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Review

Brewer's spent grain: A review of its potentials and applications

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Most developing nations continuously produce abundant agro-industrial residues such as brewer's spent grain (BSG), which are underexploited. BSG as the main by-product of brewing industry, representing approximately 85% of total by-products generated, is rich in cellulose and non-cellulosic polysaccharides and has a strong potential to be recycled. Due to the global intense pressure towards green environmental technology, both academic and industrial researchers are putting more efforts to reduce the amount of such wastes by finding alternative uses apart from the current general use as an animal feed. Thus, several products are increasingly being sought from BSG. This article intends to review some of the products that can be realized from BSG and also to stimulate researchers to explore further, especially in developing new value-added products.

Key words: Brewer's spent grain, polysaccharide, animal feed, residue.

INTRODUCTION

Beer is the fifth most consumed beverage in the world apart from tea, carbonates, milk and coffee with an estimated annual world production exceeding 1.34 billion hectolitres in 2002 (Fillaudeau et al., 2006). In the manufacture of beer, various residues and by-products are generated. The most common ones are spent grains, spent hops and surplus yeast, which are generated from the main raw materials (Mussatto, 2009).

Spent grains are the by-products of mashing process; which is one of the initial operations in brewery in order to solubilize the malt and cereal grains to ensure adequate extraction of the wort (water with extracted matter) (Fillaudeau et al., 2006). Following different separation strategies, the amount of brewers' spent grain (BSG) generated could be about 85% of the total by-products (Tang et al., 2009), which accounts for 30 to 60% of the biochemical oxygen demand (BOD) and suspended solids generated by a typical brewery (Hang et al., 1975). It was reported that about 3.4 million tonnes of BSG from the brewing industry are produced in the EU every year (Stojceska et al., 2008), out of which UK alone contributes over 0.5 million tonnes of this waste annually. However, Brazil, the world's fourth largest beer producer (8.5 billion litres/year) in 2002, generated ~1.7 million tonnes of BSG (Mussatto et al., 2006).

Thus, BSG is a readily available, high volume low cost by-product of brewing and is a potentially valuable resource for industrial exploitation (Robertson et al., 2010). Thus, increased endogenous metabolism as well as high proteolytic activity in BSG affects its composition within a very short time (Ikurior, 1995).

Several attempts have been made in utilizing BSG in animal feeds, production of value-added compounds (xylitol, lactic acid, among others), microorganisms cultivation, or simply as raw material for extraction of compounds such as sugars, proteins, acids and antioxidants. It was also found to be applicable in enzymes production, as adsorbent for removing organic materials from effluents and immobilization of various substances (Mussatto, 2009). This review describes the feasibility of transforming the BSG into different value added products to ensure a sustainable reuse of its bioresources.

PROXIMATE COMPOSITION OF BSG

Brewers' spent grains are of high nutritive value (Tang et

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Table 1. Chemical composition of brewers' spent grain (BSG) as reported in the literature.

Components (% dry weight)	Kanauchi et al. (2001)	Russ et al. (2005)	Mussatto and Roberto (2006)	Mussatto et al. (2008a)	Adeniran et al. (2008)	Khidzir et al. (2010)
Cellulose	25.4	23-25	16.8	16.8± 0.8	-	-
Hemicellulose	-	30-35	28.4	28.4 ±2.0	-	-
Lignin	11.9	7.0-8	27.8	27.8 ±0.3	-	-
Proteins	24	19-23	15.3	-	2.4 ±0.2	6.4±0.3
Ashes	2.4	4-4.5	4.6	4.6 ±0.2	7.9 ±0.1	2.3±0.8
Extractives	-	-	5.8	-	-	-
Others	21.8**	-	-	22.4 ±1.2*	-	-
Carbohydrates	-	-	-	-	79.9 ±0.6	-
Crude fiber	-	-	-	-	3.3 ±0.1	-
Moisture contents	-	-	-	-	6.4± 0.2	-
Lipid	10.6	-	-	-	-	2.5±0.1
Acid detergent fibre	-	-	-	-	-	23.3
Total carbon (%)	-	-	-	-	-	35.6±0.3
Total nitrogen (%)	-	-	-	-	-	1.025±0.05

** Represents arabinoxylan and * stands for the combination of proteins and extractives.

al., 2009), and contain cellulose, hemicelluloses, lignin and high protein content as represented in Table 1. Moreover, it is estimated that the annual production of plant biomass in nature, of which over 90% is lignocellulose, amounts to about 200 × 10^9 tons per year, where about 8 × 10^9 to 20 × 10^9 tons of the primary biomass remains potentially accessible. Hemicellulose, which is generally 20 to 35% of lignocellulose amounts to nearly ~70 × 10^9 tons per year (Chandel et al., 2010). The most abundant monosaccharides found in BSG are xylose, glucose and arabinose (Mussatto, 2009). Others include minerals, vitamins and amino acids. The vitamins include (ppm): biotin (0.1), choline (1800), folic acid (0.2), niacin (44), pantothenic acid (8.5), riboflavin (1.5), thiamine (0.7) and pyridoxine (0.7) (Huige 1994; Mussatto et al., 2006). High amounts of calcium, magnesium, silicon and phosphorus were reported to be 1038.5, 687.5, 242 and 1977 ppm, respectively (Khidzir et al., 2010), while other minerals (such as cobalt, copper, iron, manganese, potassium, selenium, sodium and sulphur) detected in BSG were of lower concentrations. Also, protein bound amino acids have been detected including the essential ones (Essien and Udotong, 2008). The variation in percentage composition of the components is attributable to the variety of the grains used, harvest time, malting and mashing conditions, and the quality and type of adjuncts used during the process (Robertson et al., 2010).

TECHNIQUES FOR BSG PRESERVATION AND STORAGE

Several methods have been proposed to prolong brewer's spent grain (BSG) storage time as a result of its high moisture content. Factory drying has been the most effective method of preserving BSG. However, owing to the growing global concern over high energy cost, many breweries, especially those in the developing countries can no longer afford this practice (Ikurior, 1995). Drying as a preservation method has the advantage of reducing the product volume, and decreases transport and storage costs. Many breweries have plants for BSG processing using two-step drying technique, where the water content is first reduced to less than 60% by pressing, followed by drying to ensure the moisture content is below 10% (Santos et al., 2003).

However, the traditional process for drying BSG is based on the use of direct rotary-drum driers. This procedure is considered to be energy-intensive. Bartolome´ et al. (2002) studied the effects of BSG preservation using freeze-drying, oven drying and freezing methods. Their findings showed that preservation by oven drying or freeze-drying reduces the volume of the product and does not alter its composition, while freezing is inappropriate as it affects the composition of some sugars such as arabinose. But overall, freeze-drying is economically not feasible at the large scale; making the oven-drying to be the preferred method.

Thin-layer drying using superheated steam was proposed by Tang et al. (2005) as an alternative method. The circulation of superheated steam occurred in a closed-loop system; this reduces the energy wastage that occurs with hot-air drying. Also, the exhaust steam produced from the evaporation of moisture from the BSG can be used in other operations. Thus, superheated steam method has several advantages including the reduction in the environmental impact, an improvement in drying efficiency, the elimination of fire or explosion risk, and a recovery of valuable volatile organic compounds. Another method is the use of membrane filter press. In this process, BSG is mixed with water and filtered at a feed pressure of 3 to 5 bar, washed with hot water (65°C), membrane-filtered and vacuum-dried to reach moisture levels of between 20 and 30% (El-Shafey et al., 2004).

Moreover, chemical preservatives such as lactic, formic, acetic, benzoic acid and potassium sorbate can effectively be used for preserving the quality and nutritional value of BSG as reported by Al-Hadithi et al. (1985).

SUSTAINABLE UTILIZATION OF BREWER'S SPENT GRAIN

Lignocellulosic substrates, being cheap and readily available, have recently gained considerable interest because of their possible use in secondary fermentation processes. However, the utilization of BSG is limited especially in developing countries and new ways of making use of this residue would be beneficial for the process economy. The following uses in various fields have been reported in this literature:

Animal nutrition and feed formulations

The utilization of this abundantly available raw material has found a place in animal nutrition, which not only reduces the cost of feeding but also creates an outlet for this material. Thus, brewery spent grains have been utilized as feed for animals for many years (Szponar et al., 2003); the presence of cellulose, hemicellulose and lignin, and also the amount of readily available substances such as sugars and amino acids aid in its utilization as feed for ruminants (Bisaria et al., 1997).

However, high moisture content of BSG (80 to 85%) together with polysaccharide and protein makes it particularly susceptible to microbial growth and subsequent spoilage in a short period of time (7 to 10 days) (Stojceska et al., 2008). Where storage may be required for downstream processing of BSG, then deterioration through microbial activity is perceived as a potential problem, unless the BSG can be stabilized post-production (Robertson et al., 2010).

The ingestion of BSG or its derived products provides some health benefits, since dietary fiber has been generally related to affect some non-infectious diseases (Prentice et al., 1978). Also, incorporation of BSG into monogastric diets is beneficial for intestinal digestion, alleviating both constipation and diarrhoea. Such effects were attributed to the content of glutamine-rich protein, and to the high content of non-cellulosic polysaccharides and smaller amounts of β-glucans (Tang et al., 2009).

It was suggested that addition of ruminantly undegradable protein (RUP) to diets for lactating cows increased milk yield. The limiting amino acids associated with this increase are methionine and lysine. Belibasakis and Tsirgogianni (1996) found that the protein content of BSG contains the limiting amino acids. Their findings showed that BSG supplementation (45% w/w) increased actual milk yield, milk total solids content, and milk fat yield when compared to control containing maize silage (45% w/w). Also, both wet and dried BSG have been utilized as animal feed (Dhiman et al., 2003).

Feeding brewers' grain dry or wet to dairy cows had no influence on feed intake (25.6 vs. 25.1 kg/d), fat corrected milk yield (40.1 vs. 40.7 kg/d), milk composition and feed consumption. The pH, ammonia, total volatile fatty acids and molar ratios of volatile fatty acids in the rumen fluid were not different between treatments. Fatty acid composition of milk fat from cows fed diets containing dry or wet brewers' grain was identical, except $C_{18:2}$ and $C_{18:3}$ fatty acids that were lower in milk fat from cows fed wet brewers' grain when compared with dried brewers' grain.

Kaur and Saxena (2004) reported the incorporation of BSG at four levels (10, 20, 30 and 40%) in supplementary fish feed, replacing rice bran at 25, 50, 75 and 100%, respectively, and its impact on growth in *Catla catla* (Ham.), *Labeo rohita* (Ham.) and *Cirrhina mrigala* (Ham.) was monitored. About 49 and 12 g in terms of body weight gain was observed in *C. catla* and *L. rohita*, respectively fed on a diet containing 30% brewery waste in the feed. However, in the case of guinea fowls and pullet chicks, apparent metabolizable energy content of feeds containing maize, soya bean meal, groundnut cake, cottonseed meal, dried brewer's yeast, palm kernel meal and brewer's spent grains was reported to be similar (Nwokolo, 1986).

Since BSG is derived from materials utilized for humans, it can be incorporated into so many human diets, such as breads and snacks; especially where there is need to boost the fibre contents. This may provide a number of benefits; as dietary fibres have been reported to aid in the prevention of certain diseases including cancer, gastrointestinal disorders, diabetics and coronary heart disease (Stojceska et al., 2008). Increase in fibre content (from 2.3 to 11.5%) was observed when 30% BSG was incorporated into wheat flour for the production of high-fiber enriched breads. However, degree of softening and loaf volume were lower than control containing only wheat flour (Stojceska and Ainsworth, 2008). Öztürk et al. (2002) showed the incorporation of BSG of different particle size (fine, <212 μm; medium, 212 to 425 μm; and coarse, 425 to 850 μm) at 5 to 25% level into wheat flour for the production of wire-cut cookies. The results indicated a proportional increment between the particle size of the BSG and the dietary fibre content. This shows that there is a real potential for developing several new products that can meet full regulatory approval.

Production of construction bricks

Little work has been carried out in the utilization of BSG for the production of bricks (Russ et al., 2005). However, other agro-industrial wastes such as sawdust, tobacco residues, grass and processed tea waste (Demir, 2008, 2006), have been used in building bricks development, so as to reduce brick weight and increase its thermal insulation ability especially when considering the recent technology of green building. The low amount of ash coupled with the high amount of fibrous material (lignin, hemicellulose and cellulose) makes BSG suitable for use in building materials. Russ et al. (2005) found that fired finished bricks produced with BSG have a characteristic higher strength, higher porosity (higher water absorption capacity) and a lower density, which give them better properties of thermal insulation than those produced from a similar production clay. Thus, as a possible utilization option, agro-wastes generally being combustible, and during the firing process in the kiln, they can burn away leaving pores in the brick. Most frequently used pore formers in clay brick manufacturing have been classified either as organic or inorganic. Thus, BSG and other agro-wastes can be considered as organic pore-forming materials, which have the advantage of ensuring a heat contribution to the firing furnace (Demir, 2008), reinforcing the structure during drying and counteracting cracking (Ducman and Kopar, 2001).

Metal adsorption and immobilization

Several methods are used for removal of heavy metals from wastewater. But adsorption method is considered as the simplest and most cost effective technique. Plant wastes, agricultural and industrial by-products have been utilized as the cheapest and unconventional adsorbents for heavy metals from aqueous solutions (Li et al., 2009). BSG was studied by Lu and Gibb (2008) for the removal of Cu(II) ions from aqueous solutions and they found its maximum adsorption capacity to be 10.47 mg g^{-1} dry weight at pH 4.2. Based on this, BSG being a process by-product, has a significant potential as a bioadsorbent for application in the remediation of metal contaminated wastewater streams. Also, the reactive functional groups such as hydroxyl, amine and carboxyl that can be activated in BSG are responsible for the binding of metal ions (Li et al., 2009). However, pretreatment of BSG with 0.5 M NaOH solution at room temperature for 4 h greatly enhanced metal sorption and higher sorption capacities was reported to be 17.3 and 35.5 mg/g for cadmium and lead, respectively, when compared with the control, that is, BSG without pretreatment (Low et al., 2000).

In the case of dye, BSG was tested as an adsorbent on acid orange 7 dye (AO7), a monoazo acid dye used in paper and textile industries. The maximum adsorption capacity was 30.5 mg AO7/g BSG, at 30°C. This led to a conclusion that high levels of colour removal (>90%) can be achieved with low contact and that BSG can be successfully used as adsorbent of AO7 dye in aqueous solution without requiring any pretreatments (Silva et al., 2004). However, solution pH greatly affects the adsorption properties of BSG. The uptake of Cd and Pb by BSG was lowered at pH less than 3.5. This could be due to the excess of H^+ ions surrounding the binding sites making sorption unfavourable (Low et al., 2000).

There is need for cheap and efficient carrier with advantageous properties such as high cell loading capacity, low mass transfer limitations, stability, rigidity, reusability, availability, non toxic and food grade. Taking into account these requirements and trying to meet the low price target, BSG, a brewing by-product with considerable cellulose content, was suggested to be a potential carrier for yeast immobilization (Brányik et al., 2001; Almeida et al., 2003).

Brányik et al. (2001) described the stepwise pretreatments using HCl and NaOH for the hydrolysis of residual starchy endosperm and delignification of BSG; this prepares it to act as a promising alternative to the available carriers used for immobilizing yeast. Also, its irregular shape and non-homogeneity in chemical composition provide 'active sites' that are readily colonized by yeasts (Mussatto et al., 2006).

Growth medium for microorganisms and enzyme production

The polysaccharide, protein content and high moisture contents of BSG make it particularly susceptible to microbial growth and degradation. The presence of resident microflora initiates these processes within the shortest time, in an attempt to utilize it as sole carbon source (Robertson et al., 2010).

BSG was reported to be used for the cultivation of *Bifidobacterium adolescentis* 94BIM, *Lactobacillus* sp. (Novik et al., 2007), actinobacteria, especially *Streptomyces (*Szponar et al., 2003), *Pleurotus ostreatus* (Gregori et al., 2008), *Penicillium janczewskii* (Terrasan et al., 2010), *Penicillium brasilianum* (Panagiotou et al., 2006), among others. Thus, BSG was recommended as a suitable medium for isolation and maintenance of unknown strains and highly suitable for screening and production of new biologically active substances and fast spores production (Szponar et al., 2003).

In order for the microorganisms to grow on this residue, they produce a number of enzymes that aid in its utilization such as endoxylanases, β-xylosidases, α-arabinofuranosidases and esterases (Mandalari et al., 2008). However, the substrate composition as well as the strain used determines the enzyme type and activity. The presence of digestible and non-digestible organic residues makes BSG, a potential substrates on which amylolytic organisms could be cultured for the production of β-amylase and amyloglucosidase (Adeniran et al., 2008). Other enzymes of interest include xylanases, feruloyl esterases and α-L-arabinofuranosidases. BSG is rich in hemicellulose (30 to 35%) (Russ et al., 2005), since its components constitute 1, 4-β linked xylose back-bone with a heterogeneous substituents such as L-arabinose, O-acetyl, ferulic acid, p-coumaric acid and 4-O-methylglucuronic acid (Panagiotou et al., 2006). Complete breakdown of these components by micro-organisms requires the action of several enzymes which are recognized as a xylanolytic system/complex (Terrasan et al., 2010). Feruloyl esterases act synergistically with xylanases and other cell wall degrading enzymes to digest the plant cell walls and facilitate the access of hydrolases to the backbone of the wall polymers. Thus, BSG has been effectively used as a carbon source for feruloyl esterase and xylanolytic enzyme production by *Talaromyces stipitatus* (as well as *Humicola grisea var. thermoidea*) and *Penicillium janczewskii*, respectively (Mandalari et al., 2008; Terrasan et al., 2010). *Streptomyces avermitilis* CECT 3339 also produces feruloyl esterase and (1 → 4)-β-D-xylan xilanohydrolase while growing on BSG (Bartolomè et al., 2003).

This indicated that utilization of abundantly available and low-cost residues like BSG, as a substrate for enzyme production could be one of the ways which substantially reduces the enzyme production cost.

Bioethanol production

Bioethanol can be produced from starch and sugar-based crops as well as lignocellulosic biomass. Most of the starch and sugar-based crop (molasses, sweet sorghum, maize starch, sugarcane, rice, wheat, sorghum, etc), compete with human food production as well as have high production prices that restrict their industrial production. But with the increasing demand for ethanol, there is search for cheaper and abundant substrate and development of an efficient and less expensive technology so that ethanol can be made available and more cheaply (Alam et al., 2007, 2009). The composition of brewer's spent grain (BSG) as described in the literature containing primarily grain husks and other residual compounds such as hemicelluloses, cellulose and lignin (Kanauchi et al., 2001; Russ et al., 2005; Mussatto and Roberto 2006; Mussatto et al., 2008a), makes it a good feedstock for ethanol production.

Current advances for the conversion of residues like BSG to ethanol requires chemical or enzymatic hydrolysis to produce majorly fermentable sugars, followed by microbial fermentation. Thus, large amounts of enzymes required for enzymatic conversion of cellulose to fermentable sugars impacts severely on the cost effectiveness of this technology. However, *Neurospora crassa* and *Fusarium oxysporum* were found to have an exceptional ability of converting cellulose and hemicellulose directly to ethanol through the consecutive steps of hydrolysis of the polysaccharides and fermentation of the resulting oligosaccharides by secreting all the necessary enzyme systems (Xiros et al., 2008; Xiros and Christakopoulos, 2009). Both Xiros et al. (2008) and Xiros and Christakopoulos (2009) reported the ethanol yield of 74 and 109 g/kg of dry BSG by *N. crassa* and *F. oxysporum*, respectively under microaerobic conditions (0.01 vvm). Thus, brewer's spent grain can be used to generate a wide range of feedstock materials to supplement current bioethanol production from starchy feedstock.

Lactic acid production

Lactic acid (2-hydroxy propanoic acid) has found many applications in connection with foods, fermentations, pharmaceuticals and the chemical industries (Ali et al., 2009). Recently, however, there has been an increasing interest in lactic acid production because it can be used as a precursor of poly-lactic acid (PLA) production. However, the realization of this potential is dependent on whether lactic acid can be produced at a low cost which is competitive on a global scale (Bai et al., 2008).

One of the major challenges in the large-scale production of lactic acid is the cost of the raw material. The use of expensive carbon sources such as glucose, sucrose or starch is not economical because lactic acid is a relatively cheap product. Thus, the exploitation of less expensive sources would be beneficial. The agro-industrial residues are attractive alternatives to substitute these costly raw materials (Mussatto et al., 2007a, 2008b). Brewer's spent grain has found a prominent position as a raw material for lactic acid production in the presence of *Lactobacillus delbrueckii* and 5.4 g/l L-lactic acid was realized at 0.73 g/g glucose consumed (Mussatto et al., 2007a).

Hydroxycinnamic acids (ferulic and *p*-coumaric) extraction

Ferulic (4-hydroxy-3-methoxy-cinnamic acid) and *p*-coumaric acid (4-hydroxycinnamic acid) are the most abundant phenolic acids in brewer's spent grain (Bartolomè et al., 1997), with chemical structures represented in Figure 1 (c & d). This opens up new possibilities for the use of this brewery by-product. Ferulic acid exhibits a number of potential applications such as natural antioxidant, food preservative/antimicrobial agent, anti-inflammatory agent, photoprotectant and as a food flavour precursor; while *p*-coumaric exhibits chemo-protectant and anti-oxidant properties (Bartolomè et al., 2002; Faulds et al., 2002; Mussatto et al., 2007b).

Bartolomè et al. (1997) used alkaline hydrolysis to extract ferulic acid from BSG; a yield of 0.3% was obtained. Enzymatic secretions especially esterase from *Aspergillus niger* led to an increase in total ferulic acid (to 3.3%). However, the action of *Trichoderma viride* on BSG

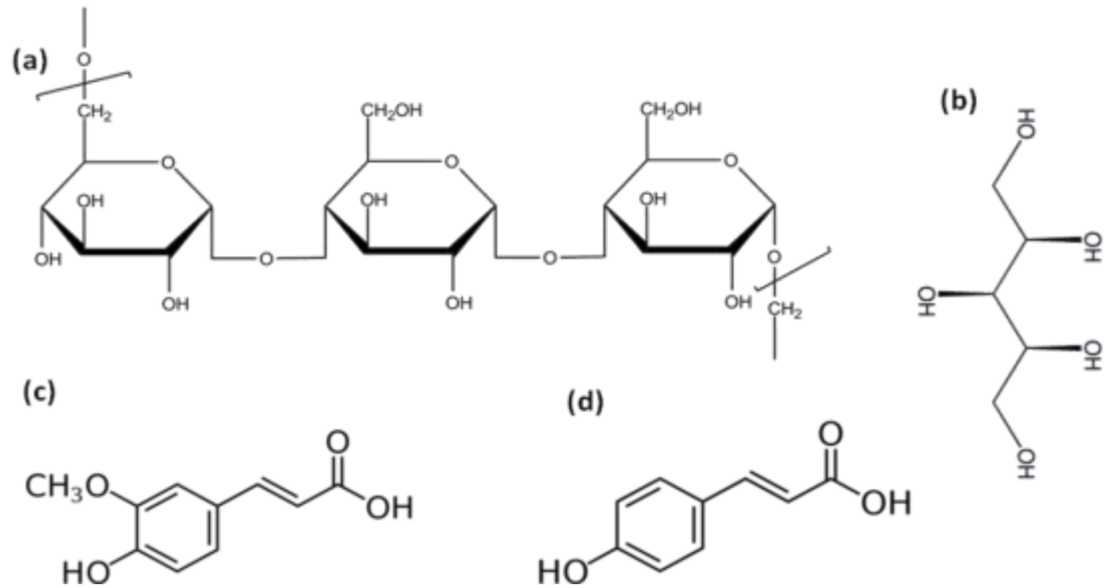

Figure 1. Chemical structures of (a) representative portion of pullulan, illustrating the primary structure of repeating linkages (b) xylitol (c) ferulic acid and (d) p-coumaric acid.

aids in the release of both xylanase and esterase, which solubilize all feruloylated material to ferulic acid. Thus, suggesting that, effective production of ferulic acid requires the combined action of both xylanase and esterase. Faulds et al. (2002) demonstrated the ability of commercial β-glucanase preparation from *Humicola insolens* used by brewing industry for reducing viscosity problems on brewer's spent grain; the preparation displayed a type-B feruloyl esterase activity against the methyl esters of ferulic, caffeic, p-coumaric and sinapic acids. This has the ability to release 65% of the available ferulic acid together with three forms of diferulate from BSG. Crude *F. oxysporum* also exhibited 2.5 folds increase in ferulic acid release (1 mg/g dry BSG) under submerged condition when compared to what was released by the recombinant *F. oxysporum* type-C FAE (FoFaeC-12213) which was used together with a commercial xylanase from *Trichoderma longibrachiatum* (Xiros et al., 2009). Thus, there is strong interests in the utilization of hydrocinnamic acids as feedstock for bioconversion into other value added products such as styrenes, polymers, epoxides alkylbenzenes, vanillic acid derivatives, guaiacol, catechol and vanillin.

Xylitol and pullulan production

Xylitol is a rare sugar that exists in low amounts in nature (Figure 1b). It acts as an excellent sweetener with some health benefits especially in its ability to combat dental caries, to treat illnesses such as diabetes, disorders in lipid metabolism and parenteral and renal lesions and to prevent lung infection (Mussatto and Roberto, 2005, 2008). Several agro-industrial residues can be used to produce xylitol, but BSG has advantage because it requires no preliminary detoxification steps; but overall production is favoured by high initial xylose concentrations, oxygen limitation, high inoculum density and appropriate medium supplementation. Brewer's spent grain has been reported to be easily and readily utilized by the yeasts *Debaryomyces hansenii* (Carvalheiro et al., 2006, 2007) and *Candida guilliermondii* where they grow and produce xylitol (Mussatto and Roberto, 2008). As such, production of xylitol from brewer's spent grain by yeasts is a potential option to upgrade this residue.

Pullulan is an extracellular water-soluble microbial polysaccharide produced by strains of *Aureobasidium pullulans*. It is a polymer of α-□-glucan consisting mainly of maltotriose units interconnected via α-(1→6) linkages (Figure 1a). This unique linkage pattern endows the polymer with distinctive physical traits, including adhesive properties and the capacity to form fibers, compression moldings and strong oxygen-impermeable films (Leathers, 2003; Roukas, 1999). Maximum pullulan concentration (6.0 g/l) was realized after 72 h of fermentation by *A. pullulans* on BSG based medium supplemented with K_2HPO_4, 0.5%; L-glutamic acid, 1%; olive oil, 2.5% and Tween 80, 0.5% (Roukas, 1999). The major problem on the use of pullulan appears to be its price. But using this cheaply available residue as a raw material makes the cost of production to be minimized.

CHALLENGES OF BSG UTILIZATION

In recent years, there has been an increasing trend towards utilization of organic wastes such as residues from the agricultural, forestry and alimentary industries as raw materials to produce value-added products using different techniques. The use of such wastes besides providing alternative substrates helps to solve environmental problems, which are otherwise caused by their disposal (Pappu et al., 2007).

As a step towards achieving the status of green environmental policy and cleaner technology approach, diversification of huge waste production and environmental preservation have focused attention on the recycling and preservation of bioresources including the brewer's spent grain (BSG). However, time, location and composition, environmental effectiveness, technological feasibility, social acceptability and economical affordability are among the key challenges associated with reliable and sustainable utilization of BSG. Though many laboratory processes, products and technologies have been explored, industrial-scale production of renewable resources from BSG is still in its infancy.

Thus, it is envisaged that in a near future based on scientific advancement in recycling and using industrial and agricultural processes for utilizing wastes including the BSG, will lead to a better use of the world resources.

CONCLUSION

Recent advances in biotechnology ensure that brewer's spent grain (BSG) is no longer regarded as a waste but rather a feedstock for producing several products. Based on this, it is an undeniable fact that BSG has its own potential for sustainable reuse through biotechnological processes. Thus, efficient recycling of BSG requires extensive R&D work towards exploring newer applications and maximizing use of existing technologies for a sustainable and environmentally sound management. Finally, more insight is required for large scale utilization, which involves both laboratory and field experiments with proper control processes.

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