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Review

Wheat bran as a brown gold: Nutritious value and its biotechnological applications

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Wheat bran, a by-product of wheat milling industry, is the outermost covering of wheat grain. It has relatively diverse application in food, feed, medicine and fermentation industries due to its richness in carbohydrates (mostly fibers), protein and fats which makes it an important dietary element. Its importance from medical view point is well documented especially in reducing blood plasma cholesterol and prevention of cardiovascular diseases and certain cancers, that is, colon cancer. In fermentation industry, wheat bran can be used as a substrate for production of a range of products such as biomass, enzyme, biofuel and production of other metabolites. In short wheat bran has immense applications and market value which makes it so important to be considered as brown gold.

Key words: Wheat bran, enzyme production, biofuel, food, health.

INTRODUCTION

Worldwide consumption of wheat, estimated by World agricultural supply and demand estimates (WASDE), has been found to be 652.18 million ton for year 2010 (WASDE, 2010). Bran is created as a by-product in milling industries (Hemery et al., 2007) and one million tons of wheat can produce upto 0.25 million tons of wheat bran (WB). WB is produced abundantly in all agricultural countries like Pakistan. WB production is coupled to the production of wheat. Wheat (*Triticum aestivum*) is an ancient known food crop, cultivated since the beginning of human civilization and ranks first among world cereal crops). Production of wheat is closely related to the supply of irrigation water and amount of rain fed water (Ahmad et al., 2010).

Although WB production is mainly dependent upon the nature of the soil (Safdar et al., 2009) and water supply but approximate yield of wheat bran is 14 to 19% of wheat kernel (Safdar, 2005). Production of WB is also dependent upon the choice of milling procedure and the physical characteristics of wheat bran tissue. More nutritionally active wheat bran fractions after debranning and degerming can be obtained by considering physical characteristics like rheology and dielectric constant. Adoption of more advanced milling techniques give rise to a quality product with more retention of the nutrient compounds and removal of the unwanted substances from the environmentally exposed outer layer of wheat. Wheat and wheat based products are primarily manufactured for human consumption (Hemery et al., 2007).

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Abbreviations: WB, Wheat bran; **SSF,** solid state fermentation; **SmF,** submerged fermentation, **LDL,** low density lipoprotein.

WHEAT BRAN COMPOSITION

Wheat kernel is made up of three major parts; seed coat or pericarp (bran), endosperm and germ (Hoseney, 1994). Detailed study by Safdar (2005) about the structure of wheat kernel shows that it contains about 68 to 80% endosperm, 14 to 19% bran and 2 to 3% germ. Antoine et al. (2002) have found that WB is a composite material made up of three discrete layers that are formed from numerous histological tissues. These tissue layers

1a 1b

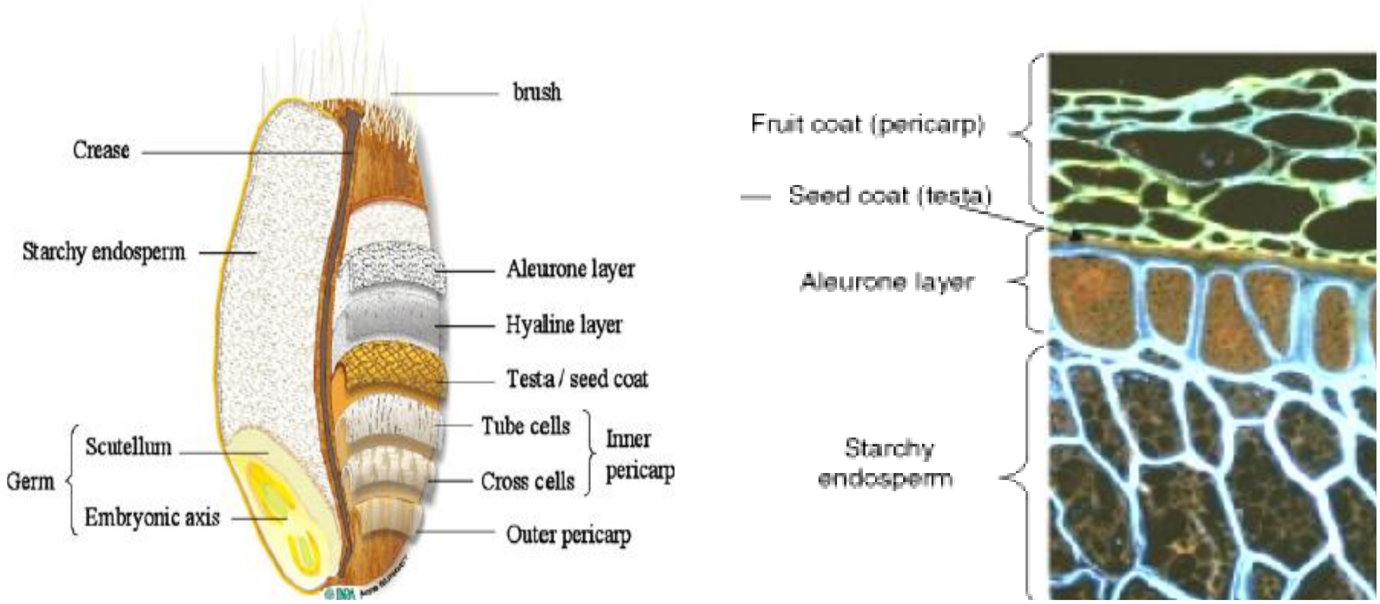

Figure 1 a). Histological composition of wheat grain. Adopted from Surget and Barron (2005), b) Microstructure of parts of intact grains of wheat. The sections have been stained with Acid Fuchsin and Calcofluor: protein appears red, cell walls rich in β-glucan appear light blue and lignified cell walls of the fruit coat appear yellowish-brown (adapted from Kamal-Eldin et al., 2009).

Table 1. Composition of wheat bran (adopted from Palmarola-Adrados et al., 2005).

Components	g/100g Wheat bran
a) Non-starch polysaccharide	
Glucan	10.5
Xylan	18.3
Arabinan	10.1
Galactan	1.1
b) Starch	34.0
c) Klason lignin	5.0
d) Crude protein	13.5
Total	92.5

are divided into outer and inner pericarp (tube cells and cross cells), testa or seed coat, hyaline layer and aleurone layer (Figure 1a and b).

WB is rich in carbohydrates (60%), protein (12%), fat (0.5%), minerals (2%), bioactive compounds and vitamins (Slavin, 2003) (Table 1). Along with these wheat bran also contains several important compounds such as phenolic acids, carotenoids, lignans, phytosterols, flavonoids, α-tochopherol and phytic acid which are distributed unequally in different WB tissues (Table 2). Precise composition of macro and micronutrients may vary from cultivar to cultivar and the extraction technique of these compounds from bran. Wheat ash content is usually measured for quantification of bran. Amount of ash (mineral content) present is a true reflective of the bran quantity in wheat (Safdar et al., 2009).

Pericarp

The outermost covering pericarp is rich in insoluble dietry fiber (cellulose, cuticle material and complex xylans with high arabinose to xylose ratio), lignin, ferulic acid and other bioactive compounds (Hemery et al., 2007). Likes et al. (2007) has investigated the presence of two important bioactive compounds; betain (an osmolyte and methyl donor) and choline in WB and found that betain is concentrated more in the bran fraction (1293.3 mg/100g flour) than the germ fraction (1163.5 mg/100g of flour) of wheat (Waggle et al., 1967).

Aleurone layer

Aleurone layer is rich in minerals, most of B vitamins and

Table 2. Location of nutrients in wheat bran layers.

Wheat bran layer	Nutrients	Reference
The pericarp	Insoluble dietry fiber Ferulic acid Bioactive compounds Vitamins	Hemery et al. (2007).
Aleurone layer	Minerals	Pomeranz, (1988); Antoine et al. (2002)
	B vitamins	
	Protein	Rhodes and Stone, (2002); Buri et al. (2004).
	Lignans	
	Bioactive compounds	
	Antioxidant	
	Phytate	Slavin et al. (1999)
	Phenolic acids	Zhou and Yu (2004); Esposito et al. (2005)
Testa tissue	Alkylresorcinols	Landberg et al. (2008)

covers about 7% of wheat grain dry mass (Antoine et al., 2002). This layer is also rich in protein and contains a good balance of amino acids than the endosperm (Rhodes and Stone, 2002; Buri et al., 2004). Lignans are also enriched in the aleurone layer of WB (Buri et al., 2004). Being an agro-economical residue it is a good source of bioactive compounds, essential vitamins and most importantly the antioxidant compounds. Other compounds that are enriched in the aleurone layer are phytate (Slavin et al., 1999) and phenolic acids (Zhou and Yu, 2004; Esposito et al., 2005). Although the prescence of various phenolic acids (vanillic, syringic, *p*-coumaric, *o*-coumaric, caffeic, and *p*-hydroxybenzoic, gallic, and gentistic acids) has been reported (Zhou et al., 2004a; Zhou et al., 2004b; Zhou and Yu, 2004; Kim et al., 2006) but the major one is the ferulic acid with a range of 1550 to 2119 mg/g bran (Li et al., 2005).

Testa tissue

According to Landberg et al. (2008) almost all alkylresorcinols (a phenolic lipid) has been present in the testa tissue of WB. The detailed composition of the three wheat bran layers is described in Table 2.

ROLE OF WHEAT BRAN

Fermentation industry

Many agro-industrial by-products are replacing the synthetic and expensive substrates for the production of biotechnological products. Among the agro-industrial substrates, WB is one of the most attractive alternatives to synthetic medium in fermentation processes (Pandey, 1992). The coarse variety of WB is an efficient substrate due to its heat dissipation, better air circulation, loose particle binding and efficient penetration by mycelia and it is cheaper than fine bran so it is a better prospect economically in fermentation industry (Malathi and Chakraborty, 1991). Almost every type of enzyme can be produced by fermentation of WB both by utilizing solid state fermentation (SSF) and submerged fermentation (SmF) systems (Table 3). Now a days WB is widely used in solid state fermentation for the production of secondary metabolites and other industrial products because it reduces pollution affects (Pandey et al., 1999). Wheat bran is a potential candidate in fermentation industry because of its unique properties listed below:

Water retaining ability

Apart from the presence of important nutritional components, physical characteristics of wheat bran also play vital role in fermentation process. WB has the ability to retain high moisture content in SSF. This ability of wheat bran promotes the fungal growth just as in the natural environmental conditions. Wheat bran proved a suitable substrate for the growth of *Trichoderma harzianum, Trichoderma viride, Trichoderma koningii,* and *Trichoderma polysporum* by SSF. There was no need of additional nutrients in WB medium for the production of *Trichoderma* spores (Cavalcante et al., (2008).

Complex substrate

Complex nature of WB lies in its unique nutrient composition. The higher starch content of WB i.e., 75.6% as compared to other agro-industrial wastes such as rice bran (coarse waste 71.1%> rice powder 55.8%> medium waste 48.6%> fine waste 34.2%) can be correlated for

Table 3. Enzyme production on wheat bran.

Enzymes	Producer microorganism	Enzyme activity	Reference
Proteases			
	Aspergillus sp. and Mucor pusilus	--	Sumantha et al. (2006)
Acid Protease	*Aspergillus oryzae*	--	Tsujita and Endo (1976); Sandhya et al. (2005)
Neutral metallo protease	*Aspergillus oryzae NRRL 2217*	--	Sumantha et al. (2005)
Acidic	*Aspergillus oryzae MTCC 5431*	8.26×10^5 U/g cell mass	Vishwanatha et al. (2009)
Alkaline	*Thermoactinomyces thalophillus PEE14*	1620 U/g cell mass	Divakar et al. (2004)
α- amylase			
	Bacillus licheniformis	--	Ikram-ul-Haq et al. (2003)
	Bacillus cereus MTCC 1305	122 U/g cell mass	Anto et al. (2006a)
	Aspergillus niger	_	Kaur et al. (2003)
	Apergillus awamori: Nakzawa MTCC 6652	9420 U/g cell mass	Negi and Banerjee (2006)
Lipase			
	Aspergillus niger	4.8 IU/ml	Falony et al. (2006)
	Bacillus megatarium AKG1	--	Sekhon et al. (2004)
	Alkalophilic Yeast		Bhushan et al. (1994)
Pectinase			
	Streptomyces lydicus	--	Jacob and Prema (2006)
	Bacillus sp. DT7	8050 IU/g cell mass	Kashyap et al. (2003)
	Aspergillus niger	36.3 IU/g cell mass	Debing et al. (2006)
	Penicillium veridicaltum RFC3	100 IU/ml	Silva et al. (2005)
	Aspergillus foetidus NRRL 341	1860 IU/g cell mass	Cavalitto etal. (1996)
Glucoamylase			
	Aspergillus HA-2	264 U/g cell mass	Anto et al. (2006b)
	Aspergillus sp.	454 U/g cell mass	Ellaiah et al. (2002)
	Aspergillus oryzae	1986 U/g cell mass	Zambare (2010)
Xylanase			
	Aspergillus niger	33%	Dobrev et al. (2007)
	Trichoderma longibrachiatum	592.7 U/g cell mass	Azin et al. (2007)
	Bacillus sp. AR009	720 U/g cell mass	Gessesse and Mamo (1999)
	Bacillus licheniformis A99	1.63 U/g cell mass	Archana and Satyanarayana (1997)
	Aspergillus niger XY-1	14637 U/g cell mass	Xu et al. (2008)

Table 3. Cont.

	Staphylococcus sp. SG-13	4525 U/l	Gupta et al. (2001)
Cellulase			
	Trichoderma reesei RUT C30	--	Sukumaran et al. (2009)
	T. viride CMGB	3.18 FPU/ml	Vintila et al. (2009)
Tannase			
	Paecilomyces variotii	--	Battestin and Macedo (2007)
	Aspergillus aculeatus DBF9	8.4 U/g cell mass	Banerjee et al. (2007)

higher amylase production (Ellaiah et al., 2002). WB can be used as an inducer for a multitude of enzymes such as CMCase, xylosidase, glucosidase, α-L-arabinofuranosidase, amylase, protease, pectinolytic enzymes, rennet, alpha galactosidase, lipase, invertase and phytase (Maheswari and Chandra, 2000; Sindhu et al., 2009; Soarse et al., 2010; Javed et al., 2011). Xylanase production on commercial scale can also be achieved by using WB as a substrate as it is an agro-economical inducer due to its high xylan content (12.65% of dry material) (Kulkarni et al., 1999; Subramanyan and Prema, 2002). Battestin and Macedo (2007) studied tannase production by *Paecilomyces variotii* and reported that the presence of important mineral contents of WB was essential for the mold growth resulting in an 8.6 fold increase in tannase production.

Nitrogen source

Naturally, higher amount of the nitrogen also requires no or little addition of other nitrogen supplements in WB containing medium. Elevated nitrogen content of WB makes it suitable for the production of enzymes such as protease, amylase and glucoamylase. Increase in the production of acid protease with an increase in the nitrogen content of WB has been reported by Vishwanatha et al., 2009. Supplementation of WB with additional protein sources such as soy flour, defatted sesame flour, casein and peptone facilitate acid protease production. Although WB alone can be used as an efficient nitrogen source but supplementation of WB with glucose, peptone, yeast extract, KH_2PO_4 and CaO resulted in the highest spore production 1.7 × 1011 spore/g dry substrate (Vishwanatha et al., 2009).

Metabolite production: WB has been used for the production of various interesting metabolites. Bacitracin was produced by *Bacillus licheniformis* using WB and soya bean in 1 : 3 (Farzana et al., 2005). Ten folds increase in the production of cyclosporine-A was observed in SSF utilizing WB than in SmF (Sekar et al., 1997). Bandelier et al. (1997) reported the production of an important plant hormone, gibberellic acid by *Gibberella fujikoroi* using WB in SSF.

Biofuel production: To deal with the problem of depletion of fossil fuel reserves with each passing years, researchers are now focusing on bioethanol production from natural substrates to meet energy challenges of the millennium (Shafiee and Topal, 2009). Wheat milling by products are now being focused for fermentative production of bioethanol (Palmarola-Adrados et al., 2005; Hawkes et al., 2008; Manikandan and viruthagiri, 2009). Manikandan and Viruthagiri (2009) investigated the simultaneous saccharification and fermentation of WB that resulted in highest ethanol concentration of 23.1 g/L after 48 h of fermentation. Palmarola-Adrados et al. (2005) converted the complex polysaccharides in WB to sugar rich feedstock for conversion to ethanol. The overall sugar yield by combined hydrolysis method (acid treatment and enzymatic hydrolysis) reached 80% of the theoretical and it consisted of 13.5 g arabinose, 22.8 g xylose and 16.7 g glucose per 100 g starch-free bran. In addition to using WB as sole source for ethanol production, it can also be used as a nutritive supplement for ethanol production by *Zymomonas mobilis* rather than the synthetic supplements (Shamala and Sreekantiah, 1988). Moreover WB can also act as potential substrate for biobutanol production, which may be used as a replacement for gasoline (Liu et al., 2010).

Fermentative bio-hydrogen production from carbohydrate-rich substances can be achieved through anaerobic digestion by bacteria (Pam et al., 2006). Acid treatment of WB followed by anaerobic digestion with mixed anaerobic culture resulted in maximum hydrogen yield of 128.2 ml/g total volatile solid (TVS) and hydrogen production rate of 2.50 ml/ (g-TVS h). Maximum hydrogen content was 62% with negligible methane production (Pan et al., 2008). Treatment of WB with NaOH and H_2O_2 and then fermentation with mixed culture in sewage sludge produced 22 and 31 m^3 H_2 per ton dry weight assuming that all the sugar is hexose. Fermentation of unhydrolysed wheat feed is also known to improve H_2 yield (Hawkes et al., 2008).

Bioremediation

The removal of heavy metal ions from abandoned industrial sites is a major challenge for decontamination and rehabilitation of industrial wastewaters. Presence of heavy metal ions such as Cu (II), Pb (II), and Cd (II) is a potential threat for human health. The use of lingo-cellulosic compounds from wheat bran for the removal of these heavy metal ions offers a cheap and flexible substrate. WB contains lignin, cellulose and fatty acid units whose functional group content (hydroxylic, carboxylic and phenolic) is ideal for ion fixation. It can be used as a natural filter for decontaminating industrial effluent containing heavy metals. This method can be a cheap alternative to conventional pollution control methods for wastewater by use of synthetic resins for heavy metal adsorption (Dupont et al., 2003).

Health aspects

Compounds (such as vitamins, lignans, phenolic acids and alkylresorcinols) present in bran are desirable ingredients to be added in daily diet to improve the nutritional value of food. So WB can be used as natural and cheaper source of value added products in preparation of functional food ingredients or for fortification of certain products. The quality, safety and stability of food products can be enhanced by adding antioxidants in the food. These antioxidants can terminate the free radical chain reactions and can reduce the incidence of diseases such as cancer, cardiovascular disease, parkinson's disease, cell injury, cell death, and slow down the aging process, when these are consumed in the human diet (Halliwell, 1996). Lignan metabolites act as antioxidants and play a role in antitumor activities resulting in the control of estrogen level (Qu et al., 2005).

Soluble and insoluble dietary fiber of WB is known to lower blood plasma cholesterol, serves as an effective laxative and plays a role in colon cancer prevention (Lupton and Turner, 1999; Topping, 2007). Several epidemiological studies have revealed that the risk of cardiovascular disease can be reduced by consuming bran based products (Halliwell et al., 1992; Gorinstein et al., 1998; Sabovic et al., 2004; Willcox et al., 2004; Minhajuddin et al., 2005; Jensen et al., 2006). Antioxidant compounds present in WB (Table 4) play a vital role in reducing the risk factor for different diseases by a variety of preventive mechanisms (Flight and Clifton, 2006). The predominant phenolic acid in wheat grain is ferulic acid, which has the potential to restore endothelial function in aortas of spontaneously hypertensive rats and to prevent trimethylin-induced cognitive dysfunction in mice (Kim et al., 2007; Suzuki et al., 2007). Oxidation of low density lipoprotein (LDL) cholesterol induced by copper can lead to atherosclerosis and ultimately the coronary heart disease. WB phenolic's binding to apo-lipoprotein has been shown to hinder the copper binding to LDL (Satue-Gracia et al., 1997) and also in copper removal from LDL surface (Decker et al., 2001). Craig (2004) demonstrated the protective role of betaine and choline against osmotic stress in internal organs and improvement of vascular risk factors. Protective role of betain against coronary heart disease has also been evidenced (Craig, 2004).

WB is also a rich source of lipid-soluble compounds and phytochemicals such as phytate, phytosterols, tocopherols etc. Among which phytates play an important role in prevention of colon cancer (Reddy et al., 2000). Sang et al. (2006) studied the effect of WB oil and its subfractions in mouse model of human colon cancer cell lines and demonstrated the intestinal cancer preventive activity of wheat bran oil. Reddy et al., (2000) also demonstrated that oil fraction of WB contains bioactive compounds that inhibits colon carcinogenesis.

From the facts it can be deduced that addition of whole grain or bran containing diet exerts certain metabolic benefits and reduces the risk of diabetes (Jensen et al., 2004) cardiovascular diseases (Pereira et al., 2002; Jensen et al., 2004), colon cancer risk (Lupton and Turner, 1999; Reddy et al., 2000; Freudenheim et al., 1990), hypertension (Whelton et al., 1997) and coronary heart disease (Craig, 2004)

As food and feed additive

20% WB supplementation to flour and baked product offer an inexpensive and interesting alternative to the synthetic vitamins and nutrient supplements for poor people by adopting some pretreatment procedures (Gomez et al., 2003). Pretreatment (grinding to obtain smaller particle size, heat treatment, pre-fermentation with yeast and lactic acid bacteria and extrusion) of bran improves the nutritional as well as physical quality of bread and baked products (De Kock et al., 1999; Salmenkallio-Marttila et al., 2001).

WB is a very acceptable raw material for animal feed preparations. Addition of 30% wheat bran and 30% rice

Table 4. Concentration of antioxidants in wheat bran.

Antioxidant	Concentration (µg/100 g)	Reference
Lignans		
lignan aglycones	2774	
Syringaresinol	1953	
Isolariciresinol	297	
Lariciresinol	257	Begum et al. (2004)
Secoisolariciresinol	142	
pinoresinol	106	
matairesinol	9.4	
Carotenoids	0.68	
Lutein	1.8	Adom et al. (2003)
Zeaxanthin	0.54–27	
Tocopherols		
α tocopherols,	1.28–21.29	
δ tocopherols,	0.23–7.0	Zhou and Yu (2004)
γ tocopherols,	0.92–6.90	

bran in daily feed of cows improved the daily milk yield up to 14.65 and12.87 L respectively. Results proved that wheat bran is nutritionally better than rice bran for the lactation of Holstein Friesian cows (Tahir et al., 2002). Saima et al. (1999) reported the production of biomass protein by growing *Candida utilis* and *Brevibacterium flavum* strains on wheat bran. Crude protein (35.97%) and true protein (30.18%) was measured in biomass. Furthermore, chicks fed on biomass protein gained comparable protein efficiency ratios and meat protein than the fish meal protein.

ECONOMIC ASPECT AND FUTURE RECOMMENDATIONS

Each year million tons of wheat-milling by-product that is, bran has been produced but only a little is consumed as a food supplement. 24.214 million tons of wheat was produced in the year 2010 to 2011 in Pakistan which can ideally yield 6.0 million tons of wheat bran. By considering the cost of wheat as $200/ton, thousands of dollars can be earned by WB inclusion in fermentation industry and several value added fermented products can also be brought into market with remarkable low price.

There is a strong emphasis that wheat should be consumed as whole grain flour (including the bran) or the bran should be supplemented in various bakery products to enrich the daily consumables with an inexpensive nutrient reservoir. In addition being a rich source of fiber it also serves as a solid inert matrix for absorption of heavy metal ions in the filtration plant manufacturing. These properties of WB has made it importance upto a million dollar product. If an effective strategy is applied then this bran can be exploited for fermentation business and food supply for health benefits. Economics of dairy and poultry industries can be improved by utilizing wheat bran pellets as cattle and broiler chicks feed. As a result it can not only support the economics sector but in addition it will prove to be a cheap raw material for production of various products of fermentation industry.

Comments

Wheat is the most important food component around the globe. It is commonly used in refined form excluding its outer husk 'The Bran'. Each year millions and tons of bran has been produced as a by-product of wheat milling industry. Wheat bran is rightly known to be the gold product and finds its applications not only in fermentation industry but also in pharmaceutics and biomedical research. Pakistan, being an agricultural country, produces tons of wheat each year. Wheat bran from wheat-milling industries in our country can serve as a potential nutritious and cheap raw material for fermentation industry while its anti-oxidative and anti-inflammatory properties can bring about a revolution in the field of melanoma research. Hence, it is rightly known to be the brown gold for its amazing properties.

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