Utilization of brewery wastes in food industry

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ABSTRACT

Beer is the most popular low-alcohol beverage consumed in large amounts in many countries each year. The brewing industry is an important global business with huge annual revenues. It is profitable and important for the economies of many countries around the world. The brewing process involves several steps, which lead to fermentation of sugars contained in malt and conversion thereof into alcohol and carbon dioxide by yeasts. Beer brewing generates substantial amounts of by-products. The three main brewing industry wastes include brewer’s spent grain, hot trub, and residual brewer’s yeast. Proper management of these wastes may bring economical benefits and help to protect the environment from pollution caused by their excessive accumulation. The disposal of these wastes is cumbersome for the producers, however they are suitable for reuse in the food industry. Given their composition, they can serve as a low-cost and highly nutritional source of feed and food additives. They also have a potential to be a cheap material for extraction of compounds valuable for the food industry and a component of media used in biotechnological processes aimed at production of compounds and enzymes relevant for the food industry.

INTRODUCTION

Beer is a fermented beverage known since ancient times. Currently, it is the fifth most frequently consumed drink on a global scale. Global beer consumption in 2018, in 170 major countries and regions, was approximately 1.8879 billion hektoliters (Kirin Holdings Company, 2019). As reported by Conway (2019), global beer production exceeded 1.94 billion hL in 2018, which makes brewing one of the industries with significant economic importance. Modern brewing is mainly a large-scale industry producing substantial quantities of beer and by-products. Beer production is divided into several successive operations: malting, milling, mashing, lautering, adding hops or hop extract and boiling the beer wort with these additives, disposal of spent hops and precipitated trub, cooling the wort and aeration, fermentation with yeasts, removal of yeast, conditioning (maturation, aging) and packaging (Fig. 1). The aim of the process is to convert grain-derived starch into simple sugars, extract these sugars, and ferment them with the use of yeast to produce a lightly carbonated beverage with low alcohol content. Such a big-scale production results in generation of large quantities of organic waste materials by the brewing industry. The
first and most abundant brewery by-product is formed after the mashing process. Residual “spent” grain is removed after the separation of the liquid produced during mashing (named wort). Another type of waste is generated after boiling the wort in the kettle. At this stage, thermal denaturation of the proteins takes place, which causes the precipitation of high molecular weight proteins (waste called hot trub). Hot trub, which contains spent hops, is then removed from the wort using a separator. Next, yeasts are added and the fermentation begins. After this step, most yeasts are removed (brewery spent yeast) from the young beer. Prior to packaging, beer is most often filtered through diatomaceous earth or cellulose filters to remove remaining yeast residues (Fig. 1) (Mathias, de Mello & Servulo, 2014; Young, 2019).

The brewery industry generates huge amounts of wastes, the management of which is economically troublesome. Their accumulation in the environment is an ecological issue as well. The increasing public concerns about environmental pollution have prompted the search for ways to reduce the production of industrial waste. The food industry is trying to find new applications that will change the traditional approach to ‘waste’ products and make them ‘co-products’ (Fărcaş et al., 2017). With their properties, by-products generated by the brewing industry have a potential to be applied as materials exploited in the food industry, but their use is still quite limited. Modern food science and technology aim to valorize food industry by-products for the production of chemicals, raw materials, and other value-added compounds (Helkar, Sahoo & Patil, 2016). Although studies focused on the reuse of brewery by-products are being conducted, there are no comprehensive review articles concerning all three types of brewery wastes showing its potential to be used in the food industry. This work is intended to summarize and disseminate research outcomes.
in this field. This will be particularly useful for brewers, food technologists, agricultural scientists, and some biotechnologists. The findings described have a practical nature through the possibility of being implemented. Knowledge of their potential may help to design new food and feed products from wastes or ways to recover functional components. The aim of this review was to summarize the possible utilization of the three main brewery wastes by the food industry and encourage search for new ways to exploit thereof.

Survey methodology
At the initial stage of designing the review, the research question was formulated. To ensure that a review in this area is needed, the research area was scanned. The focus was placed on literature reviews and other available articles in this field. This step has resulted in a conclusion that the greatest contribution to the subject matter that we have undertaken would be made by a scoping review, which will summarize and disseminate research findings. Next, the target audience that might be interested in the article was considered. Additionally, a search strategy was developed to identify studies that are relevant to the selected topic. Based on words directly related to the topic of utilization of brewery wastes in the food industry, such search terms as brewery wastes, brewer’s spent grain, hot trub, residual brewer’s yeast, possibilities of reuse of brewery by-products (in food, feed, and production of food additives) and products made of brewery wastes were selected. References were collected from the selected databases, including PubMed, Web of Science, and Google Scholar. To access proper articles and books, inclusion and exclusion criteria were established. Literature was selected based on the year of publication (the latest articles were selected where possible), the language of the article (publications in languages other than English and Polish were excluded), and the significance of results (studies that did not address this research question were excluded). Next, the selected articles were analyzed using the same approach to abstract information relevant to the topic from each article. Subsequently, data from the literature was used to discuss the topic of this review.

BREWING INDUSTRY WASTES
During beer production, three main types of by-products are generated, i.e. brewer’s spent grain, spent hops/hot trub, and residual brewer’s yeast (Fig. 1) (Mathias, de Mello & Servulo, 2014). They slightly differ between each other in some of the properties (composition, moisture, and ash content), but all of them can potentially be reused by the food industry. The chemical composition of brewery wastes can slightly vary depending on the type and quality of the ingredients used and the conditions prevailing during each step of the brewing process; nevertheless, they always have a high nutritional value. They are rich in carbohydrates, proteins, fibers, vitamins, minerals, and phenolic compounds and have high moisture content (since 1/5 of the water used in the brewing process is lost in the form of residues) (Santos et al., 2003; Olajire, 2012). This section outlines the general characteristics of the three main brewery wastes.

Brewer’s spent grain (BSG)
Brewer’s spent grain, which accounts for approx. 85% of all residues produced by the brewing industry, is the major waste generated during beer production (Aliyu & Bala,
BSG is formed in the mashing process and removed before the boiling step of the brewing process. This solid residue from wort production is composed of barley grain husks (Kerby & Vriesekoop, 2017). BSG is a heterogeneous material consisting of lignocellulosic biomass and is rich in proteins (20–30%), fiber (30–70%), lipids, vitamins, and minerals. It contains ca. 12–28% of lignin, 12–25% of cellulose, and 28% of non-cellulosic polysaccharides, mainly arabinoxylans (Mussatto & Roberto, 2005; Lynch, Steffen & Arendt, 2016). The chemical composition of BSG reported in the literature was previously determined and reviewed by Aliyu & Bala (2011). The amount of BSG produced is ca. 14 kg/hL wort, with moisture content between 75% and 90% (Robertson et al., 2010). The ash content in brewer’s spent grain is in the range of 2.3–7.9% (Aliyu & Bala, 2011). It has been evidenced that BSG contains vitamins, minerals, and many amino acids. This by-product is also rich in oligo- and polysaccharides and phenolic compounds (Cooray, Lee & Chen, 2017). Among phenolic acids, BSG has the highest content of ferulic (1860–1948 mg/g) and p-coumaric (565–794 mg g\(^{-1}\)) acids as well as sinapic (Stefanello et al., 2018), caffeic, and syringic acids (Moreira et al., 2013).

**Hot trub**

Another waste generated during manufacture of beer is hot trub. Hot trub is a term referring to sediments formed in the brewing process during wort boiling. The size of hot trub particles is estimated to be in the range of 30 to 80 \(\mu\)m (Kühbeck, Back & Krottenthaler, 2006; Mathias et al., 2015). This insoluble precipitate mainly consists of colloidal proteins coagulated during wort boiling, which form complexes with polyphenols that naturally occur in the wort. It also contains complex carbohydrates, lipids, minerals, tannins, hop residues, and smaller malt particles (Hough et al., 1982). In general, these residues, representing 0.2–0.4% of the wort volume, are removed as a by-product during the wort production process before fermentation. However, in some cases, hops can be added and removed at different stages of the brewing process. Approximately 85% of hops used for beer production are removed as a by-product (Huige, 2006).

Hot trub has high moisture content (between 80% and 90%), approx. 15-20% dry matter content, and low ash content (approx. 2–5%) (Huige, 2006). It mainly consists of high-molecular-mass proteins; however, it has been reported to have a high concentration of carbon, which is a result of the high amount of reducing sugars (20%) in this residue (Mathias et al., 2015). The protein content in hot trub depends on several factors and may vary between breweries, although the average values range between 40 and 70% (Barchet, 1993; Kühbeck, Back & Krottenthaler, 2006). Hot trub exhibits a low C/N ratio (6.3).

The formation of trub is a highly desirable process. It is important to remove a considerable amount of the main trub components (polyphenols and soluble proteins) during the brewing process, as they can react and form insoluble complexes. They are visible as precipitates in beer, and are undesirable in pale filtered beers, which are expected to be bright and clear (Hough et al., 1982).

**Brewer’s spent yeast (BSY)**

Brewer’s residual yeast is the second largest by-product from the brewing process (Huige, 2006). This slurry residue accounts for maximum 15% of total by-products generated...
during the brewing process (Kerby & Vriesekoop, 2017). BSY is recovered by sedimentation before full maturation of beer at the final stage of the second fermentation and maturation (Olajire, 2012). The excess yeast can be collected and re-used maximum six times. Saccharomyces cerevisiae yeast added at the beginning of fermentation during this process can undergo many divisions, which results in a considerably increased yeast biomass. The yeast growth rate depends on the fermentation conditions in the brewery. BSY generates beer losses in a range from 1.5 to 3% of the total volume of produced beer (Fillaudeau, Blanpain-Avet & Daufin, 2006). It was established that the average volume of residual yeast obtained from lager fermentation is 0.6–0.8 lb/bbl (2.7 kg/m³) of the final volume of beer (Huige, 2006). Yeasts are single-cell organisms containing proteins (49%), carbohydrates (40%), minerals and vitamins (7%), and lipids (4%). Brewer’s residual yeast exhibit high moisture content, i.e., approximately 74%–86%. Depending on the source, the mineral residue (ash) value for spent yeast is in the range of 2%–8.5% and its dry matter content is about 10–16% (Mathias et al., 2015). It has been reported that the mineral composition of S. cerevisiae may vary at different stages of the fermentation process. It also changes with subsequent reuses. Young yeast that has not been exploited many times is richer in phosphate and, hence, has greater ash content. BSY is also rich in polyphenolic compounds and B-group vitamins (mainly B1, B2, B3, B6, and B8) (Podpora et al., 2016). Analyses have revealed that brewer’s residual yeast exhibits high carbon content, with a value between 45% and 47% of yeast dry matter. The carbon/nitrogen ratio in this residue is 5.1–5.8 (Mathias et al., 2015).

APPLICATIONS OF BREWERY BY-PRODUCTS IN THE FOOD INDUSTRY

The brewery wastes discussed are used in various branches of the food industry, mainly as a feed additive and food ingredient. They can also serve as raw material for extraction of compounds used in the food industry or can be applied in biotechnological processes in which food industry additives are obtained.

Brewery industry by-products as animal feed

Among the by-products of the brewing industry, BSG is most often sold as animal feed due to its properties and content of essential nitrogen-containing nutrients. It is used in a wet or dry final form as feed for livestock, poultry, pigs, goats, and fish (Dhiman, Bingham & Radloff, 2003; Mussato, 2006). Wet spent grains can serve as cake for ruminants, whereas dry SG is often used as feed for monogastric animals. The high moisture content makes it easily digestible to livestock (Olajire, 2012; Kerby & Vriesekoop, 2017). It has been demonstrated that sun-dried BSG can be included into pigs’ diet in a dose between 17% and 25% to improve the profitability of production (Amoah et al., 2017). Dry BSG also represents an alternative protein source for ruminants and can replace soybean. It is cheaper, but simultaneously has a comparable nutritional value (Faccenda et al., 2017). BSG can provide ruminants with all essential amino acids when administered with cheap nitrogen sources. It has been shown that up to 75% of soybean can be replaced by BSG in feed for lactating cows. In this amount, it increases digestibility and milk production (Faccenda et al., 2017).
BSG was found to have a positive influence on the production efficiency in cattle, without affecting fertility. It improves the milk yield and composition and does not negatively influence blood components of dairy cows or dry matter intake (Belibasakis & Tsirgogianni, 1996; Chiou et al., 1998). Addition of BGS as feed for lactating cows increases the fat and protein content in milk (West, Ely & Martin, 1994; De Souza et al., 2016). BSG addition (at the level of 35%) to the lamb diet was found to exert a positive effect on their growth performance (higher body weight and daily gains). Moreover, it was shown to improve the quality of their meat. The meat exhibited lower fattiness and increased levels of linoleic cis-9 and trans-11 PUFA acids. These results indicate that BSG can be used as low-cost feed for lambs, which additionally improves meat health benefits (Radzik-Rant et al., 2018). The effect of a diet supplemented with brewery waste on the growth of fish was investigated as well. BSG was used at the levels of 10–40% to replace rice bran in the diet of catla (Catla catla), rohu (Labeo rohita), and mrigal (Cirrhina mrigala). BSG was shown to exert a positive effect on the absorption and utilization of feed. The body weight gain upon administration of the diet supplemented with 30% BSG was observed in the catla and rohu, but not in the mrigal. Therefore, the studies revealed that BSG addition to the fish diet contributed to better growth performance, although the results depended on the fish species. Improved growth performance was also observed in carps fed on BSG-containing diets, which was associated with the presence of essential amino acids in this waste (Kaur & Saxena, 2004).

Some studies investigated the effects of incorporation of sorghum-barley brewers’ spent grain (SBBSG) into poultry diet. It was shown that up to 16% SBBSG can be safely used in poultry feed since it had no adverse effects on broiler performance and health (it did not influence the blood profile or body weight gain of the broilers). Moreover, it was found to improve the feed conversion efficiency (Nortey, Frimpong & Naazie, 2018).

Despite the advantages of the addition of BSG as animal feed, its use is still limited, which is mainly related to problems with storage of the material. The high moisture content of this residue makes it susceptible to microbial growth in the usual environmental conditions prevailing on farms (Stoiceska et al., 2008). Within few days after production, wet grain can undergo molding and spoilage; therefore, preservation is a key factor in the utilization of this by-product. Wet BSG can be preserved by e.g., drying with solar radiation and ensiling (alone or with other dry forages) (Chanie & Fievez, 2017).

Another brewery waste, hot trub, is used as a feed ingredient much less frequently than BGS. Spent hops present in this waste have high fiber content, but also contribute to an unpleasant flavor, which makes hot trub impracticable for direct use in feed. According to some sources, hot trub is not used as animal feed due to the bitterness caused by hops (O’Rourke, 1994). Nonetheless, other feeding experiments with application of products containing a dried trub-yeast mixture have shown that this combination can be used in dried protein feed preparations and, despite the bitterness, the yeast-trub mixture was acceptable as pigs’ feed (Rub & Meyer-Pittroff, 2003).

Spent yeast is used in animal food not only in combination with hot trub. Surplus yeast is often sold to farmers, mostly in a wet form, as an inexpensive animal feed additive. The high digestibility of yeast was confirmed in animals such as rats, pigs, and salmon (Øverland et al., 2020).
et al., 2013). This residue is a rich source of proteins, vitamins (mainly B group), and minerals (especially phosphorus) that can be used in animal diets (Stone, 2006; Crawshaw, 2004). This brewing by-product was reported as a feed additive for fish, horses, ruminants, poultry, and swine (Ferreira et al., 2010; Tacon, Metian & Hasan, 2009; Crawshaw, 2004; Hertrampf & Piedad-Pascual, 2000). BSY can be used as feed in a fresh, liquid, or dried form. Before administration to animals, yeasts have to be inactivated by heat treatment or by addition of organic acids. It is indispensable to prevent fermentation of this residue after consumption by animals, as it can induce gastro-intestinal problems in pigs (Crawshaw, 2004). Supplements containing brewer’s spent yeast mixed with spent grain were found to positively influence the productive (increased egg production and quality) and reproductive (increased effectiveness of fertilization and hatchability) efficiency inbreeding turkeys and hens. BSY can also replace soya in diets for pigs and sows, enriching the feed with essentials amino acids (Levic, Djuragic & Sredanovic, 2010).

### Food ingredients or additives

It has been evidenced that BSG has a desirable nutritional value for the human diet. The major BSG components, i.e. fiber and proteins, are essential constituents of the human diet and can improve the value of food products. Moreover, the addition of BSG enriches food products with additional beneficial features. It enhance the aroma binding properties and has a positive effect on gelling and emulsifying potential. Since the ingredients used in the brewing process are approved for human consumption, this by-product can be safely applied for the development of new food products, which receive full health-related regulatory approval. Although currently it is not used in large-scale production of food, BSG can be added as a low-cost constituent of food intended for human consumption (Table 1) (Fârcăș et al., 2017; Thomas & Rahman, 2006).

Due to the high dietary fiber content, BSG-enriched food may provide some health benefits, such as prevention of certain chronic diseases (coronary heart disease, cancer, diabetes, and gastrointestinal disorders) (Stojceska et al., 2008). The consumption of BSG favorably influences the digestive system, reduces total lipid and cholesterol levels, and can reduce the amount of synthetic antioxidants added to products (Choi et al., 2014; Aliyu & Bala, 2011; Özvural et al., 2009). Addition of BSG enriches bread and pastries with fiber, protein, lipids, and minerals and adds a novel pleasant flavor and good organoleptic attributes (Öztürk et al., 2002). BSG can also be processed into flour. Numerous studies have shown that BSG can be incorporated into flour used for production of many foodstuffs, such as bread, waffles, cookies, pancakes, tortillas, pasta, and breakfast cereals (Waters et al., 2012) (Table 1). BSG is often used to make Spent Grain Bread. Its addition enhances the nutritional value of bread and allows full utilization of the nutritional and taste properties of malt used for beer production. The type of grain used can also be matched to the style of baked bread (for example, the BSG from Pilsner can enrich a light sandwich loaf, while the grain from an imperial stout can be suitable for dark pumpernickel) (Carpenter, 2014).

Studies have revealed that BSG addition to wheat flour bread increases the fiber amount and alters the fat content in the product. Incorporation of BSG combined with the use of appropriate enzymes extends the shelf life of bread and improves such properties as texture.
Table 1  Developed food products utilizing BGS and BSY as ingredients / additives.

| Food products incorporating brewer’s spent grain | Reference |
|-----------------------------------------------|-----------|
| Wheat bread | Plessas et al. (2007) |
| Brewer’s spent grain bread | Stojceska & Ainsworth, 2008; Ktenioudaki et al. (2015) and Steinmacher et al. (2012) |
| Spent grain ciabatta | Cina (2015) |
| Wheat dough supplemented with BSG | Ktenioudaki, O’Shea & Gallagher (2013b) |
| Breadsticks | Ktenioudaki et al. (2012) |
| Baked snacks (crispy-slices) | Ktenioudaki et al. (2013a) |
| Whole grain pizza crust | Combost & Warren (2018) |
| Whole wheat bagel | Combost & Warren (2018) |
| Whole wheat muffin | Combost & Warren (2018) |
| Doughnuts | Lynch, Steffen & Arendt (2016) |
| Brownies | Lynch, Steffen & Arendt (2016) |
| Cookies | Kissell, Prentice & Lindsay (1979) |
| Puffed snacks | ReGrained Company (2020) |
| Chickpea based snack | Ainsworth et al. (2007) |
| Ready-to-eat snacks | Stojceska et al. (2008) and Stojceska et al. (2009) |
| Bars | ReGrained Company (2020) |
| Waffles | Brooklyn Brew Shop (2017) |
| Pancakes | Făraş et al. (2017) |
| Tortillas | Combost & Warren (2018) |
| Pasta | Cappa & Alamprese (2017) and Sobukola, Babajide & Ogunsade (2013) |
| Breakfast cereals | Făraş et al. (2014) |
| Germinated barley foodstuff (GBF, protein-rich and fibrous foodstuff) | Kanauchi, Mitsuyama & Araki (2001) |
| Beef frankfurters | Özvural et al. (2009) |
| Smoked sausages | Nagy et al. (2017) |
| Chicken sausages | Choi et al. (2014) |
| Chicken patties | Kim et al. (2013) |
| Spent grain cheddar scones | Brooklyn Brew Shop (2016) |
| Vegan Burgers | Rebekah (2013) |

**Products with brewer’s spent yeast as food additive**

| Product | Reference |
|---------|-----------|
| Mayonnaise with β-glucan from BSY as a fat replacer | Worrasinchai et al. (2006) |
| Bread | Martins et al. (2015) |
| Vegan cake | Coldea et al. (2017) |
| Cooked ham with 1% BSY extract | Pancrazio et al. (2016) |
| French salad dressing with mannoprotein from BSY | Melo et al. (2015) |
| Meat substitutes | Gibson & Dwivedi (1970) |
| Carrot and beetroot juice with BSY autolysate | Rakin, Baras & Vukasnovic (2004) and Rakin et al. (2007) |

and loaf volume (Stojceska et al., 2008). Addition of BSG flour to bakery products was shown to result in enhanced water holding capacity and texture of the products and slightly increase their sweetness (Waters et al., 2012; Ktenioudaki, O’Shea & Gallagher, 2013b). BSG was also tested as an ingredient of breadsticks. It significantly increased the dietary fiber
and protein content in this product and modified its baking properties by influencing the texture and structure. The breadsticks obtained were darker and less crispy and had a lower baking volume (Ktenioudaki et al., 2013a). Moreover, BSG-containing flour (at the level between 5 and 60%) was used as an ingredient of cookies. Incorporation of 40% of BSG flour contributed to maintenance of appropriate physical quality of the cookies and, simultaneously, significantly enriched this product with N sources and fiber. BSG has also been examined as an ingredient of ready-to-eat snacks and extruded snack food. BSG incorporated into the formulation mix at levels ranging from 10 to 30% had a positive effect on textural and functional properties and, as previously, increased the crude protein and fiber content. Partial replacement of maize flour with BSG (at levels ranging from 10 to 30%) in chickpea snacks increased the protein, fat, and fiber content in the product (Stojceska et al., 2008).

BSG can also be used as a beneficial adjunct to meat products, as it can replace animal protein or/and enrich these products with dietary fiber. There are reports on the utilization of brewer’s spent grain in the production of low-fat beef Frankfurters, smoked sausages, and reduced-fat chicken sausages (Table 1) (Özvural et al., 2009; Nagy et al., 2017; Choi et al., 2014). Dietary fiber extracts from BSG were also used to prepare patties from chicken breast and pork back fat. The studies revealed that 3% of BSG dietary fiber extract could be applied as a source of dietary fiber for enhancing the quality characteristics of meat patties (Kim et al., 2013). Brewer’s spent grain addition has no negative effect on the quality characteristics of produced meat products, but increases the health-promoting properties of food.

Spent yeast can also be applied for production of functional food ingredients (Table 1). This by-product contains many valuable and bioactive substances that are important for human nutrition (Ferreira et al., 2010). The use of this residue is limited by its strong bitter taste resulting from the presence of hops in boiled wort, although there are methods for removal of the taste (Mathias et al., 2017). Given its high mineral content, BSY can bring beneficial effects in other branches of the food industry, including confectionery, dairy industry, and production of beverages, such as juices and mead. BSY has been successfully applied in the bakery industry for production of flour (Rakowska et al., 2017). Addition of BSY to foodstuffs has been found to be beneficial, since it exhibits prebiotic properties (Borchani et al., 2016). BSY is an important source of proteins and essential amino acids. It can be used to formulate new food products and food supplements rich in B-complex vitamins, minerals (selenium, chromium), and polyphenolic compounds with antioxidant activity (Coldea et al., 2017; Podpora et al., 2016). BSY proteins can replace soy proteins as a snack food ingredient, and their higher digestibility is an additional advantage (Ferreira et al., 2010). The by-product was also used for fortification of vegan cake with increased protein, lipid, and carbohydrate content (Coldea et al., 2017). Food products containing BSG and BSY as an additive are summarized in Table 1.

Among brewery wastes, hot trub is the least frequently used in the food industry because of the bitterness originating from its ingredients. However, Saraiva et al. (2019) has developed an extraction process to reduce the bitterness of its taste while maintaining and even improving its characteristics. Hot trub with changed composition and functionality
can be used in the food industry for enrichment of fat-rich products or as an alternative source of vegetable protein (Saraiva et al., 2019).

**Extraction of bioactive compounds**

Brewery wastes can be used for recovery of some bioactive compounds, which can be further used as functional food ingredients (Fârcas et al., 2017). Some components of BSG, such as arabinoxylans and phenolic compounds, are interesting compounds for application in the food industry due to their properties and potential health benefits (Severini et al., 2015).

BSG residues are rich in phenolic acids, especially ferulic and p-coumaric acids, which are contained in the husk and cell wall of grain used for the brewing process and remain in this by-product (Stefanello et al., 2018; Bartolomé, Faulds & Williamson, 1997). Hence, BSG can potentially serve as an inexpensive source for extraction of these valuable compounds. Many studies have revealed that phenolic acids can be extracted from BSG. The most commonly applied methods consist in liquid-liquid or liquid-solid extraction (with such solvents as methanol and ethyl acetate), acid hydrolysis, and saponification (with NaOH) (Stalikas, 2007; McCarthy et al., 2013). Some researchers have tested the efficiency of novel extraction techniques for this purpose, such as the rapid microwave-assisted derivatization process (Athanasiou et al., 2007).

Ferulic acid (4-hydroxy-3-methoxy-cinnamic acid) is a phenolic acid with a variety of potential applications as a natural antioxidant, photoprotectant, food flavor precursor, and food preservative/antimicrobial and anti-inflammatory agent. p-Coumaric acid (4-hydroxycinnamic acid) can serve as a chemoprotectant and antioxidant (Bartolomé et al., 2002; Faulds, Sancho & Bartolomé, 2002). Ferulic acid was successfully extracted from BSG via alkaline hydrolysis, with a yield of 0.3% (Bartolomé, Faulds & Williamson, 1997; Aliyu & Bala, 2011). Studies have revealed that the amount of ferulic acid released from BSG can be increased (3.3%) by application of esterase from Aspergillus niger or xylanase and esterase secreted by Trichoderma viride growing on BSG. An increase in the content of ferulic acid obtained from BCG was also observed when crude Fusarium oxysporum was used (Xiros et al., 2009). It has also been reported that β-glucanase from Humicola insolens can effectively release available ferulic acid from BSG (Faulds, Sancho & Bartolomé, 2002).

It has been shown that polyphenols and flavonoids can be extracted from BSG using supercritical CO₂. This method coupled with further microencapsulation of these compounds masks their unwanted bitter taste in food products fortified with these bioactive ingredients. Moreover, this method preserves the stability of polyphenols derived from BSG. Microencapsulation not only prevents degradation of bioactive compounds derived from BSG, but is also used to minimize the unpleasant sensorial properties and appearance of this by-product. Production of BSG extracts and microencapsulation make it more attractive for use in human food products while maintaining its desirable properties. Microencapsulated polyphenols obtained with this method were applied as an additive to fish burgers. The product was richer in phenolic compounds and flavonoids than the control sample and exhibited higher antioxidant activity, which makes BSG an attractive food supplement (Spinelli, Conte & Del Nobile, 2016).
BSG has also been used for extraction of arabinoxylans and proteins in an integrated process of sequential extraction of proteins and arabinoxylans from BSG with increasing concentrations of alkali (KOH or NaOH). This extraction process is characterized by good efficiency, i.e., 82–85% of total proteins and 66–73% of total AX (Vieira et al., 2014), and the products obtained can be subsequently used as functional food ingredients (Rosicka et al., 2015). With its properties, arabinoxylan can be used as a film-forming and surface active agent or cryostabilizer in food products. It is used in the food industry, as it can influence the water-holding capacity of food and dough starch retrogradation and can improve the quality and properties of bread (Cui, Wu & Ding, 2013). Moreover, BSG has been tested as a potential raw material for production of cellulose nanofibres, which are applied in the food industry, for example as emulsion/dispersant agents (Klemm et al., 2011).

Since it is rich in proteins (74–78% of malt protein remains insoluble in the BSG), BSG can be potentially used as a healthy functional food, similarly to whey protein. Essential amino acids constitute approximately 30% of the total BSG protein content (Fárcas et al., 2017). BSG usually contains large amounts of lysine, leucine, phenylalanine, isoleucine, threonine, and tryptophan, although the amino acid profiles of BSG may vary significantly, depending on the type of malt used in the brewing process (Waters et al., 2012). However, BSG proteins are not widely used in food products due to their insolubility (Fárcas et al., 2017). It has been shown that the insoluble protein fraction obtained from BSG can be used as a substrate for production of hydrolysates, which can be incorporated into food products (Celus, Brijs & Delcour, 2007; Vieira et al., 2014). Protein hydrolysates obtained from BSG exhibit various biological properties desirable in the food industry, e.g. emulsifying, antimicrobial, anti-inflammatory, and immunomodulatory activity (Crowley et al., 2015; McCarthy et al., 2013).

Spent hops are another by-product of the brewing industry used for extraction of useful compounds. It has been reported that this waste can be a source of compounds used for protection of stored food. Essential oils from spent hops were characterized after extraction using hydrodistillation. Their yield reached 0.11% of dry weight of the material. The main essential oils obtained from this by-product (myrcene, α-humulene, and β-caryophyllene) exhibit repellent activity and represent an eco-friendly and low-cost alternative to synthetic insect pest repellents used for protection of stored food-stuff (Bedini et al., 2015).

Due to its high moisture content and chemical composition, post-fermentation yeast biomass is vulnerable to rapid degradation, which makes the storage of BSY without previous preservation difficult. However, BSY can be successfully used as a source of food-grade yeast extracts (Ravishankar, 2016). Furthermore, hydrolyzed BSY can potentially yield a raw material for use in the food industry. This substrate derived from BSY has a potential to be applied in the wine industry as a fermentation-activating compound. It is also possible to use this raw material as a source of bioactive peptides. These health-stimulating compounds introduced into food support the human organism in removal of free radicals due to their anti-oxidant properties (Podpora et al., 2016).

The production of autolysates from BSY is attractive to manufacturers, since it brings high profits from the use of inexpensive raw materials for the production of value-added...
compounds. A process of cell lysis induced by saponin action, which is a simple and low-cost procedure, has been developed. It provides pro-health ingredients for functional foods and beverages (Berlowska et al., 2017). Yeast extracts obtained from BSY by autolysis vary in the free amino acids content (depending on the strain used) and can contain peptides with different molecular weights. For this reason, these various yeast extracts can be adapted to specific nutritional needs as an additive for functional foods and dietary supplements. These extracts leave a bitter aftertaste, which is mainly a result of the high content of free glutamic acid released from proteins during hydrolysis. This can be an advantage during creation of new functional foods with this particular taste profile (Podpora et al., 2016).

Yeast extracts obtained from BSY may serve as natural flavor enhancers. A combination of compounds contained in the extracts, such as 5-nucleotides, peptides, and amino acids (especially glutamic acid), is responsible for improving the flavor of food products and spice mixtures. This safe ingredient can potentially replace glutamates and protein hydrolysates that are commonly added to processed foods (Ferreira et al., 2010; Podpora et al., 2016). Yeast extract can also serve as a source of peptides and free amino acids included in functional foods. However, the amount of yeast extract obtained from BSY that can be used in food is limited by its sensory quality (Coldea et al., 2017).

Yeast extracts from BSY have been found to be strong antioxidants, since BSY exhibits high antioxidant activity (22.18–32.73 mMol TEAC/100 ml) due to the presence of polyphenolic compounds (Podpora et al., 2016). These substances are absorbed by yeasts from the external medium, which in the case of beer brewing is rich in phenolic and polyphenolic compounds derived from BSG and hot trub (Vieira et al., 2016). Substances with antioxidant activity are used in food, since they can prevent or delay some types of cell damage caused by the oxidation of biologically relevant molecules (Shahidi & Ambigaipalan, 2015). Inclusion of antioxidants into diet can lower the risk of development of certain diseases (cancer, cardiovascular and neurodegenerative diseases) (Huang, 2018).

The use of enzymatic hydrolysis and autolysis processes enables to obtain from BSY fractions that can be subjected to selective membrane filtration. It allows to recover four fractions which exhibit different molecular weights (with protein and sugar contents between 30-69% and 20-48%, respectively). This process yields nutritional ingredients extracted from BSY (protein, minerals, and carbohydrates), which can be incorporated into dietary products. These compounds are also useful for the food industry because of their mineral content (they are rich in sodium and potassium) and amino acids content (high level of glutamine, glutamic acid, and alanine) (Amorim et al., 2016).

BSY contains compounds that are valuable for the food industry, e.g. nucleic acids and vitamin D, which can be extracted from yeast (Tacon, 2015; Hertrampf & Piedad-Pascual, 2000). BSY is an inexpensive source of a raw material used for the enrichment with D2 (ergocalciferol) from the precursor ergosterol. Vitamin D2 derived from yeasts is a source of vitamin D, which can be applied as a dietary supplement in vegan food products (Metzger, Scholl & Barnes, 2012). Since BSY contains approximately 10% of nucleic acids, it is an excellent source for large-scale production of the aforementioned 5’-nucleotides. They are used in the food industry as taste and scent enhancers e.g. in soups, bouillons, and
Gravies. They are used in small amounts and can replace beef extract, which is currently widely applied as a flavor enhancer (El-Aleem et al., 2017).

Brewer’s spent yeasts are an important source of some valuable saccharides with a wide variety of molecular weights, such as β-glucans or mono-, di-, and oligosaccharides (e.g. trehalose and mannans). Glucan is able to bind water and has therefore been successfully used in the food industry as a water retention additive, thickening agent, etc (Krapan et al., 2009). In recent years, β-glucans have drawn researchers’ attention due to their pro-health properties (Podpora et al., 2016; Rakowska et al., 2017). β-glucan obtained from BSY has been reported to exhibit multi-directional biological activity. This compound improves the immunological system of humans and other animals, exhibits prebiotic and antioxidant activity, and positively influences blood lipid content (Rakowska et al., 2017; Otero et al., 2011). These properties make glucans attractive supplements for functional food, and BSY is a good source for extraction of this compound (Waszkiewicz-Robak, Karwowska & Swiderski, 2005).

Another potential application of BSY can be the production of trehalose, which is synthesized by yeasts during fermentation (Mahmud, Hirasawa & Shimizu, 2010; Benaroudj, Lee & Goldberg, 2001; Rúa et al., 2008). It has been reported that it can be extracted from BSY using high-intensity pulsed electric fields (PEF) (efficiency 103.15 g/s). Trehalose is a highly stable disaccharide composed of two glucose molecules. It is widely used in the food industry as a food additive (Jin et al., 2011). Trehalose is known to be a good bio-protectant of biomolecules against freezing. This property makes it an excellent supplement for foods that undergo the freezing and drying process (Otero et al., 2011). It is also used to improve the texture of food, release food flavor, and stabilize proteins contained in food. It is less sweet than sucrose (45% of its sweetness). Due to its humectant activity, trehalose is added to a wide variety of products, such as confectionery, bread, ice creams, and soft drinks. Crude extracts from BSY have also been found to be a source of invertase, i.e., an enzyme converting sucrose and polysaccharides to fructose and glucose (De León-González et al., 2016). Invertases are used in the food industry, mainly in confectionery, as a catalytic agent in production of artificial sweeteners (Veana et al., 2018).

**Application of brewery wastes in other branches of the food industry**

BSG derived from grain is rich in arabinoxylan and ligninocellulose, i.e. materials with high content of polysaccharides. These compounds can be subjected to hydrolysis (enzymatic, acidic, or hydrothermal) and degraded into their constituents. As a result of hydrolysis, glucose can be obtained from cellulose, whereas hemicellulose is degraded into arabinose, xylene, mannose, galactose, acetic acid, and hydroxycinnamic acids (Wyman et al., 2005). These products can be further used as a substrate for the fermentation process and yield other valuable compounds. Due to its high polysaccharide, protein, nutrient, and water content, BSG is susceptible to degradation by microorganisms and promotes their growth (Mathias et al., 2015). Therefore, there are attempts to use this residue in biotechnological processes. BSG biomass can be exploited via fungal and bacterial processing to obtain enzymes and value-added compounds for the food industry (Ravindran & Jaiswal, 2016).
Similarly, hydrolysates produced from BSG can be subjected to fermentation processes to produce various compounds for the food industry. The valuable chemicals obtained can serve as raw materials for further processing or become functional ingredients for production of new functional food products (Lynch, Steffen & Arendt, 2016). BSG can be utilized as a growth substrate for microorganisms that are able to degrade the fibrous husk materials contained in this by-product. It has been shown that media formulated with BSG contain nutrients that support the growth of such bacteria as Escherichia coli, (Archibong et al., 2016), actinobacteria (Szponar et al., 2003), Bifidobacterium adolescentis 94BIM, and Lactobacillus spp. (Novik et al., 2007). Actinobacteria and E. coli are used for the production of a wide range of bioactive metabolites, including enzymes and metabolites applied in the food industry (Ramírez & Calzadiaz, 2016; Kallscheuer, 2018). In turn, Bifidobacterium and Lactobacillus are most widely used probiotics in food products (Song, Hayek & Ibrahim, 2012). Moreover, BSG has been effectively used for cultivation of fungi, among others Pleurotus ostreatus (Gregori et al., 2008), Penicillium brasillianum (Panagiotou, Granouillet & Olsson, 2006) and Rhodosporidium toruloides (Cooray, Lee & Chen, 2017). BSG was also successfully used as an alternative to expensive nitrogen sources for preparation of media for yeast cultivation. Growth media containing fermented BSG were tested on the Rhodosporidium toruloides, and the by-product was able to support the growth of this yeast at comparable levels as YPD, sustaining its normal metabolic activity. Rhodosporidium toruloides cultivated on BSG-based media produced fatty acids and carotenoids, which can be used in food products, for example as natural colorants (Cooray, Lee & Chen, 2017; Zalynthios & Varzakas, 2016). Brewery spent grain can substitute yeast extract-peptone, which is usually used for cultivation of fungi producing useful and valuable bio products, such as succinic acid (Cooray, Lee & Chen, 2017), microbial oil (Saenge et al., 2011), xylitol (Mussatto & Roberto, 2008), or pullulan (Singh & Saini, 2012; Mussatto & Roberto, 2008; Cooray, Lee & Chen, 2017). Processes for production of xylitol from BSG have been developed. Xylitol is a sugar occurring in nature in small amounts. In the food industry, it is used as a sweetener and a healthier alternative to sucrose. It is beneficial for prevention of lung infection and dental caries and recommended for diabetics and patients suffering from renal lesions and lipid metabolism disorders (Mussatto & Roberto, 2008). It has been indicated that such yeasts as Debaryomyces Hansenii (Carvalheiro et al., 2006) and Candida guilliermondii growing on BSG produce xylitol (Mussatto & Roberto, 2008). Another metabolite that can be produced on BSG is an extracellular water-soluble polysaccharide named pullulan. It is a linear α-D-glucan produced by the fungus Aureobasidium pullulans, consisting mainly of maltotriose units with α-(1 → 6) or (1 → 4) linkages. Fermentation of medium based on BSG by A. pullulans yields 6.0 g/l of pullulan after 72 h linkages (Roukas, 1998). Dietary pullulan functions as a prebiotic promoting the growth of beneficial bifidobacteria (Sugawa-Katayama et al., 1994). This polysaccharide can replace starch in some foods; it can also be used as a binder and stabilizer in food paste or as low-viscosity filler in beverages and sauces. Pullulan can be incorporated into dietetic foods beneficial for diabetics or patients with impaired glucose tolerance (Singh & Saini, 2012).
Brewer’s spent grain has been found to be a less expensive alternative to the traditional carbon sources (such as glucose, sucrose, or starch) for production of L-lactic acid (2-hydroxy propanoic acid). This compound can be found in milk, dairy products, and many other fermented food products (pickled vegetables, jams, frozen desserts). This natural food additive is used e.g. as a preservative, pH regulator, flavor, solvent, and gelling agent (Ali, Anjum & Zahoor, 2009; Ameen & Caruso, 2017). Studies have demonstrated that BSG hydrolysate can be used as a substrate for lactic acid production by Lactobacillus delbrueckii, Lactobacillus pentosus, or Lactobacillus rhamnosus NBRC14710 (Cruz et al., 2007; Shindo & Tachibana, 2004).

BSG has also been tested as an inexpensive substrate for citric acid production. Citric acid is a widely used compound serving as an antioxidant, flavor enhancer, and preservation agent in food and beverages. Considerable amounts of citric acid were produced from BSG-utilizing Aspergillus niger and Saccharomyces cerevisiae in submerged fermentation (0.512% and 0.312%, respectively) (Femi-ola & Atere, 2013). Hydrolysates obtained from BSG have also been successfully applied as a fermentation medium for production of ethanol by Saccharomyces cerevisiae and Debaryomyces hansenii or glycerol and arabitol by Debaryomyces hansenii (Laws & Waites, 1986; Duarte et al., 2004; Carvalheiro et al., 2006).

Microorganisms growing on BSG produce various types of enzymes that can be used in food processing. For this reason, BSG can also be applied as a low-cost and widely available substrate for enzyme production by bacteria. The type and activity of produced enzymes depends on the cultivated strain and exact growth substrate composition. BSG is a potential substrate for cultivation of amylolytic organisms, which are known to produce β-amylase and amylglucosidase (Adeniran & Abiose, 2009). Such microorganisms as Aspergillus oryzae and Bacillus have been used for production of α-amylase (Xu et al., 2008; Hashemi et al., 2011). In the food industry, amylases are used for production of fructose and maltotetraose syrup, oligosaccharide mixtures, or for reduction of starch viscosity during liquefaction (Adeniran & Abiose, 2009). BSG has been demonstrated to promote the production of cellulases, hemicellulases, endoxylanases, β-xilosidas, α-arabinoferanosidas, and feruloyl esterases used by microorganisms to degrade hemicellulose contained in this residue (Mandalari et al., 2008; Panagiotou, Granouillet & Olsson, 2006). These enzymes have been applied in food processing. There are some examples indicating the use of Aspergillus fumigatus, Fusarium oxysporum, and Streptomyces malaysiensis for production of cellulases (Grigorevski-Lima et al., 2009; Xiros et al., 2009; Nascimento et al., 2009). BSG was also applied as a carbon source for production of xylanolytic enzymes by Penicillium janczewskii and feruloyl esterase by Talaromyces stipitatus, Humicola grisea var. thermoidea (Mandalari et al., 2008), and Streptomyces avermitilis CECT 3339. The latter strain growing on BGS was also found to produce (1 → 4)- β-D-xylan xilanohydrolase (Bartolomé et al., 2003). Xylanolytic enzymes are widely used in the food industry. With their properties, they can be applied in bread and pastry to improve their quality or for removal of coffee bean mucilage. These enzymes are also used to improve the digestibility of crops intended for ruminant feed (Bajpai, 2014).

Since the carbon/nitrogen ratio in hot trub is similar to that in the microbial cell composition, it is suggested that, like BSG, this residue can be applied as an additive in
fermentation media used in bioprocesses, as it exerts a positive effect on cell divisions (Mathias et al., 2015). Potentially, it can be effectively used as a supplement in cultures of some microbes producing compounds for the food industry.

BSY can be used as an additive to media for cultivation of microorganisms producing relevant value-added compounds used in the food industry. For this purpose, mainly hydrolysates and autolysates obtained from BSY are used. BSY is a potential supplement to media utilized for the growth of lactic acid bacteria and production of lactic acid, for production of ethanol by genetically modified E. coli strain, and for synthesis of succinic acid. The applications of BSY as a source of nutrients in microbiological media have been summarized by Ferreira et al. (2010). Microorganisms growing on BSY release extracellular proteolytic enzymes. This residue has been reported to have the highest potential to be used as an additive to media for producing proteases. BSY has also been shown to be a promising alternative nitrogen source for microbial growth (Mathias et al., 2017). With their chemical properties, also yeast autolysates obtained from BSY can be used as supplements for fermentation media. They are suitable for the growth of microorganisms producing specific products that can be used in special-purpose foods (Berlowska et al., 2017).

CONCLUSIONS

Beer is one of the most frequently consumed beverages worldwide. Yet, a huge amount of waste is generated during beer production. Approximately 85% of by-products generated in this process can be changed into valuable resources, thus significantly reducing production costs and at the same time contributing to an increase in self-sufficiency. The by-products reviewed in this article have a potential to be used in products that are vital for human and animal nutrition and to extract some compounds for the food industry and culture of microorganisms in industrial bioprocesses, which yield valuable compounds for the food industry. However, disposal of wastes in an environmentally sustainable manner is an important challenge. There is still a need to design and develop feasible and financially viable processes for utilization or revalorization of brewery waste. Efficient management of these by-products can be ensured by a solution aimed at limiting the environmental pollution hazard caused by the disposal thereof, simultaneously making them useful for the food industry. For better environmental and economic performance, these by-products should be converted into some valuable products instead of being considered as useless wastes. Utilization thereof will reduce the costs of food and feed production and will allow taking full advantage of the nutritional value of this waste. While some attempts have been made to incorporate the bioactive components of BSG and BSY into foodstuffs, further research in this area should be conducted.
ADDITIONAL INFORMATION AND DECLARATIONS

Funding
The authors received no funding for this work.

Competing Interests
The authors declare that they have no competing interests.

Author Contributions
• Kamila Rachwał conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.
• Adam Waśko performed the experiments, analyzed the data, authored or reviewed drafts of the paper, and approved the final draft.
• Klaudia Gustaw and Magdalena Polak-Berecka analyzed the data, authored or reviewed drafts of the paper, and approved the final draft.

Patent Disclosures
The following patent dependencies were disclosed by the authors:
Laws, D. R.J. & Waites, M.J. (1986). Utilization of Spent Grains. Patent Number EP85305109A.

Data Deposition
The following information was supplied regarding data availability:
This is a review article. There is no code included and no data from research experiments.

REFERENCES
Adeniran AH, Abiose SH. 2009. Amylolytic potentiality of fungi isolated from some Nigerian agricultural wastes. *African Journal of Biotechnology* 8:667–672.
Ainsworth P, Ibanoglu S, Plunkett, A, Ibanoglu E, Stojceska V. 2007. Effect of brewers spent grain addition and screw speed on the selected physical and nutritional properties of an extruded snack. *Journal of Food Engineering* 81:702–709 DOI 10.1016/j.jfoodeng.2007.01.004.
Ali Z, Anjum FM, Zahoor T. 2009. Production of lactic acid from corn cobs hydrolysate through fermentation by Lactobaccillus delbrukii. *African Journal of Biotechnology* 8:4175–4178.
Aliyu S, Bala M. 2011. Brewer’s spent grain: A review of its potentials and applications. *African Journal of Biotechnology* 10:324–331.
Ameen SM, Caruso G. 2017. *Lactic acid in the food industry*. Cham, Switzerland: Springer International Publishing AG.
Amoah KO, Asiedu P, Wallace P, Bumbie GZ, Rhule SWA. 2017. The performance of pigs at different phases of growth on sun-dried brewers spent grain. *Livestock Res Rural Dev* 29:90.
Amorim M, Pereira JO, Gomes D, Dias C. 2016. Nutritional ingredients from spent brewer’s yeast obtained by hydrolysis and selective membrane filtration integrated in a pilot process. *Journal of Food Engineering* 185:42–47 DOI 10.1016/j.jfoodeng.2016.03.032.

Archibong E, Obuboegbunam E, Ewelukwa U, Onuora VC, Ezemba CC, Okeke CB, Okafor UC. 2016. Formulation of microbial growth media using brewers’ spent grains (BSG) and growth rate assessment with three bacterial species. *European Journal of Experimental Biology* 6:19–24.

Athanasios M, Paul L, Argyro B, Athanasios K, Michael K. 2007. Ambient and low temperature winemaking by immobilized cells on brewher’s spent grains: effect on volatile composition. *Food Chemistry* 104:918–927 DOI 10.1016/j.foodchem.2006.12.047.

Bajpai P. 2014. *Xylanolytic Enzymes*. Cambridge: Academic Press DOI 10.1016/C2013-0-18577-7.

Barchet R. 1993. Hot Trub: Formation and removal. *Brewing Techniq* 1:4.

Bartolomé B, Faulds CB, Williamson G. 1997. Enzymic release of ferulic acid from barley spent grain. *Journal of Cereal Science* 25:285–288 DOI 10.1006/jcrs.1996.0091.

Bartolomé B, Gómez-Cordovés C, Sancho AI, Diez N, Ferreira P, Soliveri J, Copacabana JL. 2003. Growth and release of hydroxycinnamic acids from Brewer’s spent grain by Streptomyces avermitilis CECT 3339. *Enzyme and Microbial Technology* 32:140–144 DOI 10.1016/S0141-0229(02)00277-6.

Bartolomé B, Santos M, Jimenez JJ, del Nozal MJ, Gomez-Cordoves C. 2002. Pentoses and hydroxycinnamic acids in brewers’ spent grain. *Journal of Cereal Science* 36:51–58 DOI 10.1006/jcrs.2002.0442.

Bedini S, Flaminig i G, Girardi J, Cosci F, Conti B. 2015. Not just for beer: Evaluation of spent hops (Humulus lupulus L.) as a source of eco-friendly repellents for insect pests of stored foods. *Journal of Pest Science* 88:583–592 DOI 10.1007/s10340-015-0647-1.

Belibasakis NG, Tsirgogianni D. 1996. Effects of wet brewers grains on milk yield, milk composition and blood components of dairy cows in hot weather. *Animal Feed Science and Technology* 57:175–181 DOI 10.1016/0377-8401(95)00860-8.

Benaroudj N, Lee DH, Goldberg AL. 2001. Trehalose accumulation during cellular stress protects cells and cellular proteins from damage by oxygen radicals. *Journal of Biological Chemistry* 276:24261–24267 DOI 10.1074/jbc.M101487200.

Berlowska J, Dudkiewicz-Kołodziejska M, Pawlikowska E, Pielęci-Przybylska K, Balcerzak M, Czysowska A, Kregiel D. 2017. Utilization of post-fermentation yeasts for yeast extract production by autolysis: the effect of yeast strain and saponin from Quillaja saponaria. *Journal of the Institute of Brewing* 123:396–401 DOI 10.1002/jib.438.

Borchani C, Fonteyn F, Jamin G, Destain J, Willems I, Paquot M, Blecker C, Thonart P. 2016. Structural characterization, technological functionality, and physiological aspects of fungal β-d-glucans: a review. *Critical Reviews in Food Science and Nutrition* 56:1746–1752 DOI 10.1080/10408398.2013.854733.
Brooklyn Brew Shop. 2016. Retrieved April 24, 2020. Available at http://pdxfoodlove.com/2013/02/07/daves-incomparable-veggie-burgers/.

Brooklyn Brew Shop. 2017. Available at https://brooklynbrewshop.com/blogs/themash/recipe-spent-grain-waffles/ (accessed on 24 April 2020).

Cappa C, Alamprese C. 2017. Brewer’s spent grain valorization in fiber-enriched fresh egg pasta production: Modelling and optimization study. LWT - Food Science and Technology 82:464–470 DOI 10.1016/j.lwt.2017.04.068.

Carpenter D. 2014. 5 ways to use spent grain. Available at https://beerandbrewing.com/5-ways-to-use-spent-grain/ (accessed on 22 April 2020).

Carvalheiro F, Duarte LC, Lopes S, Parajó JC, Pereira H, Girio FM. 2006. Supplementation requirements of brewery’s spent grain hydrolysate for biomass and xylitol production by Debaryomyces hansenii CCM 941. Journal of Industrial Microbiology and Biotechnology 33:646–654 DOI 10.1007/s10295-006-0101-8.

Celus I, Brijs K, Delcour JA. 2007. Enzymatic hydrolysis of brewers’ spent grain proteins and technofunctional properties of the resulting hydrolysates. Journal of Agricultural and Food Chemistry 55:8703–8710 DOI 10.1021/jf071793c.

Chanie D, Fievez V. 2017. Review on preservation and utilization of wet brewery spent grain as concentrate replacement feed for lactating dairy cows. Journal of Animal Health and Production 5:10–13.

Chiou PWS, Chen CR, Chen KJ, Yu B. 1998. Wet brewers’ grains or bean curd pomance as partial replacement of soybean meal for lactating cows. Animal Feed Science and Technology 74:123–134 DOI 10.1016/S0377-8401(98)00170-9.

Choi MS, Choi YS, Kim HW, Hwang KE, Song DH, Lee SY, Kim CJ, Hwang K, Song D, Lee S, Kim C. 2014. Effects of replacing pork back fat with brewer’s spent grain dietary fiber on quality characteristics of reduced-fat chicken sausages. Food Science of Animal Resources 34:158–165 DOI 10.5851/kosfa.2014.34.2.158.

Cina C. 2015. Spent-grain ciabatta with beer butter recipe. Available at https://beerandbrewing.com/spent-grain-ciabatta-with-beer-butter-recipe/ (accessed on 24 April 2020).

Coldea TE, Mudura E, Rotar AM, Cuibus L, Pop CR, Darab C. 2017. Brewer’s spent yeast exploitation in food industry. Hop and Medicinal Plants 25:94–99.

Combest S, Warren C. 2018. Perceptions of college students in consuming whole grain foods made with Brewers’ Spent Grain. Food Science & Nutrition 7:225–237.

Conway J. 2019. Beer production worldwide from 1998 to 2018. Available at https://www.statista.com/statistics/270275/worldwide-beer-production/ (accessed on 14 April 2020).

Cooray ST, Lee JI, Chen WN. 2017. Evaluation of brewers’ spent grain as a novel media for yeast growth. AMB Express 7:1–10 DOI 10.1186/s13568-016-0313-x.

Crawshaw R. 2004. Co-product feeds: animal feeds from the food and drinks industries. Nottingham: Nottingham University Press.

Creative Commons. 2020. CC search tool. Available at https://ccsearch.creativecommons.org/ (accessed on 14 March 2020).
Crowley D, O'Callaghan Y, McCarthy A, Connolly A, Piggott CO, FitzGerald RJ, O'Brien NM. 2015. Immunomodulatory potential of a brewers’ spent grain protein hydrolysate incorporated into low-fat milk following in vitro gastrointestinal digestion. *International Journal of Food Sciences and Nutrition* **66**:672–676 DOI 10.3109/09637486.2015.1077788.

Cruz JM, Moldes AB, Bustos G, Torrado A, Domínguez JM. 2007. Integral utilisation of barley husk for the production of food additives. *Journal of the Science of Food and Agriculture* **87**:1000–1008 DOI 10.1002/jsfa.2796.

Cui S, Wu Y, Ding H. 2013. The range of dietary fibre ingredients and a comparison of their technical functionality. In: Delcour J, Poutanen K, eds. *Fibre-rich and wholegrain foods*. 1st edition. Woodhead Publishing, 96–119.

De León-González G, González-Valdez J, Mayolo-Deloisa K, Rito-Palomares M. 2016. Intensified fractionation of brewery yeast waste for the recovery of invertase using aqueous two-phase systems. *Biotechnology and Applied Biochemistry* **63**:886–894 DOI 10.1002/bab.1435.

De Souza L, Zambom M, Alcalde CR, Fernandes T, Castagnara DD, Radis AC, Santos SM, Possamai AP, Pasqualoto M. 2016. Feed intake, nutrient digestibility, milk production and composition in dairy cows fed silage of wet brewers grain. *Semin Ciênc Agrár* **37**:1069–1080 DOI 10.5433/1679-0359.2016v37n2p1069.

Dhiman TR, Bingham HR, Radloff HD. 2003. Production response of lactating cows fed dried versus wet brewers’ grain in diets with similar dry matter content. *Journal of Dairy Science* **86**:2914–2921 DOI 10.3168/jds.S0022-0302(03)73888-0.

Duarte LC, Carvalheiro F, Lopes S, Marques S, Parajo JC, Girio FM. 2004. Comparison of two posthydrolysis processes of brewery’s spent grain autohydrolysis liquor to produce a pentose-containing culture medium. *Applied Biochemistry and Biotechnology* **113/116**:1041–1058.

El-Aleem F, Taher S, Shereen NL, El-massry K, Fadel H. 2017. Influence of extracted 5-nucleotides on aroma compounds and flavour acceptability of real beef soup. *International Journal of Food Properties* **20**(sup1):S1182–S1194 DOI 10.1080/10942912.2017.1286506.

Faccenda A, Zambom M, Castagnara D, de Avila AS, Fernandes T, Eckstein El, Anschau FA, Schneider CR. 2017. Use of dried brewers’ grains instead of soybean meal to feed lactating cows. *Revista Brasileira de Zootecnia* **46**:39–46 DOI 10.1590/s1806-92902017000100007.

Fárcas A, Socaci S, Mudura E, Dulf F, Vodnar D, Tofana M, Salanta LC. 2017. Exploitation of brewing industry wastes to produce functional ingredients. In: *Brewing technology*. Budapest: Makoto Kanauchi, IntechOpen DOI 10.5772/intechopen.69231.

Fárcas A, Tofana M, Socaci S, Mudura E, Scrob S, Salanta L, Muresan V. 2014. Brewers’ spent grain –A new potential ingredient for functional foods. *Journal of Agroalimentary Processes and Technologies* **20**:137–141.

Faulds CB, Sancho AI, Bartolomé B. 2002. Mono- and dimeric ferulic acid release from brewer’s spent grain by fungal feruloyl esterases. *Applied Microbiology and Biotechnology* **60**:489–493 DOI 10.1007/s00253-002-1140-3.
Femi-ola TO, Atere VA. 2013. Citric acid production from brewers spent grain by Aspergillus niger and Saccharomyces cerevisiae. *International Journal of Research in Biosciences* 2:30–36.

Ferreira MPLVO, Pinho O, Vieira E, Tavarela JG. 2010. Brewer’s Saccharomyces yeast biomass: characteristics and potential applications. *Trends in Food Science & Technology* 21:77–84 DOI 10.1016/j.tifs.2009.10.008.

Fillaudeau L, Blanpain-Avet P, Daufin G. 2006. Water, wastewater and waste management in brewing industries. *Journal of Cleaner Production* 14:463–471 DOI 10.1016/j.jclepro.2005.01.002.

Gibson DL, Dwivedi BK. 1970. Production of meat substitutes from spent brewers’ yeast and soy protein. *Canadian Institute of Food Technology Journal* 3:113–115 DOI 10.1016/S0008-3860(70)74291-8.

Gregori A, Svageli M, Pahor B, Berovic M, Pohleven F. 2008. The use of spent brewery grains for Pleurotus ostreatus cultivation and enzyme production. *New Biotechnology* 25:157–161 DOI 10.1016/j.nbt.2008.08.003.

Grigorevski-Lima AL, Da Vinha FN, Souza DT, Bispo A, Bon E, Coelho R, Nascimento RP. 2009. Aspergillus fumigatus thermophilic and acidophilic endoglucanases. *Applied Biochemistry and Biotechnology* 155:321–329.

Hashemi M, Razava SH, Shojaosadati SA, Mousavi SM. 2011. The potential of brewer’s spent grain to improve the production of α-amylase by Bacillus sp. KR-8104 in submerged fermentation system. *New Biotechnology* 28:165–172 DOI 10.1016/j.nbt.2010.10.009.

Helkar PB, Sahoo AK, Patil NJ. 2016. Review: food industry by-products used as a functional food ingredients. *International Journal of Waste Resources* 6:248–253.

Hertrampf JW, Piedad-Pascual F. 2000. *Handbook on ingredients for aquaculture feeds*. Dordrecht: Kluwer Academic Publishers.

Hough J, Briggs SDE, Stevens R, Young TW. 1982. *Malting and brewing science*. 2nd edition. Cambridge: Cambridge University Press.

Huang D. 2018. Dietary antioxidants and health promotion. *Antioxidants* 7:9.

Huige N. 2006. Brewery by-products and effluents. In: Priest FG, Stewart GG, eds. *Handbook of brewing*. 2nd edition. Boca Raton: Taylor & Francis Group, 656–707.

Jin Y, Wang M, Lin S, Guo Y, Liu J, Yin Y. 2011. Optimization of extraction parameters for trehalose from beer waste brewing yeast treated by high-intensity pulsed electric fields (PEF). *African Journal of Biotechnology* 10:19144–19152.

Kallscheuer N. 2018. Engineered microorganisms for the production of food additives approved by the european union-A systematic analysis. *Frontiers in Microbiology* 9:1746 DOI 10.3389/fmicb.2018.01746.

Kanauchi O, Mitsuyama K, Araki Y. 2001. Development of a functional germinated barley foodstuff from brewer’s spent grain for the treatment of ulcerative colitis. *Journal of the American Society of Brewing Chemists* 59:59–62.

Kaur VI, Saxena PK. 2004. Incorporation of brewery waste in supplementary feed and its impact on growth in some carps. *Bioresource Technology* 91:101–104 DOI 10.1016/S0960-8524(03)00073-7.
Kerby C, Vriesekoop F. 2017. An overview of the utilisation of brewery by-products as generated by british craft breweries. Beverages 3:24 DOI 10.3390/beverages3020024.

Kim H, Hwang K, Song D, Lee S, Choi M, Lim Y, Choi J, Choi Y, Kim H, Kim C. 2013. Effects of dietary fiber extracts from brewer’s spent grain on quality characteristics of chicken patties cooked in convective oven. Journal of the American Society of Brewing Chemists 33:45–52 DOI 10.5851/kosfa.2013.33.1.45.

Kirin Holdings Company. 2019. Kirin Beer University Report. Global Beer Consumption by Country in 2018. Available at https://www.kirinholdings.co.jp/english/news/2019/1224_01.html (accessed on 24 April 2020).

Kissell L, Prentice N, Lindsay R. 1979. Protein and fiber enrichment of cookie flour with brewer’s spent grain. Cereal Chemistry 56:261–266.

Klemm D, Kramer F, Moritz S, Lindström T, Ankerfors M, Gray D, Dorris A. 2011. Nanocelluloses: a new family of nature based materials. Angewandte Chemie International Edition in English 50:5438–5466 DOI 10.1002/anie.201001273.

Krpan V, Petrvacic-Tominac V, Krbav cic I, Slobodan G, Berkovic K. 2009. Potential application of yeast β-glucans in food industry. Agriculturae Conspectus Scientificus 74:277–282.

Ktenioudaki A, Alvarez-Jubete L, Smyth TJ, Kilcawley K, Rai DK, Gallagher E. 2015. Application of bioprocessing techniques (sourdough fermentation and technological aids) for brewer’s spent grain breads. Food Research International 73:107–116 DOI 10.1016/j.foodres.2015.03.008.

Ktenioudaki A, Chaurin V, Reis SF, Gallagher E. 2012. Brewer’s spent grain as a functional ingredient for breadsticks. International Journal of Food Science & Technology 47:1765–1771.

Ktenioudaki A, Crofton E, Scannell A, Hannon J, Kilcawley K, Gallagher E. 2013a. Sensory properties and aromatic composition of baked snacks containing brewer’s spent grain. Journal of Cereal Science 57:384 DOI 10.1016/j.jcs.2013.01.009.

Ktenioudaki A, O’Shea N, Gallagher E. 2013b. Rheological properties of wheat dough supplemented with functional by-products of food processing: brewer’s spent grain and apple pomace. Journal of Food Engineering 116:362–368 DOI 10.1016/j.jfoodeng.2012.12.005.

Kühbeck F, Back W, Krottenthaler M. 2006. Influence of lauter turbidity on wort composition, fermentation performance and beer quality –a review. Journal of the Institute of Brewing 112:215–221 DOI 10.1002/j.2050-0416.2006.tb00716.x.

Laws DRJ, Waites MJ. 1986. Utilization of Spent Grains. Patent Number 85-305109 169068. Brewing Research Foundation, UK.

Levic J, Djuragic O, Sredanovic S. 2010. Use of new feed from brewery by-products for breeding layers. Romanian Biotechnological Letters 15:5559–5565.

Lynch KM, Steffen EJ, Arendt EK. 2016. Brewers’ spent grain: a review with an emphasis on food and health. Journal of the Institute of Brewing 122:553–568 DOI 10.1002/jib.363.
Mahmud SA, Hirasea T, Shimizu H. 2010. Differential importance of trehalose accumulation in Saccharomyces cerevisiae in response to various environmental stresses. *Journal of Bioscience and Bioengineering* **109**:262–266 DOI 10.1016/j.jbiosc.2009.08.500.

Mandalari G, Bisignano G, Lo Curto RB, Waldron KW, Faulds CB. 2008. Production of feruloyl esterases and xylanases by Talaromyces stipitatus and Humicola grisea var. thermoidea on industrial food processing by-products. *Bioresource Technology* **99**:5130–5133 DOI 10.1016/j.biortech.2007.09.022.

Martins ZE, Erben M, Gallardo AE, Silva R, Barbosa I, Pinho O, Ferreira IMPLVO. 2015. Effect of spent yeast fortification on physical parameters, volatiles and sensorial characteristics of home-made bread. *International Journal of Food Science & Technology* **50**:1855–1863.

Mathias TRDS, Fernandes de Aguiar P, Batista de Almeida E, Silva J, Moretzsohn de Mello PP, Sérvulo EFC. 2017. Brewery waste reuse for protease production by lactic acid fermentation. *Food Technology and Biotechnology* **55**:218–224.

Mathias TRS, Alexandre VMF, Cammarota MC, Mello PPM, Sérvulo EFC. 2015. Characterization and determination of brewer’s solid wastes composition. *Journal of the Institute of Brewing* **121**:400–404 DOI 10.1002/jib.229.

Mathias TRDS, de Mello PPM, Servulo EFC. 2014. Solid wastes in brewing process: a review. *Journal of Brewing and Distilling* **5**:1–9 DOI 10.5897/JBD2014.0043.

McCarthy AL, O’Callaghan YC, Piggott CO, FitzGerald RJ, O’Brien NM. 2013. Brewers’ spent grain; bioactivity of phenolic component, its role in animal nutrition and potential for incorporation in functional foods: a review. *Proceedings of the Nutrition Society* **72**:117–125 DOI 10.1017/S0029665112002820.

Melo ANF, Souza EL, Silva Araujo VB, Magnani M. 2015. Stability, nutritional and sensory characteristics of French salad dressing made with mannoprotein from spent brewer’s yeast. *LWT - Food Science and Technology* **62**:771–774 DOI 10.1016/j.lwt.2014.06.050.

Metzger BT, Scholl C, Barnes DM. 2012. Supercritical fluid extraction of vitamin D2 from UV enhanced yeast. *FASEB Journal* **26**(1_supplement):643.11–643.11.

Moreira MM, Morais S, Carvalho DO, Barros AA, Delerue-Matos C, Guido LF. 2013. Brewer’s spent grain from different types of malt: Evaluation of the antioxidant activity and identification of the major phenolic compounds. *Food Research International* **54**:382–388 DOI 10.1016/j.foodres.2013.07.023.

Mussatto SI. 2006. Brewer’s spent grains generation, characterization and potential application. *Journal of Cereal Science* **43**:1–14 DOI 10.1016/j.jcs.2005.06.001.

Mussatto SI, Roberto IC. 2005. Acid hydrolysis and fermentation of brewers’ spent grain to produce xylitol. *Journal of the Science of Food and Agriculture* **85**:2453–2460 DOI 10.1002/jsfa.2276.

Mussatto SI, Roberto IC. 2008. Establishment of the optimum initial xylose concentration and nutritional supplementation of brewer’s spent grain hydrolysate for xylitol production by Candida guilliermondii. *Process Biochemistry* **43**:540–546 DOI 10.1016/j.procbio.2008.01.013.
Nagy M, Semeniuc CA, Socaci SA, Pop CA, Rotar AM, Salagean CD, Tofana M. 2017. Utilization of brewer’s spent grain and mushrooms in fortification of smoked sausages. *Food Science and Technology* 37:315–320 DOI 10.1590/1678-457x.23816.

Nascimento R, Junior N, Pereira Jr N, Bon E, Coelho R. 2009. Brewer’s spent grain and corn steep liquor as substrates for cellulolytic enzymes production by *Streptomyces* *malaysiensis*. *Letters in Applied Microbiology* 48:529–535 DOI 10.1111/j.1472-765X.2009.02575.x.

Nortey TNN, Frimpong R, Naazie A. 2018. Effect of metabolizable energy content and ileal amino acid digestibility of sorghum-barley brewer’s spent grain on growth, carcass and blood parameters in broilers. *Journal of Animal and Feed Research* 8:20–32.

Novik GI, Wawrzynczyk J, Norrlow O, Szwajcer-Dey E. 2007. Fractions of barley spent grain as media for growth of probiotic bacteria. *Microbiology* 76:804–808 DOI 10.1134/S0026261707060227.

Olajire AA. 2012. The brewing industry and environmental challenges. *Journal of Cleaner Production* 30:1–21.

O’Rourke T. 1994. Making the most of your hops. *New Brewer* 11:20–33.

Otero M, Guerrero I, Wagner JR, Cabello AJ, Sceni P, García R, Soriano J, Tomasini A, Saura G, Almazán O. 2011. Yeast and its derivatives as ingredients in the food industry. *Biotecnologia Aplicada* 28:272–275.

Øverland M, Karlsson A, Mydland LT, Romarheim OH, Skrede A. 2013. Evaluation of *Candida* *utilis*, *Kluveromyces* *marxianus* and *Saccharomyces* *cerevisiae* yeasts as protein sources in diets for Atlantic salmon (*Salmo* *salar*). *Aquaculture* 402:1–7.

Öztürk S, Özboy O, Cavidoglu I, Köksel H. 2002. Effects of brewers’ spent grains on the quality and dietary fibre content of cookies. *Journal of the Institute of Brewing* 108:23–27 DOI 10.1002/j.2050-0416.2002.tb00116.x.

Özvural EB, Vural H, Gokbulut I, Ozboy-Ozbas O. 2009. Utilization of brewer’s spent grain in the production of Frankfurters. *International Journal of Food Science & Technology* 44:1093–1099 DOI 10.1111/j.1365-2621.2009.01921.x.

Panagiotou G, Granouillet P, Olsson L. 2006. Of arabinoxylan- degrading enzymes by *Penicillium* *brasiliannum* under solid-state fermentation. *Applied Microbiology and Biotechnology* 7:1117–1124.

Pancrazio G, Cunha SC, de Pinho PG, Loureiro M, Meireles S, Ferreira IMPLVO, Pinho O. 2016. Spent brewer’s yeast extract as an ingredient in cooked hams. *Meat Science* 121:382–389 DOI 10.1016/j.meatsci.2016.07.009.

Plessas S, Trantallidi M, Bekatorou A, Kanellaki M, Nigam P, Koutinas AA. 2007. Immobilization of kefir and Lactobacillus casei on brewery spent grains for use in sourdough wheat bread making. *Food Chemistry* 105:187–194 DOI 10.1016/j.foodchem.2007.03.065.

Podpora B, Swiderski F, Sadowska A, Rakovska R, Wasiak-Zys G. 2016. Spent brewer’s yeast extracts as a new component of functional food. *Czech Journal of Food Sciences* 34:554–563 DOI 10.17221/419/2015-CJFS.
Radzik-Rant A, Rant W, Niznikowski R, Swiatek M, Szymanska Z, Slezak M, Niemiec T. 2018. The effect of the addition of wet brewers grain to the diet of lambs on body weight gain, slaughter value and meat quality. *Archives Animal Breeding* **61**:245–251 DOI 10.5194/aab-61-245-2018.

Rakin M, Baras J, Vukasinovic M. 2004. The influence of brewers yeast autolysate and lactic acid bacteria on the production of a functional food additive based on beetroot fermentation. *Food Technology and Biotechnology* **42**:105–109.

Rakin M, Vukasinovic M, Siler-Marinkovic S, Maksimovic M. 2007. Contribution of lactic acid fermentation to improved nutritive quality vegetable juices enriched with brewer’s yeast autolysate. *Food Chemistry* **100**:599–602 DOI 10.1016/j.foodchem.2005.09.077.

Rakowska R, Sadowska A, Dybkowska E, Swiderski F. 2017. Spent yeast as natural source of functional food additives. *Roczniki Państwowego Zakładu Higieny* **68**:115–121.

Ramírez MV, Calzadíaz L. 2016. Industrial enzymes and metabolites from actinobacteria in food and medicine industry. In: Dhanasekaran D, Jiang Y, eds. *Actinobacteria—basics and biotechnological application*. INTECH. World’s largest Science, Technology & Medicine, 315–328.

Ravindran R, Jaiswal AK. 2016. Microbial enzyme production using lignocellulosic food industry wastes as feedstock: a review. *Bioengineering* **3**:30.

Ravishankar R. 2016. *Advances in food biotechnology*. Department of Studies in Microbiology, University of Mysore, India. John Wiley & Sons, Chichester, West Sussex, UK.

Rebekah. 2013. Available at http://pdxfoodlove.com/2013/02/07/daves-incomparable-veggie-burgers/ (accessed on 24 April 2020).

ReGrained Company. 2020. Available at https://www.regrained.com/ (accessed on 24 April 2020).

Robertson JAI, Anson KJA, Treimo J, Faulds CB, Brocklehurst TF, Eijsink VGH, Waldron KW. 2010. Profiling brewer’s spent grain for composition and microbial ecology at the site of production. *LWT-Food Science and Technology* **43**:890–896 DOI 10.1016/j.lwt.2010.01.019.

Rosicka J, Komisarczyk A, Nebesny E, Makowski B. 2015. The influence of arabinoxylans on the quality of grain industry products. *Eur Food Res Technol* **242**:295–303.

Roukas T. 1998. Citric acid production from carob pod extract by cell recycle of Aspergillus niger ATCC 9142. *Food Biotechnol* **12**:91–104 DOI 10.1080/08905439809549945.

RuB W, Meyer-Pittroff R. 2003. The use of phenolic protein precipitates (trub) from beer production in animal feed. *Monatsschr Brauwiss* **56**:84–88.

Rúa J, Cima SD, Valle PD, Gutiérrez-Larraínzar M, Busto F, Arriaga DD. 2008. Glycogen and trehalose mobilization by acetic acid in Phycomyces blakesleeanus: dependence on the anion form. *Research in Microbiology* **159**:200–206 DOI 10.1016/j.resmic.2008.01.002.
Saenge C, Cheirsilp B, Suksaroge TT, Bourtoom T. 2011. Potential use of oleaginous red yeast Rhodotorula glutinis for the bioconversion of crude glycerol from biodiesel plant to lipids and carotenoids. *Process Biochemistry* **46**:210–218 DOI 10.1016/j.procbio.2010.08.009.

Santos M, Jiménez JJ, Bartolomé B, Gómez-Cordovés C, del Nozal MJ. 2003. Variability of brewers’ spent grain within a brewery. *Food Chemistry* **80**:17–21 DOI 10.1016/S0308-8146(02)00229-7.

Saraiva BR, Anjo FA, Vital ACP, Da Silva LHM, Ogawa CYL, Sato F, Coimbra LB, Matumoto-Pintro PT. 2019. Waste from brewing (trub) as a source of protein for the food industry. *International Journal of Food Science & Technology* **54**:1247–1255.

Severini C, Ricci I, Marone M, Derossi A, De Pilli T. 2015. Changes in the aromatic profile of espresso coffee as a function of the grinding grade and extraction time: a study by the electronic nose system. *Journal of Agricultural and Food Chemistry* **63**:2321–2327 DOI 10.1021/jf505691u.

Shahidi F, Ambigaipalan P. 2015. Phenolics and polyphenolics in foods, beverage and spices: antioxidant activity and health effects –A review. *Journal of Functional Foods* **18**:820–897 DOI 10.1016/j.jff.2015.06.018.

Shindo S, Tachibana T. 2004. Production of L-lactic acid from spent grain, a by-product of beer production. *Journal of the Institute of Brewing* **110**:347–351 DOI 10.1002/j.2050-0416.2004.tb00631.x.

Singh R, Saini G. 2012. Biosynthesis of pullulan and its applications in food and pharmaceutical industry. In: Satyanarayana T, Johri B, Prakash A, eds. *Microorganisms in sustainable agriculture and biotechnology*. Dordrecht: Springer, 509–553.

Sobukola OP, Babajide JM, Ogunsade O. 2013. Effect of brewers spent grain addition and extrusion parameters on some properties of extruded yam starch-based pasta. *The Journal of Food Processing and Preservation* **37**:734–743 DOI 10.1111/j.1745-4549.2012.00711.x.

Song D, Hayek S, Ibrahim S. 2012. Recent application of probiotics in food and agricultural science. In: Rigobelo EC, ed. *Probiotics*. InTech Open Access Publisher, NY, 3–36.

Spinelli S, Conte A, Del Nobile MA. 2016. Microencapsulation of extracted bioactive compounds from brewer’s spent grain to enrich fish-burgers. *Food and Bioprod Process* **100**:450–456 DOI 10.1016/j.fbpp.2016.09.005.

Stalikas CD. 2007. Extraction, separation, and detection methods for phenolic acids and flavonoids. *Journal of Separation Science* **30**:3268–3295 DOI 10.1002/jssc.200700261.

Stefanello FS, Dos Santos CO, Bochi VC, Fruet APB, Soquetta MB, Dörr AC, Nörnberg JL. 2018. Analysis of polyphenols in brewer’s spent grain and its comparison with corn silage and cereal brans commonly used for animal nutrition. *Food Chemistry* **239**:385–401 DOI 10.1016/j.foodchem.2017.06.130.

Steinmacher NC, Honna FA, Gasparetto AV, Anibal D, Grossmann MVE. 2012. Bioconversion of brewer’s spent grains by reactive extrusion and their application in bread-making. *LWT - Food Science and Technology* **46**:542–547 DOI 10.1016/j.lwt.2011.11.011.
Stojceska V, Ainsworth P, Plunkett A, Ibanoglu S. 2008. The recycling of brewer’s processing by-product into ready-to-eat snacks using extrusion technology. Journal of Cereal Science 47:469–479 DOI 10.1016/j.jcs.2007.05.016.

Stojceska V, Ainsworth P, Plunkett A, Ibanoglu S. 2009. The effect of extrusion cooking using different water feed rates on the quality of ready-to-eat snacks made from food by-products. Food Chemistry 114:226–232 DOI 10.1016/j.foodchem.2008.09.043.

Stojceska V, Ainsworth W. 2008. The effect of different enzymes on the quality of high-fibre enriched brewer’s spent grain breads. Food Chemistry 110:865–872 DOI 10.1016/j.foodchem.2008.02.074.

Stone CW. 2006. Yeast products in the feed industry: a practical guide for feed professionals. In: Engormix, the largest online agricultural community in the world. Cedar Rapids, Iowa: Diamond V Mills Inc.

Sugawa-Katayama Y, Kondou F, Mandai T, Yoneyama M. 1994. Effects of pullulan, polydextrose and pectin on cecal microflora. Oyo Toshitsu Kagaku 41:413–418.

Szponar B, Pawlik KJ, Gamian A, Dey ES. 2003. Protein fraction of barley spent grain as a new simple medium for growth and sporulation of soil Actinobacteria. Biotechnology Letters 25:1717–1721 DOI 10.1023/A:1026046403010.

Tacon AGJ, Metian M, Hasan MR. 2009. Feed ingredients and fertilizers for farmed aquatic animals. Sources and composition. FAO Fisheries and Aquaculture technical paper, 540. FAO, Roma, Italy.

Tacon P. 2015. New feed protein sources. Products from fermentation - yeast -. New protein resources - How to secure effective risk analysis?, workshop FEFAC/ASSALZOO.

Thomas BKR, Rahman PKSM. 2006. Brewery wastes. Strategies for sustainability. A review. Aspects of Applied Biology 80:147–153.

Veana F, Flores C, Gonzalez A, Michel-Michel M, Lopez L, Aguilar-Zarate P, Ascacio-Valdes J, Rodriguez R. 2018. Invertase: An Enzyme with Importance in Confectionery Food Industry: Improvements and Innovations. In: In book: Enzymes in Food Technology. Singapore: Springer, 187–212.

Vieira EF, Carvalho J, Pinto E, Cunha S, Almeida AA, Ferreira IMPLVO. 2016. Nutritive value, antioxidant activity and phenolic compounds profile of brewer’s spent yeast extract. Journal of Food Composition and Analysis 52:44–51 DOI 10.1016/j.jfca.2016.07.006.

Vieira E, Rocha MAM, Coelho E, Pinho O, Saraiva JA, Ferreira IMPLVO, Coimbra MA. 2014. Valuation of brewer’s spent grain using a fully recyclable integrated process for extraction of proteins and arabinoxylans. Industrial Crops and Products 52:136–143 DOI 10.1016/j.indcrop.2013.10.012.

Waszkiewicz-Robak B, Karwowska W, Swiderski F. 2005. β-glukan jako składnik zywności funkcjonalnej. Bromatologia i Chemia Toksykologiczna 3:301–306.

Waters DM, Jacob F, Titze J, Arendt EK, Zannini E. 2012. Fibre, protein and mineral fortification of wheat bread through milled and fermented brewer’s spent grain enrichment. European Food Research and Technology 235:767–778 DOI 10.1007/s00217-012-1805-9.
West JW, Ely LO, Martin SA. 1994. Wet brewers grains for lactating dairy-cows during hot, humid weather. Journal of Dairy Science 77:196–204. DOI 10.3168/jds.S0022-0302(94)76942-3.

Worrasinchai S, Suphantharika M, Pinjai S, Jamnong P. 2006. β-Glucan prepared from spent brewer’s yeast as a fat replacer in mayonnaise. Food Hydrocolloids 20:68–78. DOI 10.1016/j.foodhyd.2005.03.005.

Wyman C, Decker S, Himmel ME, Brady JW, Skopec CE, Viikari L. 2005. Hydrolysis of cellulose and hemicellulose. In: Dumitriu S, ed. Polysaccharides: structural diversity and functional versatility. New York: Marcel Dekker, Inc., 995–1033.

Xiros C, Moukouli M, Topakas E, Christakopoulos P. 2009. Factors affecting ferulic acid release from Brewer’s spent grain by Fusarium oxysporum enzymatic system. Bioresource Technology 100:5917–5921. DOI 10.1016/j.biortech.2009.06.018.

Xu H, Sun L, Zhao D, Zhang B, Shi Y, Wu Y. 2008. Production of α-amylase by Aspergillus oryzae As 3951 in solid state fermentation using spent grains substrate. Journal of the Science of Food and Agriculture 88:529–535. DOI 10.1002/jsfa.3118.

Young TW. 2019. Beer. In Encyclopedia Britannica. Place of publication. Available at https://www.britannica.com/topic/beer (accessed on 15 February 2020).

Zalynthios G, Varzakas T. 2016. Carotenoids: from Plants to Food Industry. Current Research in Nutrition and Food Science 4:38–51. DOI 10.12944/CRNFSJ.4.Special-Issue1.04.