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ALEKSANDER HEJNA, JOANNA SZULC, BŁAŻEJ BŁASZAK

# BREWERS' SPENT GRAIN – SIMPLY WASTE OR POTENTIAL INGREDIENT OF FUNCTIONAL FOOD?

S u m m a r y

**Background.** The food industry generates large amounts of food waste during production, which is often underutilized. Various sorts of food waste with different chemical composition and physicochemical properties are produced depending on the type of industry. Due to increasing public concern about waste production, environmental protection, circular economy and knowledge about the chemical composition of food waste, it is becoming a potential raw material in food production as a high nutritional by-product.

**Results and conclusions**. The main food waste generated during beer production is brewers' spent grain (BSG), accounting for approx. 85 % of all by-products. Owing to low cost and significant protein content, it is currently used in animal feeding. However, high levels of dietary fiber, minerals and antioxidants create an opportunity to apply BSG not only as a bioactive compound extraction material but also as a raw material in human food processing. Therefore, this literature review concerned the possibility of applying BSG in the production of various value-added food products and its impact on chemical, physicochemical and sensory properties. The main issue related to the application of BSG in food products is decreasing product sensory scores due to changes in color, aroma and texture. However, increasing a nutritional value and health-beneficial effects could enhance attractiveness, reduce sensory barriers and increase interest in BSG-derived food products.

**Keywords:** Brewers’ spent grain; beer; waste management; functional food

## Introduction

Food waste and by-products are generated in large amounts during food processing worldwide. Agricultural and food production more than tripled between 1960 and 2015. Globalization and industrialization are the results of the transformation of the agri-food sector during this period, and it is expected that food technology will develop dynamically since the agricultural and food industry is going to be challenged

*Dr inż. A. Hejna ORCID: 0000-0001-9125-6164, Instytut Technologii Materiałów, Wydział Inżynierii Mechanicznej, Politechnika Poznańska ul. Piotrowo 3, 61-138 Poznań; dr inż. J. Szulc ORCID: 0000-0002-5479-6820, mgr inż. B. Błaszak ORCID: 0000-0003-2963-8991, Zakład Technologii i Inżynierii Przemysłu Spożywczego, Wydział Technologii i Inżynierii Chemicznej, Politechnika Bydgoska im. Jana i Jędrzeja Śniadeckich, ul. Seminaryjna 3, 85-326 Bydgoszcz. Kontakt: aleksander.hejna@put.poznan.pl*

in 2050, if it is capable of meeting the needs of nine billion people [18, 30]. The growing need to feed the world's population will manifest in expanding food production. It is estimated that about 38 % of food waste is produced by the food industry [6, 67]. During food processing, a wide variety of by-products are generated. They can be categorized by the type of industry, depending on which by-products with different chemical composition are produced [6]. Owing to the large scale of waste production, both the industry and scientists look forward to alternative waste use. It is connected with financial and functional benefits due to highly nutritional and functional ingredients that are contained in food waste (polysaccharides, proteins, vitamins, minerals, dietary fiber and bioactive compounds) [51].

Apart from being discarded to landfills, the most common use of food waste is for animal feeding or compost production. Nowadays, the rapidly developing method transforms agricultural and food waste into biomass and further into energy and biofuels. This reduces greenhouse gas emissions, waste recycling and energy production from woody and herbaceous crops or biobased material transformed by food and agro-industrial processing (e.g. waste from fruit and vegetable processing) [53, 58]. An interesting method that allows for using food waste, residues or by-products is to use them as raw materials or enriching additives in food processing. Such an approach can decrease the amount of other raw materials needed for food processing, decrease the amount of discarded food waste and increase the nutritional value of food products. The potential to use food waste in food processing is described in papers, where waste from agricultural and food industry, such as fruit and vegetable peels, seeds, pomaces, cereal waste, fish waste and whey, were applied in the beverage, bakery, dairy and meat industries [51, 56, 59, 74]. Depending on the waste type, products applied can be enhanced in different ways: increased amount of dietary fiber, antioxidant capacity, proteins, better physicochemical and sensory properties, and enhanced microbiological safety [56].

Another possibility to use food waste is to extract bioactive compounds from food waste. This kind of treatment can be critical, especially for waste typically discarded because there are no possibilities to apply it in the industry [28, 36]. Repeatedly, it is an excellent source of various chemicals, from antioxidants, vitamins, pigments, flavors, proteins and oils to gelling agents. Thus, knowledge about the chemical composition of food waste is essential for proper extraction or application. Types of compounds in different types of food waste are described in numerous papers [1, 28, 36, 55, 59, 65]. Applying food waste as raw materials or additives leads to increased innovation and products with better characteristics, including both nutritional and sensory ones. Additionally, it allows the acquisition of bioactive compounds and novel foods in a sustainable way. This treatment can also help enhance human health [51]. This paper aimed to summarize brewers' spent grain (BSG) as a potential raw material in novel, sustainable food production with a higher nutritional value.

## Brewers' spent grain

### *General information, statistics, composition*

BSG is the main by-product of beer production, accounting for approx. 85 % of all by-products [22]. It is generated during mashing, followed by lautering and filtration aimed at the separation of wort [21]. The main goal of mashing is the enzymatic conversion of starch present in malts to fermentable and non-fermentable sugars. This process can be carried out in one step or several steps related to the temperature ranges attributed to the maximum efficiency of particular enzymes. The most popular range is 62 ÷ 72 °C, which covers the activity of β-amylase (58 ÷ 65 °C) and α-amylase (68 ÷ 74 °C), converting starch to maltose and dextrins, respectively [41]. After mashing, wort is separated from grains in the lautering process, which includes filtration and additional sparging of the grainbed with water to wash out residual sugars. The resulting liquid, clear wort, is transferred to a kettle for further steps of the brewing process, while used grains – BSG are removed from the process as a by-product.

Industrial breweries do not reveal their beer recipes, hence it is hard to precisely assess the utilization of malt and determine the amount of generated BSG. We have collected and analyzed available data from the biggest Polish brewing portal – www.piwo.org. Results presented in Figure 1 consider 235 beer recipes from over 50 brewers for original gravity (OG) range from 7.2 to 35.0 °BLG, wort volumes from 6.5 to 94.0 liters, and malt weight from 1.05 to 23.4 kg. Also, it has to be considered that the analyzed recipes included various beer styles and the use of malt having different levels of extract, from the most efficient pilsen or pale ale malt to roasted barley. Therefore, the data presented provides a comprehensive overview and indicates that the malt usage for the commercially most popular OG range (10 ÷ 12 °BLG) is between 16.3 and 20.6 kg/hl.

Keeping in mind that industrial brewing is focused chiefly on light lagers, uses mainly highly efficient pale malt, and is characterized by a higher process yield than homebrewing, it is safe to assume that the production of a hectoliter of beer requires 20 kg of malt. The literature data [70] demonstrates that around 69 % of the malt initial mass is extracted, hence brewing each hectoliter yields approx. 6.2 kg of BSG. Reports indicate that over the last years, global beer production has been in the range of 1.91 ÷ 1.97 billion hectoliters, associated with the generation of almost 12 million tonnes of BSG, often underutilized. Currently, BSG is mainly landfilled or used in animal feeding. As evidenced by the literature data, the combustion of BSG results in the emissions of nitrogen and sulfur oxides in relatively high concentrations exceeding 480 mg/m$^3$, therefore its application in energy production is limited [26].

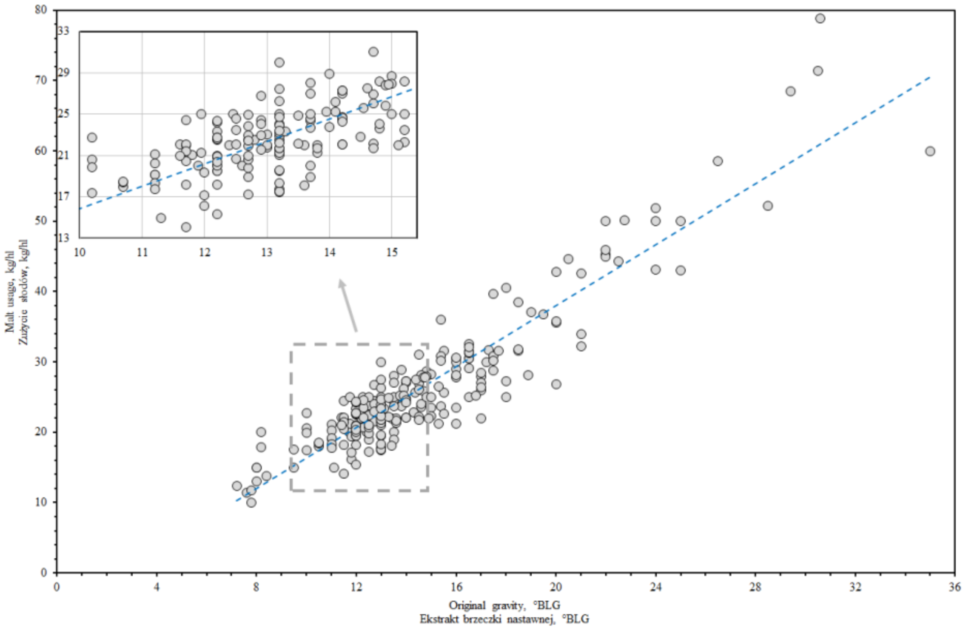


Fig. 1. The relationship between beer original gravity and malt usage (for 235 beer recipes)
Rys. 1. Zależność pomiędzy ekstraktem brzeczki nastawnej oraz zużyciem słodu (dla 235 receptur)

The main characteristic of BSG, associated with the characteristics of the mashing process, is the high moisture content, typically above 75 %, which, combined with the presence of polysaccharides, makes it a perishable material. Regarding dry mass composition, BSG is quite similar to various by-products from the food sector. Literature reports on BSG composition have been collected and summarized in Table 1. Its detailed composition may differ depending on the analysis method applied, source and malt used, mostly crop species. However, BSG is generally rich in fiber and proteins, with lower starch content, which is removed during mashing. As a result, the total carbohydrate content of BSG is lower compared to various plant-based materials, which may provide promising effects in terms of its application in the food sector.

Multiple works dealt with the BSG proteins and the determination of their composition [57, 69]. They revealed that the most abundant amino acids in BSG are glutamine, histidine, lysine and leucine, but their particular share differed between the analyzed samples. Irrespective of the amino acid composition, BSG should be considered a protein-rich by-product.

Table 1. Collected literature reports on the chemical composition of BSG
Tabela 1. Zebrane dane literaturowe dotyczące składu chemicznego młóta browarnianego (MB)

| Component / Składnik | Content [% of dry mass] / Zawartość [% suchej masy] | | | | | | |
|---|---|---|---|---|---|---|---|
| Cellulose / Celuloza | 25.4 | 16.8 | 22.2 | 21.9 | 12.0 | 21.7 | 17.0 |
| Hemicellulose / Hemiceluloza | 21.8 | 28.4 | 26.8 | 29.6 | 40.0 | 19.2 | 39.0 |
| Lignin / Lignina | 11.9 | 27.8 | 14.1 | 21.7 | 11.5 | 19.4 | 4.0 |
| Ash / Popiół | 2.4 | 4.6 | - | 1.2 | 3.3 | 4.2 | - |
| Protein / Białko | 24.0 | 15.3 | - | 24.6 | 14.2 | 24.7 | 24.0 |
| Fat / Tłuszcz | 10.6 | - | - | | 13.0 | | 6.0 |
| Reference / Cytowanie | [29] | [44] | [8] | [9] | [71] | [40] | [68] |

Except for the main components listed in Table 1, BSG is rich in antioxidants (mostly phenolics, but also flavonoids and tannins), micro- and macroelements, vitamins and melanoidins. Considering the first group, the most abundant are hydroxycinnamic and hydroxybenzoic acids, mainly ferulic, *p*-coumaric, sinapic, syringic and caffeic acids [17]. Cumulatively, they may account even for 2 wt % of BSG dry mass, which suggests the noticeable antioxidant activity of this by-product. However, their particular content and composition may differ depending on the beer recipe followed. It has already been reported [38, 42] that BSG richer in dark malt, especially the roasted one like roasted barley, chocolate or black malt, whose kilning temperature exceeds 200 °C, is characterized by phenolics content reduced by 50 %.

Table 2 presents the literature reports on the micro- and macroelements in BSG, which are essential, considering potential applications in the food sector. The content of particular elements differs between literature reports, which can be attributed to the origin of various BSG samples and is a typical phenomenon for plant-based materials [16, 61]. Moreover, the nutritional composition of BSG can differ depending on the parameters of water used in the brewing process, which impacts the extraction of particular compounds and elements to wort [54].

BSG is also a rich source of vitamins, especially group B, such as thiamine ($B_1$), riboflavin ($B_2$), niacin ($B_3$), pyridoxine ($B_6$), biotin ($B_7$), pantothenic ($B_5$) and folic ($B_9$) acids [16]. Moreover, BSG contains noticeable amounts of vitamin E, tocotrienols and tocopherols, which may act as antioxidants, anticarcinogenic and neuroprotective agents, and can beneficially reduce LDL cholesterol levels [50].

Table 2. Collected literature reports on BSG micro- and macroelement content
Tabela 2. Zebrane dane literaturowe dotyczące zawartości mikro- i makroelementów w młócie browarnianym

| Elements / Pierwiastki | Content [mg/kg dry mass] / Zawartość [mg/kg suchej masy] | | | | |
|---|---|---|---|---|---|
| Silicon / Krzem | 10 740 | - | 1 400 | 242 | 5 200 |
| Phosphorous / Fosfor | 5 186 | 6 000 | 4 600 | 1 977 | 9 600 |
| Calcium / Wapń | 3 515 | 3 600 | 2 200 | 1 039 | 4 800 |
| Magnesium / Magnez | 1 958 | 1 900 | 2 400 | 688 | 6 200 |
| Sulfur / Siarka | 1 980 | 2 900 | - | 8.5 | - |
| Potassium / Potas | 258 | 600 | 700 | - | - |
| Sodium / Sód | 309 | 173 | 100 | 60.5 | - |
| Iron / Żelazo | 193 | 155 | 100 | 63.5 | - |
| Zinc / Cynk | 178 | 82.1 | 100 | - | - |
| Aluminum / Glin | 36.0 | 81.2 | - | - | 3 200 |
| Manganese / Mangan | 51.4 | 40.9 | - | 9.5 | - |
| Cobalt / Kobalt | - | 17.8 | - | - | - |
| Copper / Miedź | 18.0 | 11.4 | - | 2.5 | - |
| Strontium / Stront | 12.7 | 10.4 | - | - | - |
| Iodine / Jod | - | 11.0 | - | - | - |
| Barium / Bar | 13.6 | 8.6 | - | - | - |
| Chromium / Chrom | 5.9 | <0.5 | - | - | - |
| Molybdenum / Molibden | - | 1.4 | - | - | - |
| Boron / Bor | - | 3.2 | - | - | - |
| Reference / Cytowanie | [43] | [40] | [69] | [27] | [73] |

*Applications in animal feeding*

Currently, BSG is applied mainly in animal feeding in the areas adjacent to breweries, which can be attributed to its high moisture content and perishable character. Breweries often sell BSG to local farmers, but such agreements aim to reduce utilization costs. Nevertheless, farmers take advantage of BSG composition, which can be utilized in animal feeding either in wet or previously dried form, and as silage. As mentioned above, BSG is very rich in protein and dietary fiber, which beneficially impacts animal nutrition. Belibasakis and Tsirgogianni [4] reported the results of the two-month experiment during which cows were fed a diet containing 16 wt% of wet BSG. As a result, the milk yield, milk fat content and milk fat yield increased from 21.7 to 24.8 kg/day, from 3.82 to 4.08 %, and from 0.83 to 1.01 kg/day, respectively. At the same time, cows' blood analysis revealed that blood plasma metabolites and electrolyte concentrations were not affected. Other studies performed for chickens [12], pigs [13] or fish [46] also pointed to the beneficial impact of BSG addition on animal feeding.

However, the economic analysis revealed that the profitability of the application of wet BSG as animal feed is rather limited to the neighboring areas of breweries [5]. However, the distance limit varies depending on the share of BSG in animal feed, the size of a brewery (amount of generated BSG) and the size of a farm (amount of required BSG), which determine the transportation costs.

*Applications in human feeding*

In the past, literature focused on extracting proteins or phenolics from BSG. These approaches have been well documented and described in multiple review works [7, 19, 24, 25, 34, 35, 64, 70, 75], therefore they will not be discussed in this work. Nevertheless, their results point to the promising potential of BSG extracts as food additives, mainly antioxidants [11, 37, 38, 62]. The present article focuses on applying BSG as a whole, aligning to a greater extent with the current pursuit of a Circular Economy, which is the element of the endless pathway to sustainability, existing to find a balance between economic, societal and environmental needs, considering the changing realities.

As mentioned above, BSG is rich in dietary fiber, which has already been reported to show a beneficial impact on blood cholesterol levels [72] or glycemic responses [63]. On the other hand, high dietary fiber content adversely impacts the rheological properties of dough, affecting the proofing and baking processes [33]. It points to the need for a compromise between the composition and processing of food products, which also affects profitability.

Table 3 summarizes the literature reports dealing with the application of BSG as a functional ingredient in various food products. In most cases, BSG was utilized as a substitute for the most commonly used wheat flour. Typically, wheat flour contains approximately 70 ÷ 76 wt % of carbohydrates, mainly starch, 10 ÷ 14 wt % of proteins, 1 ÷ 2 wt % of fats, and has a calorific value exceeding 340 kcal/100 g. Considering the composition of BSG presented in Table 1 and noticeable differences in the composition resulting from the abovementioned details on BSG generation, significant changes in the food product nutritional value have been noted.

When introduced, BSG increased the fiber content and reduced the amount of starch, which is removed during mashing, leading to a significantly lower calorific value [14, 15, 20, 66], even despite a noticeably higher fat content, whose calorific density is approximately twice as high as for carbohydrates. At the same time, the

Table 3. Summary of the literature reports on BSG application in food products with main conclusions
Tabela 3. Podsumowanie doniesień literaturowych związanych z zastosowaniem MB w produktach spożywczych oraz główne wnioski

| Food product / Produkt spożywczy | Main component / Główny składnik | BSG content, wt % / Zawartość MB, % mas | Conclusions / Wnioski | Reference Cytowanie |
|---|---|---|---|---|
| Flour / Mąka | Wheat flour Mąka pszenna | 100 | Fiber: 0.6 → 41.3 %, starch: 81.1 → 10.1 %, protein: 13.3 → 18.0 %, ash: 1.7 → 3.8 %, calorific value: 335.4 → 228.6 kcal/100 g. / Błonnik: 0,6 → 41,3 %, skrobia: 81,1 → 10,1 %, białka: 13,3 → 18,0 %, minerały: 1,7 → 3,8 %, kaloryczność: 335,4 → 228,6 kcal/100 g. | [15] |
| Composite flour / Mieszanka mąk | Wheat flour (amaranth flour, apple pomace flour) / Mąka pszenna (mąki z amarantusa i wytłoków jabłkowych) | 2.0-4.1 | Increasing BSG loading from 2.0 to 4.1 wt % (along with the variation of the share of other flour components). Fiber: 1.6 → 3.1 %, ash: 1.7 → 2.8 %. / Wzrost zawartości MB z 2,0 do 4,1 %mas. (z jednoczesną zmianą zawartości innych komponentów). Błonnik: 1,6 → 3,1 %, minerały: 1,7 → 2,8 %. | [3] |
| Bread / Chleb | Wheat flour / Mąka pszenna | 10 | Fiber: 2.6 → 4.9 %, carbohydrates: 72.5 → 65.1 %, protein: 11.3 → 15.4 %, ash: 2.2 → 3.2 %, calorific value: 360 → 341 kcal/100 g, sensory panel score: 80.8 → 70.0 %. / Błonnik: 2,6 → 4,9 %, węglowodany: 72,5 → 65,1 %, białka: 11,3 → 15,4 %, minerały: 2,2 → 3,2 %, kaloryczność: 360 → 341 kcal/100 g, ocena panelu sensorycznego: 80,8 → 70,0 %. | [20] |
| | | 25 | Fiber: 2.6 → 7.5 %, carbohydrates: 72.5 → 59.9 %, protein: 11.3 → 16.8 %, ash: 2.2 → 3.6 %, calorific value: 360 → 330 kcal/100 g, sensory panel score: 80.8 → 62.7 %. / Błonnik: 2,6 → 7,5 %, węglowodany: 72,5 → 59,9 %, białka: 11,3 → 16,8 %, minerały: 2,2 → 3,6 %, kaloryczność: 360 → 330 kcal/100 g, ocena panelu sensorycznego: 80,8 → 62,7 %. | |
| | Wheat flour / Mąka pszenna | 10 | Carbohydrates: 53.7 → 46.2 %, protein: 6.6 → 8.3 %, ash: 0.4 → 0.9 %, calorific value: 245 → 223 kcal/100 g, sensory panel score: 7.80 → 7.83. / Węglowodany: 53,7 → 46,2 %, białka: 6,6 → 8,3 %, minerały: 0,4 → 0,9 %, kaloryczność: 245 → 223 kcal/100 g, ocena panelu sensorycznego: 7,80 → 7,83. | [14] |
| | | 20 | Carbohydrates: 53.7 → 40.5 %, protein: 6.6 → 10.0 %, ash: 0.4 → 1.3 %, calorific value: 245 | |

| | | | | |
|---|---|---|---|---|
| | | | → 211 kcal/100 g, sensory panel score: 7.80 → 7.35. / Węglowodany: 53,7 → 40,5 %, białka: 6,6 → 10,0 %, minerały: 0,4 → 1,3 %, kaloryczność: 245 → 211 kcal/100 g, ocena panelu sensorycznego: 7,80 → 7,35. | |
| | Wholegrain wheat flour / Mąka pszenna pełnoziarnista | 9 | Fiber: 7.0 → 9.7 %, carbohydrates: 41.6 → 38.5 %, ash: 0.67 → 0.76 %, calorific value: 236.7 → 229.1 kcal/100 g. Hardness and chewiness: 142 and 81 %, higher than for control bread. / Błonnik: 7,0 → 9,7 %, węglowodany: 41,6 → 38,5 %, minerały: 0,67 → 0,76 %, kaloryczność: 236,7 → 229,1 kcal/100 g. Twardość i żujność: 142 i 81 % wyższe niż dla chleba kontrolnego. | [66] |
| Breadsticks / Paluszki | Wheat flour / Mąka pszenna | 15 | Starch: 62.5 → 54.5 %, protein: 14.3 → 15.2 %, ash: 2.6 → 3.3 %, fat: 0.3 → 0.8 %, sensory panel score: 7.80 → 7.35. Breadsticks containing BSG were darker, less crispy, and of lower baking volume. The breadsticks' quality was unchanged for up to 50 days of storage. / Skrobia: 62,5 → 54,5 %, białka: 14,3 → 15,2 %, minerały: 2,6 → 3,3 %, tłuszcze: 0,3 → 0,8 %, ocena panelu sensorycznego: 7,80 → 7,35. Paluszki zawierające MB były ciemniejsze, mniej chrupiące i o mniejszej objętości wypieku. Jakość paluszków pozostała niezmieniona przez 50 dni przechowywania. | [31] |
| | | 35 | Starch: 62.5 → 41.5 %, protein: 14.3 → 18.4 %, ash: 2.6 → 3.4 %, fat: 0.3 → 2.1 %, sensory panel score: 7.80 → 7.35. Breadsticks containing BSG were darker, less crispy and of lower baking volume. The breadstick quality was unchanged for up to 50 days of storage. / Skrobia: 62,5 → 41,5 %, białka: 14,3 → 18,4 %, minerały: 2,6 → 3,4 %, tłuszcze: 0,3 → 2,1 %, ocena panelu sensorycznego: 7,80 → 7,35. Paluszki zawierające MB były ciemniejsze, mniej chrupiące i o mniejszej objętości wypieku. Jakość paluszków pozostała niezmieniona przez 50 dni przechowywania. | |
| Batters / Panierka | Corn groats / Kasza kukurydziana | 10-30 | Increased BSG content resulted in more rounded extrudate fractions. The compacting factor indicated greater accuracy of coverage of products with batter, improving product quality. Zwiększenie zawartości MB skutkowało bardziej zaokrąglonym kształtem cząstek. Współczynnik zagęszczenia wskazywał na większą dokładność pokrycia produktów panierką, podnosząc jakość produktu. | [76] |
| Cookies / Ciastka | Wheat flour / Mąka pszenna | 15 | Fiber: 3.1 → 6.8 %, protein: 5.5 → 7.6 %, lightness: 79.3 → 73.2. The addition of BSG affected the hardness and chewiness of cookies, BSG content should be limited to 25 wt %. / | [52] |

| | | | | |
|---|---|---|---|---|
| | | | Błonnik: 3,1 → 6,8 %, białka: 5,5 → 7,6 %, jasność: 79,3 → 73,2. Dodatek MB negatywnie wpłynął na twardość i żujność ciastek, zawartość MB powinna być ograniczona do 25 % mas. | |
| | | 50 | Fiber: 3.1 → 15.6 %, protein: 5.5 → 9.7 %, lightness: 79.3 → 58.2. BSG addition affected the hardness and chewiness of cookies, BSG content should be limited to 25 wt %. / Błonnik: 3,1 → 15,6 %, białka: 5,5 → 9,7 %, jasność: 79,3 → 58,2. Dodatek MB negatywnie wpłynął na twardość i żujność ciastek, zawartość MB powinna być ograniczona do 25 % mas. | |
| | Wheat flour / Mąka pszenna | 20 | Protein: 5.9 → 7.9 %, ash: 1.1 → 1.4 %, fat: 16.2 → 16.4 %, total antioxidant activity (ABTS assay): 100.4 → 120.7 μM TE/g, total antioxidant activity (DPPH assay): 6.7 → 45.2 μM TE/g. The preparation of cookies containing BSGwas too time-consuming. Up to 20 wt % of BSG, sensory evaluation was similar to the control sample. 20 wt % of BSG reduced the glycemic index from 81.1 to 74.7. / Białka: 5,9 → 7,9 %, minerały: 1,1 → 1,4 %, tłuszcze: 16,2 → 16,4 %, całkowita aktywność antyoksydacyjna (test ABTS): 100,4 → 120,7 μM TE/g, całkowita aktywność antyoksydacyjna (test DPPH): 6,7 → 45,2 μM TE/g. Przygotowanie ciastek zawierających MB było zbyt czasochłonne. Do 20 % mas. MB, ocena sensoryczna była na poziomie próbki kontrolnej. 20 %mas. MB spowodowało obniżenie indeksu glikemicznego z 81,1 do 74,7. | [23] |
| | | 30 | Protein: 5.9 → 8.3 %, ash: 1.1 → 1.5 %, fat: 16.2 → 16.5 %, total antioxidant activity (ABTS assay): 100.4 → 129.3 μM TE/g, total antioxidant activity (DPPH assay): 6.7 → 55.2 μM TE/g. The preparation of cookies containing BSG was too time-consuming. Up to 20 wt % of BSG, sensory evaluation was similar to the control sample. 20 wt % of BSG reduced the glycemic index from 81.1 to 74.7. / Białka: 5,9 → 8,3 %, minerały: 1,1 → 1,5 %, tłuszcze: 16,2 → 16,5 %, całkowita aktywność antyoksydacyjna (test ABTS): 100,4 → 129,3 μM TE/g, całkowita aktywność antyoksydacyjna (test DPPH): 6,7 → 55,2 μM TE/g. Przygotowanie ciastek zawierających MB było zbyt czasochłonne. Do 20 % mas. MB, ocena sensoryczna była na poziomie próbki kontrolnej. 20 %mas. MB spowodowało obniżenie indeksu glikemicznego z 81,1 do 74,7. | |
| Pasta / Makaron | Yam starch / Skrobia z batata | 5 ÷ 15 | Approximately 9.6 wt % content of BSG increased protein, carbohydrate and fat content with acceptable physicochemical properties of pasta. / Wprowadzenie około 9,6 % mas. MB zwiększyło zawartość białka, węglowodanów i tłuszczu przy akceptowalnych właściwościach fizykochemicznych makaronu. | [60] |

| | | | | |
|---|---|---|---|---|
| | Durum wheat flour / Mąka pszenna durum | 10 | Fiber: 3.1 → 4.7 %, ash: 0.84 → 0.97 %, β-glucan: 0.21 → 0.31 %, total antioxidant activity: 46.9 → 51.6 mmol TEAC/kg. The noticeable browning of pasta was noted. Despite lower sensory panel score, 10 wt % of BSG provided the best compromise between technological performance, nutritional and sensorial aspects. / Błonnik: 3,1 → 4,7 %, minerały: 0,84 → 0,97 %, β-glukan: 0,21 → 0,31 %, całkowita aktywność antyoksydacyjna: 46,9 → 51,6 mmol TEAC/kg. Odnotowano wyraźne brązowienie makaronu. Pomimo niższej oceny panelu sensorycznego, 10 % mas. MB zapewniło najlepszy kompromis pomiędzy właściwościami technologicznymi, aspektami odżywczymi i sensorycznymi. | [47] |
| | | 20 | Fiber: 3.1 → 7.3 %, ash: 0.84 → 1.16 %, β-glucan: 0.21 → 0.39 %, total antioxidant activity: 46.9 → 56.0 mmol TEAC/kg. The noticeable browning of pasta was noted. / Błonnik: 3,1 → 7,3 %, minerały: 0,84 → 1,16 %, β-glukan: 0,21 → 0,39 %, całkowita aktywność antyoksydacyjna: 46,9 → 56,0 mmol TEAC/kg. Odnotowano wyraźne brązowienie makaronu. | |
| Extruded snacks / Wytłaczane przekąski | Maize flour / Mąka kukurydziana | 20 | Fiber: 4.7 → 14.5 %, starch: 64.8 → 55.4 %, protein: 11.8 → 15.8 %, fat: 1.5 → 3.1 %, total antioxidant activity: 13.1 → 9.5 mM Trolox equiv/g, lightness: 65.1 → 56.4. Specific mechanical energy required for extrusion was at a similar level. / Błonnik: 4,7 → 14,5 %, skrobia: 64,8 → 55,4 %, białka: 11,8 → 15,8 %, tłuszcze: 1,5 → 3,1 %, całkowita aktywność antyoksydacyjna: 13,1 → 9,5 mM Trolox equiv/g, jasność: 65,1 → 56,4. Jednostkowe zużycie energii wymaganej do wytłaczania było na podobnym poziomie. | [2] |
| | | 30 | Fiber: 4.7 → 20.0 %, starch: 64.8 → 48.2 %, protein: 11.8 → 19.1 %, fat: 1.5 → 3.5 %, total antioxidant activity: 13.1 → 10.9 mM Trolox equiv/g, lightness: 65.1 → 52.3. Specific mechanical energy required for extrusion was at a similar level. / Błonnik: 4,7 → 20,0 %, skrobia: 64,8 → 48,2 %, białka: 11,8 → 19,1 %, tłuszcze: 1,5 → 3,5 %, całkowita aktywność antyoksydacyjna: 13,1 → 10,9 mM Trolox equiv/g, lightness: 65,1 → 52,3. Jednostkowe zużycie energii wymaganej do wytłaczania było na podobnym poziomie. | |
| Frankfurters /Frankfurterki | Beef (BSG replaced starch) / Wołowina (młóto | 5 (<212, 212 ÷ 425, or 425 ÷ 850 | For different fraction: fiber: 0.0 → 3.9 ÷ 4.6 %, fat: 18.1 → 14.8 ÷ 15.9 %, hardness: 44.3 → 16.7 ÷ 32.2 N, chewiness: 24.6 → 13.1 ÷ 18.9 N·mm, sensory panel score: 7.6 → 5.5 ÷ 5.8. / Dla różnych frakcji: błonnik: 0,0 → 3,9 ÷ 4,6 %, tłuszcze: 18,1 → 14,8 ÷ 15,9 %, twardość: | [49] |

| | | | | |
|---|---|---|---|---|
| | zastępowało skrobie) | µm) | 44,3 → 16,7 ÷ 32,2 N, żujność: 24,6 → 13,1 ÷ 18,9 N·mm, ocean panelu sensorycznego: 7,6 → 5,5 ÷ 5,8. | |
| Yogurt / Jogurt | Cow's milk / Mleko krowie | 5 ÷ 20 | Adding BSG shortened the fermentation time and increased yogurt viscosity and shear stress. BSG provided the nutrients for the lactic acid bacteria survival during the storage and maintained the amount of lactic acid in yogurt during 14-day refrigerated storage. The 5 ÷ 10 % addition of BSG improved the yogurt quality, its acidity, rheological behavior and lactic acid bacteria growth. Even though 15 ÷ 20 % of BSG led to the same level of acidity and lactic acid bacteria and had the lowest syneresis, it diminished the flow performance of the yogurt. / Dodatek MB skrócił czas fermentacji, zwiększył lepkość i naprężenie ścinające jogurtu. MB dostarczało składników odżywczych dla przetrwania bakterii kwasu mlekowego podczas przechowywania i utrzymało ilość kwasu mlekowego w jogurcie podczas 14-dniowego przechowywania w lodówce. Dodatek 5 ÷ 10 % MB poprawił jakość jogurtu, jego kwasowość, właściwości reologiczne i wzrost bakterii kwasu mlekowego. Mimo że 15 ÷ 20 % MB generowało ten sam poziom kwasowości i bakterii kwasu mlekowego i miało najniższą synerezę, zmniejszyło wydajność przepływu jogurtu. | [45] |
| Crispy slices / Krakersy | Wheat flour / Mąka pszenna | 10 | Fiber: 6.2 → 11.9 %, starch: 57.4 → 56.3 %, protein: 12.7 → 13.5 %, fat: 0.6 → 0.8 %, crispiness index: 30.1 → 23.5. The sample showed sensory analysis scores similar to the control sample. / Błonnik: 6,2 → 11,9 %, skrobia: 57,4 → 56,3 %, białka: 12,7 → 13,5 %, tłuszcze: 0,6 → 0,8 %, indeks chrupkości: 30,1 → 23,5. Próbka wykazała wynik analizy sensorycznej na poziomie próbki kontrolnej. | [32] |
| | | 25 | Fiber: 6.2 → 20.1 %, starch: 57.4 → 44.2 %, protein: 12.7 → 14.6 %, fat: 0.6 → 1.5 %, crispiness index: 30.1 → 2.5. Sensory panel score was noticeably lower. / Błonnik: 6,2 → 20,1 %, skrobia: 57,4 → 44,2 %, białka: 12,7 → 14,6 %, tłuszcze: 0,6 → 1,5 %, indeks chrupkości: 30,1 → 2,5. Ocena panelu sensorycznego była znacząco obniżona. | |

content of proteins in the prepared food products was significantly higher after the substitution of conventional food ingredients, mainly flour, with BSG. Data provided in Table 1 indicates that the increase in protein content of the analyzed food products was proportional to the BSG content. Together with a substantial increase in ash content and antioxidant activity of the final food products, these features indicate that the incorporation of BSG can be a significant step towards the development of functional food.

At the same time, literature data points to the reduced acceptability of food products in terms of sensory characteristics caused by the introduction of BSG. Multiple reports indicated that sensory panels gave lower score for food containing BSG due to the darkening of products [2, 20, 31, 32, 47, 52], but considering appearance, more significant allegations related to the texture of products. It was more brittle due to the high fiber content of BSG and increased hardness [14, 23]. Aroma was also affected when BSG was incorporated, which was attributed to the increased amount of alcohols and aldehydes (mainly 3-methyl-1-butanol, 2-methyl-propanal and 3-methyl-butanal) among the volatile organic compounds emitted by food products [14, 32]. Most notably, the taste of food products was also affected, which, as showed by the literature data, was associated with the high fiber content of BSG compared to substituted components like wheat flour. The appearance of bitter taste was attributed to tannins [23], whose presence in BSG is entirely justified when lautering and filtration operations after mashing are correctly performed, and when the temperature of water added is not excessive.

## Conclusions, current limitations and future remarks

As mentioned above, currently, the central aspect related to the properties of BSG limiting its more comprehensive utilization is the perishable character attributed to the high moisture content. This issue increases transportation costs and shortens the shelf life of BSG. Moreover, high moisture content facilitates the proliferation of microorganisms and spoilage of BSG. As described by Ben-Hamed et al. [5], in the case of animal feeding, the profitability of BSG application is closely related to a distance from a brewery, e.g. due to the high moisture content of the by-product. Olawoye et al. [48] performed an economic analysis of cookie production using BSG as a primary raw material in Nigeria. They assumed a total capital cost of $1.39 million and a total production cost of $10.08 million per year when the plant operated for 330 days annually. The total revenue after tax was $1.63 million per year, which is mainly from the sales of cookies. The return on investment was 63 %, the single payback period and discounted payment period were 1.58 and 2.08 years, respectively, while the internal rate of return was 78.95 %. In this case, the plant's location was also chosen based on the BSG availability, which points to the essentiality of this aspect. Nevertheless, the analysis indicated significant profitability of the BSG application in manufacturing food products, providing promising insights. Moreover, using BSG in food product manufacturing could beneficially impact the profitability of beer production.

Except for the high moisture content of BSG, another aspect is associated with legislative issues. BSG as a waste material has limited application in the food sector. In Poland, BSG is classified in the Waste Catalogue under code 02 07 80 – Pomace; must and fermentation sludge; broths (*Wytłoki; osady moszczowe i pofermentacyjne; wywary*). This classification defines recycling and recovery procedures in the food sector. Brewers can provide BSG to entities authorized to treat waste, where BSG may be recycled or treated to recover organic substances that are not used as solvents (including composting and other biological transformation processes, gasification and pyrolysis). Farmers can also use BSG waste as a fertilizer (land treatment that benefits agriculture or improves the environment). The EU law allows the use of BSG as a feed material. According to Commission Regulation (EU) No 68/2013 of 16 January 2013 on the Catalogue of feed materials, brewers' spent (code 1.12.12) can be the source of crude protein in feed. The possibilities of using BSG in line with the current law in Poland and the EU are restricted. Therefore, the application of BSG in producing novel food products may need amendments to the regulations.

If BSG is considered a component of novel food for human or animal consumption, safety issues should be taken into account. Microbiological parameters mainly determine the quality of BSG as a raw material. If any of the ingredients used in the brewing process is contaminated or brewing equipment is unclean, it can be expected that BSG will be characterized with a lower quality, and it will not be accepted for food production. When all safety hazards are limited, also the contamination of BSG is limited. Robertson et al. [57] defined naturally-associated microflora of fresh BSG from seven breweries, and they concluded that immediately after lautering, BSG can be considered as a microbiological stable with $10^2 \div 10^3$ CFU $g^{-1}$. Due to the high water content and the microbiological hazards of BSG, its processing should be carried out as soon as possible after release in order to be used for human consumption. The overall quality of BSG is determined by further processing, limiting microbial activity, e.g. fast cooling down to room or refrigerator temperature, freezing or drying.

Moreover, literature reports often point to relatively low scores in the sensory evaluation of various food products containing high loadings of BSG or BSG-based flour [39]. On the other hand, developing BSG-based functional food with a beneficial composition and a clearly indicated, undeniably positive impact on human health could change human perception and enhance its attractiveness, reducing sensory barriers, as suggested by Combest and Warren [10].

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## MŁÓTO BROWARNIANE – JEDYNIE ODPAD CZY POTENCJALNY SKŁADNIK ŻYWNOŚCI FUNKCJONALNEJ?

S t r e s z c z e n i e

**Wprowadzenie.** Przemysł spożywczy generuje podczas produkcji duże ilości odpadów żywnościowych, które często nie są w pełni wykorzystywane. W zależności od rodzaju przemysłu produkowane są odpady żywnościowe o różnym składzie chemicznym i właściwościach fizykochemicznych. Ze względu na rosnące zainteresowanie społeczne dotyczące produkcji odpadów, ochrony środowiska, gospodarki o obiegu zamkniętym i wiedzy na temat składu chemicznego odpadów spożywczych, stają się one potencjalnymi surowcami w produkcji żywności jako produkty uboczne o wysokiej wartości odżywczej. **Wyniki i wnioski.** Głównym odpadem powstającym podczas produkcji piwa jest młóto browarniane (MB), stanowiące około 85 % wszystkich produktów ubocznych. Ze względu na niski koszt oraz znaczną zawartość białka, jest ono obecnie wykorzystywane w żywieniu zwierząt. Jednak wysoki poziom błonnika pokarmowego, minerałów i przeciwutleniaczy stwarza możliwość zastosowania MB nie tylko jako materiału do ekstrakcji związków bioaktywnych, ale także jako surowca w przetwórstwie żywności dla ludzi. Dlatego też niniejszy przegląd literaturowy dotyczy możliwości zastosowania MB w produkcji różnych produktów spożywczych o wartości dodanej oraz jego wpływu na właściwości chemiczne, fizykochemiczne i sensoryczne. Główną kwestią związaną z zastosowaniem MB w produktach spożywczych jest obniżenie oceny sensorycznej produktów ze względu na zmiany koloru, aromatu i tekstury. Jednak zwiększenie wartości odżywczej i korzystnych dla zdrowia efektów może zwiększyć atrakcyjność, zmniejszyć bariery sensoryczne i zwiększyć zainteresowanie produktami spożywczymi wytworzonymi z młóta browarnianego.

**Słowa kluczowe:** Młóto browarniane; piwo; zagospodarowanie odpadów; żywność funkcjonalna