm >)	2B/25	2B/50	2B/75	2B/100
Milling	3/25	3/50	3/75	3/100

2.2. Colour analysis

The colour test was performed immediately after the biscuits were baked and cooled. A Konica Minolta Chroma Meter (CR-410 type) was used to determine the lightness (L*), redness (a*), and yellowness (b*) of the samples (n = 17). Since the biscuits were smaller than the diameter of the chromameter (50 mm), the biscuits were crushed and poured into Petri dishes. The Petri dishes were placed on a white surface, and the instrument was inserted as shown in *Figure 1*. The tests were repeated in triplicate, with particular attention paid to environmental conditions such as lighting and table surface. The results were processed and evaluated using Microsoft Excel (*Fratianni et al.*, 2005; *Baráth et al.*, 2023; *Primet*, 2023).

Figure 1. Colour analysis of the biscuits

2.3. Organoleptic analysis

In the organoleptic study, 43 people participated. At the beginning of the questionnaire, we asked for general information such as gender, age, and smoking habits. We wanted to know how healthy the respondents thought their diets were and how much attention they paid to adequate fibre intake. Then the evaluators had to rate the following key parameters on a scale of 1 to 9 – with 1 being the worst and 9 being the best score: appearance, flavour, aroma/smell, colour, texture, and overall acceptance. The questionnaire listed 17 samples in total, numbered from sample 1 through sample 17, with sample 17 as the control sample that did not contain BSG. Samples 1–4 were produced using the first fraction (1) of BSG and were enriched at the amounts of 25%, 50%, 75%, and 100%. Samples 5–8 were produced using the second fraction (2A) of BSG; samples 9–12 were produced using the third BSG fraction (2B); samples 13–16 were produced using the fourth BSG fraction (3) and the same four levels of enrichment. The research participants were unaware of the coding or its meaning in the interests of full objectivity (*Molnár*, 1991; *Romvári et al.*, 2009).

2.4. Nutritional value determination

The nutritional value of the biscuits enriched with different fractions of BSG was also determined. To prepare the nutritional table, the recipe of the products was needed, which included the amount as well as the average nutritional values of each ingredient, which were used to determine the amount of each nutrient for the whole product. Then the nutrients per 100 g were calculated. Each ingredient has a specific energy content per mass unit. The current regulation defines the conversion factors for all nutrients; this value is multiplied by the amount of ingredients per 100 g of product. The nutritional value and the nutrient content were determined as follows: energy (kJ and kcal), fat-, carbohydrate-, sugar-, protein-, salt-, and fibre-content (all expressed in g) (*1169/2011/EU regulation*, 2011; *Kuti*, 2016).

3. Results and discussions

3.1. Product development

The study included 17 biscuit samples in total: 16 enriched with BSG and one control sample, which was labelled "C" and contained no BSG (*Figure 2*). The terms shown in *Table 1* have been used to express the results in all cases (colour analysis, organoleptic analysis, and nutritional value analysis).

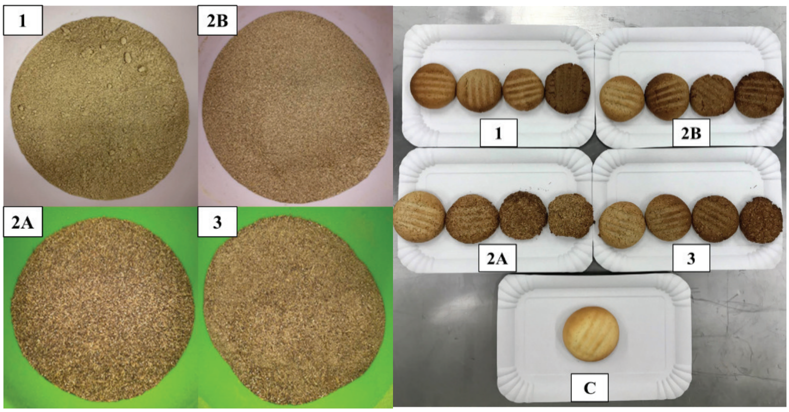
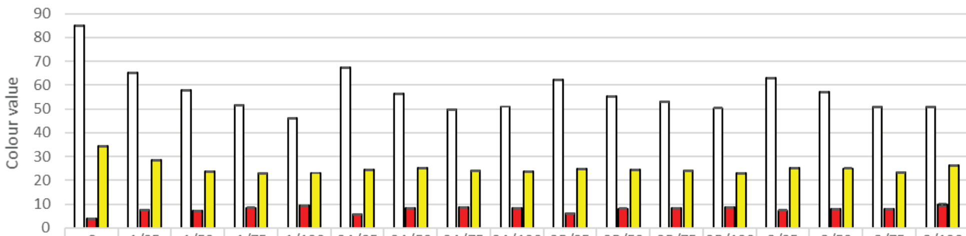


Figure 2. The used BSG fractions (left) and the enriched biscuits (right)

3.2. Colour analysis

Figure 3 shows the colour test results for biscuits fortified with BSG. By observing the lightness values (L*) of the biscuits, it can be stated that the values varied from 46.2 (1/100 sample) to 85.1 (C: control sample). The average lightness value was 57.3, which was exceeded by the lightness values of six samples: C (85.1); 1/25 (65.3); 1/50 (57.9); 2A/25 (67.3); 2B/25 (62.5); 3/25 (63.1). It can be seen that the lightness value of biscuits decreases in direct proportion to the increase in enrichment. The redness value (a*) varied between 3.82 (C) and 9.70 (3/100). The average redness score was 7.76, while the average yellowness (b*) score was 25.1. Regarding the yellowness values, it can be noted that the lowest value (23.0) was recorded for the 1/100 sample, while the highest value (34.5) was recorded for the control sample.

When analysing the colour and lightness (L*) values of snack products enriched with by-products, it can be determined that the by-products reduce the lightness values of the samples compared to the control sample. It can be a common result, as by-products often contain e.g. husk fragments, which may usually contain some darker brownish pigments (*Mir et al.*, 2015; *Pasqualone et al.*, 2020).



	C	1/25	1/50	1/75	1/100	2A/25	2A/50	2A/75	2A/100	2B/25	2B/50	2B/75	2B/100	3/25	3/50	3/75	3/100
L*	85.1	65.3	57.9	51.7	46.2	67.3	56.5	49.9	51.1	62.5	55.3	53.3	50.4	63.1	57.2	51.0	51.1
a*	3.82	7.46	7.09	8.53	9.54	5.67	8.28	8.86	8.41	6.21	8.17	8.21	8.63	7.43	7.98	8.01	9.70
b*	34.5	28.6	23.6	23.1	23.0	24.6	25.3	24.1	23.6	24.9	24.6	24.3	23.2	25.4	25.0	23.3	26.2

Biscuit samples

Figure 3. Results of the biscuits' colour analysis

3.3. Organoleptic analysis

The six parameters (appearance, flavour, aroma/smell, colour, texture, and overall acceptability) evaluated in the organoleptic analysis were graphically analysed individually.

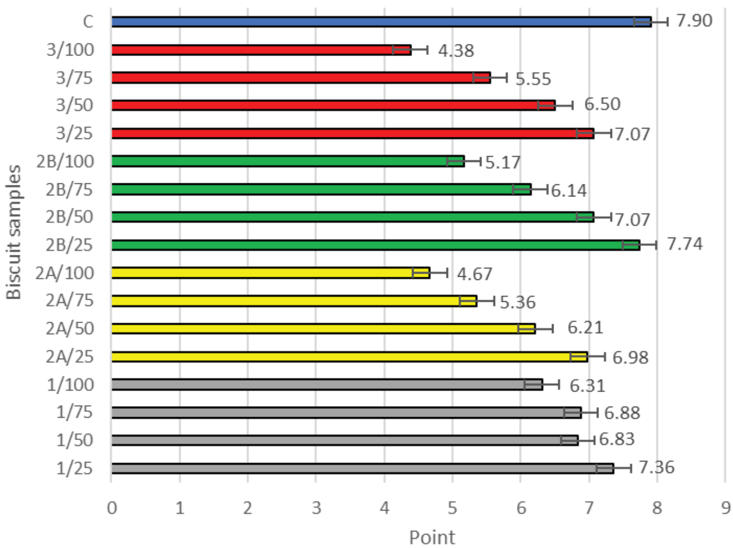


Figure 4. Results of appearance evaluation of the enriched biscuits

Figure 4 summarizes the data on appearance. It was found that on the 1–9 scale used, the biscuits scored between 4.38 and 7.90. The lowest value was achieved by the 3/100 sample (4.38) while the highest value (7.90) by the control sample. In terms of appearance, the biscuits had an average score of 6.36, which was exceeded by 9 samples (3/50: 6.50; 1/50: 6.83; 1/75: 6.88; 2A/25: 6.98; 2B/50: 7.1; 3/25: 7.07; 1/25: 7.36; 2B/25: 7.74; C: 7.90). It can be observed that as a result of fortification with BSG, the scores for the appearance of biscuits decreased in all cases and decreased in inverse proportion to the degree of fortification (exception: 1/75).

The 1/75 sample (6.88) scored one-tenth higher than the 1/50 sample (6.83). Among the enriched biscuits, sample 2B/25 was the judges' favourite in terms of appearance with a score of 7.74, which was only two-tenths less than the control sample's score.

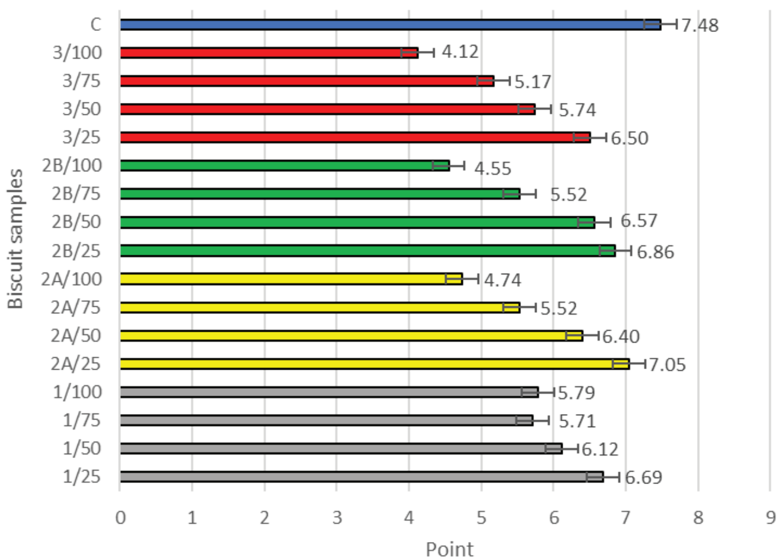


Figure 5. Results of organoleptic flavour determination of the enriched biscuits

Figure 5 summarizes the flavour results of the biscuits fortified with BSG. The graph shows that the values for flavour ranged from 4.12 to 7.48. The lowest value was achieved by the 3/100 sample (4.12) while the highest value (7.48) by the control sample. The average flavour value of the samples was 5.91, exceeded by 8 samples (1/50: 6.12; 2A/50: 6.40; 3/25: 6.50; 2B/50: 6.57; 1/25: 6.69; 2B/25: 6.86; 2A/25: 7.05; C: 7.48). Also, in this case, it was found that as a result of fortification with BSG, the taste scores were reduced in all cases compared to the control sample. As the enrichment increased, the flavour scores decreased in inverse proportion (exception: 1/100). The 1/100 sample (5.79) scored one tenth higher than the

1/75 sample (5.71). In terms of flavour, the judges' favourites for the enriched biscuits were samples 2A/25 (7.05) and 2B/25 (6.86).

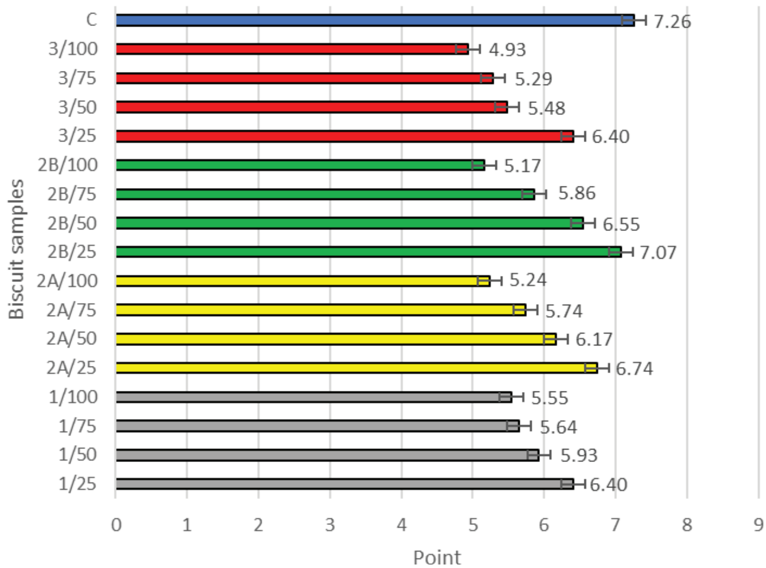


Figure 6. Results of organoleptic aroma/smell determination of the enriched biscuits

Figure 6 shows the results for aroma/smell as an organoleptic parameter. The results varied between 4.93 (3/100) and 7.26 (C). The samples had an average aroma/smell of 5.96 points, exceeded by 7 samples (2A/50: 6.17; 1/25: 6.40; 3/25: 6.40; 2B/50: 6.55; 2A/25: 6.74; 2B/25: 7.07; C: 7.26). Looking at the aroma/smell results, all samples without exception scored lower than the control sample as a result of the enrichment. There was a decrease in aroma/smell scores with increasing enrichment levels. The best result among the enriched biscuits was achieved by sample 2B/25 with a value of 7.07, only two-tenths of a point lower than the control sample (7.26).

Figure 7 summarizes the results of the organoleptic analysis of the colour of the enriched biscuits. The scores for colour ranged from 4.52 to 7.83, with the lowest score being given to the 3/100 samples (4.52) and the highest score to 2 samples in a tie (C: 7.83 and 2B/25: 7.81). The average score for biscuit colour was 6.52, exceeded by 10 samples (3/50: 6.55; 2A/50: 6.55; 2B/50: 6.86; 3/25: 7.02; 1/75: 6.98; 1/50: 7.29; 2A/25: 7.38; 1/25: 7.52; C: 7.83; 2B/25: 7.81).

Concerning colour as an organoleptic parameter, it can be observed that enrichment again resulted in a decrease in the colour values. Still, the 2B/25 sample (7.81) scored the highest in a dead heat with the control sample.

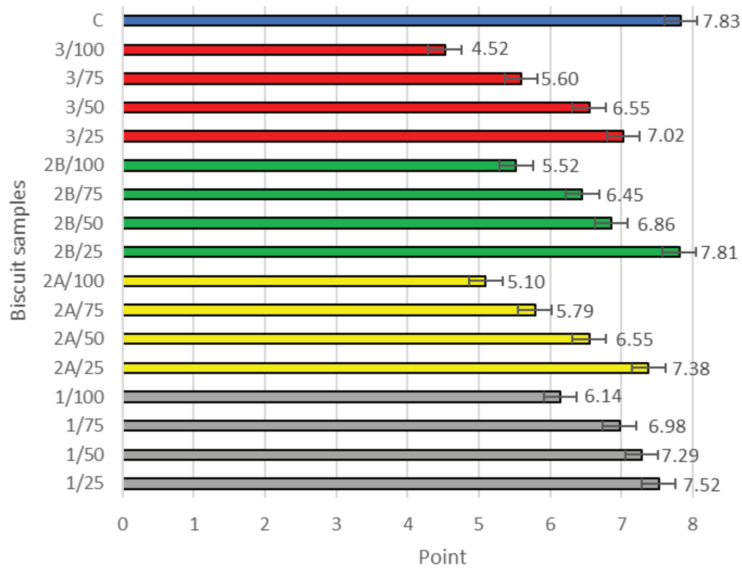


Figure 7. Results of the organoleptic colour evaluation of the enriched biscuits

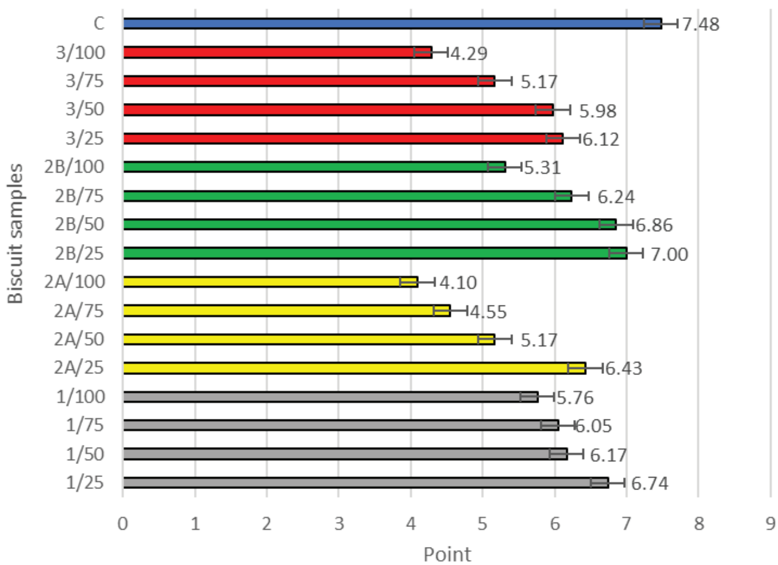


Figure 8. Results of the organoleptic texture evaluation of the enriched biscuits

Figure 8 shows the results for the texture of the enriched biscuits. The results varied between 4.10 (2A/100) and 7.48 (C). The samples had an average texture of 5.85 points, exceeded by 10 samples (1/75: 6.05; 3/50: 5.98; 3/25: 6.12; 2B/75: 6.24; 1/50: 6.17; 2A/25: 6.43; 1/25: 6.74; 2B/50: 6.86; 2B/25: 7.00; C: 7.48). Fortification with BSG also reduced the consistency values in all cases. The best result among the fortified biscuits was achieved by sample 2B/25 with a score of 7.00.

Figure 9 summarizes the results of the organoleptic analysis of the overall acceptability of the enriched biscuits. The scores for overall acceptability ranged from 4.21 to 7.71, with the lowest score being given to the 3/100 samples (4.21) and the highest to the control sample (C: 7.71). The average score for biscuit overall acceptability was 6.11, exceeded by 9 samples (1/75: 6.24; 2A/50: 6.26; 1/50: 6.40; 3/25: 6.64; 2B/50: 6.67; 1/25: 6.93; 2A/25: 7.12; 2B/25: 7.48; C: 7.71). Concerning the overall acceptability as an organoleptic parameter, it can be observed that enrichment again resulted in a decrease in the values. Still, the 2B/25 sample scored the highest (7.48) considering the enriched biscuits.

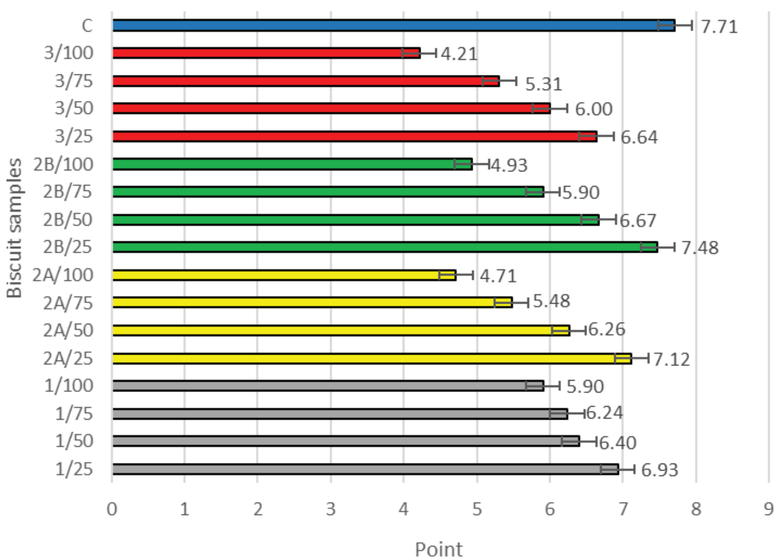


Figure 9. Overall acceptability of the enriched biscuits

Although the use of fortifiers can lead to better nutritional value, the various sensory parameters (colour, taste, texture, aroma, smell, overall acceptability) may be worse (*Tańska et al.*, 2016; *Goubgou et al.*, 2021). However, despite some sensory differences, new products can be made from by-products that can be easily incorporated into the diets of people who follow a health-conscious diet (*Blasi et al.*, 2024).

3.4. Nutritional value analysis

The calculated nutritional values for the control sample and the best-performing biscuit enriched with BSG according to the organoleptic test are summarized in *Table 2.* With the amount of 25% fortification, an increase was observed for all nutritional parameters (energy, fat, carbohydrate, sugar, protein, salt, fibre). As a result of the fortification, the main objective was to increase the fibre content, which was achieved by increasing the value from 1.71 g/100 g to 6.00 g/100 g.

In terms of fibre results, it was found that fortification with BSG increased the fibre content of the biscuits in all cases (*Table 3*). The lowest fibre content was observed in the control sample (1.71 g/100 g) while the highest value in the 3/100 sample (21.1 g/100 g). The biscuits had an average fibre content of 12.5 g/100 g, which could be considered as a fibre-rich category.

Table 2. Nutrition table for biscuit samples (for 100 g)

Parameter	**Control**	**2B/25**
Energy (kJ/kcal)	2313.6/572.4	2449.3/581.1
Fat (g)	13.3	14.1
Carbohydrate (g)	71.6	73.1
Sugar (g)	28.9	31.4
Protein (g)	5.82	6.01
Salt (g)	0.090	0.100
Fibre (g)	1.71	6.00

Table 3. Fibre content of enriched biscuits

BSG-enriched biscuit samples	**Fibre content (g/100 g)**
1/25	5.65
1/50	8.60
1/75	11.5
1/100	20.3
2A/25	5.60
2A/50	10.8
2A/75	16.2
2A/100	18.8
2B/25	6.00
2B/50	9.84
2B/75	14.1
2B/100	17.7
3/25	6.41
3/50	11.2
3/75	16.1
3/100	21.1

It is observable that the fibre content of the biscuits increased proportionally with the fortification degree. *Table 2* shows that the enrichment of 25% resulted in values of 5.60–6.41 g/100 g (average 5.92 g/100 g), regardless of the fraction. At 50% enrichment, the fibre content of the biscuits was 8.60–11.2 g/100 g (average 10.1 g/100 g), at 75% enrichment, it was 11.5–16.2 g/100 g (average 14.5 g/100 g), while 100% enrichment (no added BL55 flour) resulted a fibre content of 17.7–21.1 g/100 g (average 19.5 g/100 g).

Some products are labelled as "high fibre" (≥ 6 g/100 g) or "source of fibre" (≥ 3 g/100 g) according to EU legislation. The most popular biscuit (25% BSG-enriched sample – 2B/25) from the organoleptic test has a nutritional value of 6 g/100 g fibre content and would be classified as a "high-fibre" food if sold to the general public (*1169/2011/EU Regulation*, 2011). Biscuits enriched with some type of fibre (wheat bran, inulin, beta-glucan, cellulose, etc.) are generally used to aid digestion, improve satiety, regulate blood sugar levels, or lower cholesterol (*Goubgou et al.*, 2021; *Blasi et al.*, 2024).

4. Conclusions

Our results show that BSG could be used to enrich biscuits, increasing their fibre content, but it is important to prepare BSG in the right technological way, finding the form and particle size distribution best suited to each particular food category.

Colour analysis, sensory evaluation, and nutritional profiling are key aspects of product development, as they support the creation of functional foods that align with consumer expectations while contributing to health promotion and disease prevention. In the case of food by-products, all product development measurements must be implemented in order to be able to safely declare the reuse of a by-product in the food industry.

In terms of colour analysis, it was found that fortification with BSG reduced the lightness (L*) values of the biscuits in all cases compared to the control sample, which was possible due to the brown colour of the BSG. Increasing the enrichment rate with BSG resulted in a decrease in the lightness (L*) value, with associated changes in the redness (a*) and yellowness (b*) values, which should be better understood by performing a colour test for the fortifier (BSG) as well in the future.

As regards the results of the organoleptic analysis of the BSG-enriched biscuits, it can be concluded that the enrichment with different fractions of BSG in all cases worsened the organoleptic parameters of the products (appearance, taste, aroma/smell, colour, texture, and overall acceptability) according to the evaluators. Still, the results were very close to the control samples in several cases. In terms of the results of the organoleptic test, sample 2B/25, i.e. milled and sifted with a 250 μm sieve, lower fraction (d < 250 μm) and enriched with 25% of BSG relative to the flour weight, obtained the best results (closely following the control sample for all parameters). In the case of taste as an organoleptic parameter, sample 2A/25 even scored one-tenth better than sample 2B/25. Overall, it was found that fortification with BSG at 25% gave the best results for biscuit products. According to the tasters, the 2B fraction (milled and shifted) was the most popular, so this processing is proposed for the future. The lowest scores were obtained for the 3/100 sample in all cases (except for texture, where the lowest score was obtained for the 2A/100 sample), and the results suggest that fortification with 100% BSG is not recommended.

Overall, fortification with BSG resulted in an increase in fibre content for all biscuits (compared to the control sample). The lowest fibre content was found in sample 2A/25 while the highest in sample 3/100.

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