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Research progress on antioxidant activity and application of sorghum bran

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Abstract: *Sorghum bran (SOB), a by-product derived from the processing of sorghum grains, is rich in various bioactive compounds such as polyphenols, flavonoids, dietary fiber, and minerals. Although traditionally considered a low-value agricultural waste, SOB has recently garnered attention due to the demand for sustainable development and efficient utilization of natural resources. Extensive research indicates that SOB can reduce oxidative stress levels in the body through its significant free radical scavenging ability, exhibiting notable antioxidant, anti-inflammatory, and health-promoting functions. This review discusses the composition of SOB and its applications in both food and non-food sectors, and outlines its potential biological activities and antioxidant functions. Overall, with further in-depth research and technological development, SOB is poised for widespread use in food additives, functional foods, natural antioxidants, and other areas, thereby providing new ideas for the development of antioxidants and functional foods.*

Keywords: *Sorghum Bran, Bioactive Compounds, Antioxidant*

1. Introduction

Sorghum ranks fifth in annual production, following rice, wheat, corn, and barley [1]. Before being used as food, sorghum grains typically undergo abrasive dehulling, and during milling, the bran portion is readily separated [2]. In recent years, whole grain foods have become more popular, as diets that include grain bran can significantly improve chronic diseases related to nutrition and promote sustainability by reducing waste generated from food processing. Compared to commonly consumed sorghum, sorghum bran (SOB) is richer in beneficial components, such as dietary fiber and polyphenols, which have significant roles in anti-biofilm activity [3], antiviral [4], immunomodulatory activity [5], and antioxidant effects [6]. Studies have shown that the polyphenol content in sorghum bran is 3 to 6 times higher than in sorghum caryopsis. Among them, brown sorghum has the highest extractable tannin content, black sorghum has the highest 3-deoxyanthocyanidin content, while the phenol content in the bran of white sorghum is much lower than that of black and brown sorghum [2].

Free radicals and reactive oxygen species are continuously formed in the human body, and may induce autoimmune diseases when the human body is exposed to harmful stimuli, causing acute or chronic, local or systemic inflammation. Reactive oxygen species can prevent pathogen invasion, consume malignant cells, and promote wound healing. However, if the immune response is sustained for a long time, it will lead to immune imbalance, causing irreversible damage [7]. Dietary polyphenols are among the most important natural antioxidants and chemopreventive agents in the human diet. The content of phenolic compounds in SOB is relatively high, exhibiting strong antioxidant activity. Polyphenolic compounds, with their directional characteristics and highly conjugated systems containing polyhydroxyl groups, act as excellent electron or hydrogen atom donors, thereby neutralizing free radicals and other reactive oxygen species. Dietary polyphenols also function as antioxidants, interfering with oxidative stress signaling, inhibiting pro-inflammatory signaling, directly reacting with reactive oxygen species, and activating cell signaling pathways [8].

The yield of milled SOB is approximately 20%, making it an important functional by-product that not only enhances the resource utilization of sorghum but also provides significant health and environmental benefits. Therefore, this paper will outline the application progress, bioactive functions, and antioxidant mechanisms of SOB, offering insights into its development as a novel antioxidant with advantages such as low cost and wide availability.

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2. Composition of sorghum bran

SOB is a significant functional byproduct, rich in nutrients such as plant proteins, phytin, and various phenolic compounds, displaying a diverse and abundant array of phenolic substances. Its composition includes different forms of phenolic compounds, including free phenols, soluble esterified phenols, soluble glycosylated phenols, bound esterified phenols, and bound glycosylated phenols [9]. Additionally, SOB contains a variety of phenolic compounds, such as gallic acid, chlorogenic acid, caffeic acid, p-coumaric acid, ferulic acid, salicylic acid, among others, albeit in varying proportions, demonstrating the diversity and richness of phenolic substances in SOB [10]. Its main constituents include moisture, starch, proteins, crude fiber, ash, tannins, and crude fat, alongside phenolic compounds, alcohol-soluble proteins, and carbohydrates [11, 12]. SOB, a byproduct of sorghum processing, serves as a rich source of protein, containing alcohol-soluble proteins albeit in lower amounts compared to sorghum endosperm [12]. The carbohydrate content in SOB mainly comprises starch, cellulose, and hemicellulose, serving as suitable carbohydrate sources.

3. Application of sorghum bran in food and non-food industries

3.1 Food industries

SOB is commonly employed as a nutritional fortifier in food, added to flour, cereal products, or baked goods. It is rich in fiber, vitamins, and minerals, contributing to the enhancement of the nutritional value of food. Additionally, SOB can function as a component in food items such as biscuits, cereals, or energy bars. SOB can be utilized in functional foods and beverages, as well as nutritional supplements and cosmetic formulations [13]. Furthermore, SOB is a starch-rich byproduct of food processing that can be subjected to submerged fungal fermentation using Aspergillus niger to produce glucoamylase, yielding results similar to those obtained using commercial glucoamylase. Glucoamylase can hydrolyze α-1,4-glycosidic bonds within polysaccharides like starch, widely applied in alcohol production, starch hydrolysis, monosodium glutamate, and antibiotics [14]. SOB can condense tannins (proanthocyanidins) and inhibit hyaluronidase activity. Hyaluronidase activity is crucial in diseases like osteoarthritis and skin aging. Gluten-free foods often exhibit poorer nutritional profiles, compromised health benefits, and higher costs. Sorghum are gluten-free grain with elevated phenolic compound content and cost-effectiveness. Therefore, SOB holds tremendous potential and can be utilized in food applications as a functional ingredient in the production of health-oriented food items, such as biscuits [15].

In addition, bioactive compounds in food play a crucial role in preventing oxidative stress. SOB contains a substantial amount of phenolic compounds, serving as a source of phenolic antioxidants. The content and composition of proanthocyanidins in the mixture significantly enhance its antioxidant activity. In the field of food, products enriched with SOB exhibit robust antioxidant and anticancer capabilities. The application of SOB pericarp as a natural phenolic antioxidant in the production of functional food formulations has been proposed [16]. The pericarp of Lacquer tree sorghum (Sorghum bicolor L. Moench) contains polyphenolic compounds promoting health and has been utilized in the production of an acidified cold-brew SOB beverage. The beverage, containing condensed tannins and other flavonoids, demonstrates in vitro antioxidant capacity [17]. In bread products, sorghum (Sorghum bicolor L. Moench) flour can impart acceptable gluten-free bread characteristics, with tannin-rich sorghum varieties concentrating antioxidants and dietary fiber in the bran. The addition of Lacquer tree SOB enhances the dietary fiber and antioxidant potential of sorghum-based bread without compromising quality attributes [18]. The imbalance between free radicals and antioxidants, known as oxidative stress, promotes cell aging and the development of chronic non-communicable diseases. Caffeic acid, ferulic acid, and coumaric acid in SOB contribute to the scavenging of 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS) free radicals in varying proportions. Various interactions among different bioactive substances in sorghum have a significant impact on their potential biological activity [19]. In addition to antioxidant activity, SOB also showed excellent anti-cancer activity and improved diabetes and insulin resistance, which may suggest that SOB can be used as a special health food. But these functions still require sufficient in vivo experiments to verify [20].

3.2 Non-food industries

SOB finds diverse applications in non-food industries. It is commonly utilized in animal feed to provide fiber and nutrition. Furthermore, the fiber characteristics of SOB make it a raw material in the

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production of pulp and paper [21]. In the industrial context, SOB serves as a source of biomass energy, contributing to power generation or the production of biofuels [11]. Its fiber and other properties also present potential applications in areas such as construction materials, fiber products, and bioplastics. SOB particles exhibit promising reinforcing capabilities in polymer-based composite materials, suggesting their thermal stability for potential future composite material applications [22].

4. Biological function of sorghum bran

SOB is widely acknowledged for its multifaceted biological functions, including antioxidative, anti-inflammatory, antibacterial, and antiproliferative capabilities. However, its bioavailability is constrained by structural properties, as approximately 80% of the compounds are esterified to arabinoxylans, limiting their effective utilization in vivo [23]. Studies have shown that high-temperature extrusion processing can significantly increase the content of phenolic compounds and enhance the antioxidative capacity of SOB, potentially benefiting patients with oxidative stress and inflammation-related diseases. Furthermore, high-temperature treatments, such as boiling and extrusion, aid in enhancing the bioavailability of hydroxycinnamic acids in SOB, although the bioavailability of caffeic acid, ferulic acid, p-coumaric acid, and sinapic acid is relatively low [24].

SOB extract is rich in polyphenolic compounds, such as gallic acid, chlorogenic acid, caffeic acid, p-coumaric acid, ferulic acid, and salicylic acid [10]. These polyphenolic compounds not only promote human health but also exhibit antibacterial and antioxidative activities, as well as anti-inflammatory and anticancer properties [25]. SOB extract demonstrates significant scavenging effects on DPPH and ABTS radicals, exhibiting concentration-dependent behavior. Moreover, SOB extract has been validated for its inhibitory effects on HepG2 cell proliferation, with the subcritical water extraction extract showing higher inhibitory rates at a concentration of 200 μg/mL, and its half maximal inhibitory concentration value significantly lower than that of the hot water extraction extract. These findings are consistent with previous reports of anticancer activity of sorghum grains or bran extracts against cancer cells, suggesting a pivotal role of polyphenolic substances in anticancer activity [26]. Procyanidin-rich extract (PARE), a flavonoid compound extracted from SOB, exhibits various biological functions, including anti-inflammatory, anticancer, and cardiovascular protective effects. Studies have demonstrated its significant antioxidative activity, preventing D-galactose-induced oxidative stress and reversing oxidative damage in aging mice [27].

SOB extract also exhibits inhibitory effects on protein glycation, a non-enzymatic reaction pivotal in the pathogenesis of diabetic complications. Additionally, the intake of SOB may confer significant health benefits for individuals with metabolic syndrome and diabetes [28]. Previous studies have also indicated the inhibitory effects of certain components in SOB on the proliferation of human cancer cells. PARE has been shown to inhibit tumor growth and metastasis formation in Lewis lung carcinoma mice, significantly suppressing tumor volume and weight [27]. PARE demonstrates potential antitumor activity by effectively inhibiting tumor growth and metastasis formation. Moreover, SOB extract exhibits antibacterial activity against common foodborne microorganisms, such as Escherichia coli and Staphylococcus aureus. Therefore, SOB, as a plant extract, holds promising prospects for health and medicinal applications [25].

5. Antioxidant activity of sorghum bran

As a by-product of sorghum grain processing, SOB has garnered increasing attention and research interest for its antioxidant activity in recent years. SOB is rich in various bioactive substances, including polyphenols, flavonoids, anthocyanins, dietary fiber, and minerals [29]. These components endow SOB with a high antioxidant capacity, presenting promising applications in the fields of food, medicine, and health products [30]. Studies have demonstrated a positive correlation between the antioxidant activity of SOB and its total phenolic compound content [16]. Among these, caffeic acid, cinnamic acid, ferulic acid, gallic acid, salicylic acid, vanillic acid, and p-coumaric acid are the dominant phenolic acids in sorghum grains [31]. The average antioxidant activities of total phenolic substances, DPPH, ABTS, and oxygen radical absorbance capacity in brown tannin SOB are 3.5 times higher than those of whole grains, with the polyphenol content in white SOB being nearly twice that of red SOB [30, 32]. The addition of SOB from lacquer tree can enhance the dietary fiber content and antioxidant potential of sorghum-based bread without affecting its quality attributes [18].

The antioxidant defense system has evolved as a means to prevent oxidative stress, with nuclear factor

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erythroid 2–related factor 2 (Nrf2) being a key regulator. Nrf2 is responsible for regulating a wide array of antioxidant enzymes involved in the detoxification and elimination of oxidative stress and has been extensively studied in various disease contexts [32]. Research has found that methyl caffeate, a major component of SOB, exerts antioxidant effects via the Nrf2/HO-1 pathway [33]. SOB extracts exhibit significant free radical scavenging ability, effectively inhibiting lipid peroxidation reactions and reducing free radical-induced cellular damage [34]. Free radicals are highly reactive molecules produced during metabolic processes within the body, capable of damaging cells and tissues, leading to various chronic diseases such as cardiovascular diseases, cancer, and Alzheimer's disease. The free radical scavenging activity of SOB is significantly correlated with its polyphenolic compound content [18]. Specifically, phenolic acids and anthocyanins can exert antioxidant effects by directly scavenging free radicals or inhibiting their formation, thereby reducing oxidative stress on the body [35, 36]. Research indicates that diets supplemented with SOB extracts significantly increase the antioxidant enzyme activity in experimental animals, reducing oxidative stress levels and associated biomarkers such as malondialdehyde (MDA) [27]. SOB extracts not only effectively reduce MDA concentrations in red blood cells but also increase the glutathione/glutathione disulfide (GSH/GSSG) ratio, restoring red blood cells to normal states. Red blood cells with relatively low activities of superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GSH-Px) are also protected [37]. The flavonoids in SOB can further enhance the body's antioxidant defense mechanism by regulating antioxidant enzyme activity. Studies show that proanthocyanidins and simple flavonoids extracted from SOB of lacquer tree can inhibit aromatase with mixed kinetics, indicating potential therapeutic potential for breast cancer [38]. Additionally, the total phenolic content and ferric reducing ability value of SOB correlate positively with hyaluronidase activity, where proanthocyanidins and polyphenols play a crucial role, suggesting potential in treating inflammatory arthritis [13]. These enzymes play a critical role in the body's antioxidant defense system, effectively neutralizing oxidants and protecting cells from oxidative damage. Furthermore, the dietary fiber in SOB also has significant antioxidant effects. Although not traditional antioxidants, dietary fibers can combat oxidative damage through various mechanisms. They can adsorb and bind to oxidants and heavy metals in the body, reducing their accumulation and toxic effects, thereby lowering oxidative stress [39, 40]. Moreover, dietary fiber can promote the growth of beneficial gut bacteria, producing short-chain fatty acids with notable antioxidant and anti-inflammatory effects, aiding in improving oxidative stress status in the body [41].

In summary, as a rich source of antioxidant components, SOB holds significant application value. Through further research and development, SOB is expected to play a vital role in the fields of functional foods and natural antioxidants, thereby achieving efficient resource utilization and enhancing health levels.

6. Conclusion

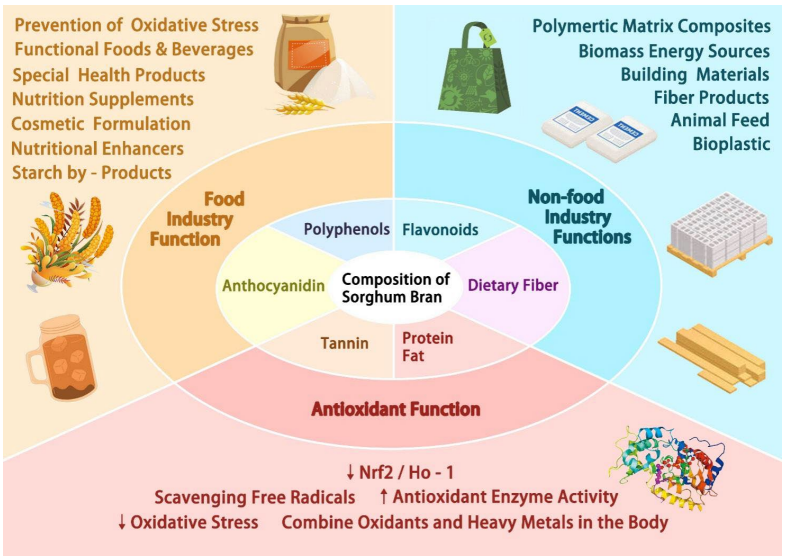

Figure 1: Summary of the composition of sorghum bran and its food industry, non-food industry, antioxidant function

SOB is a by-product of sorghum grain processing, rich in nutrients and bioactive compounds such as

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polyphenols, flavonoids, dietary fiber, and minerals. In recent years, SOB has garnered extensive attention due to its exceptional antioxidant activity, demonstrating significant potential for various applications. As a cost-effective and sustainable raw material, SOB has found multiple uses in the food industry, including as a functional food ingredient that enhances the nutritional value and antioxidant capacity of food products. Additionally, SOB exhibits broad application prospects in non-food sectors, such as serving as a natural antioxidant, a feed additive, and a raw material for bio-based materials (figure 1). These applications not only contribute to the efficient utilization of resources but also promote sustainable development practices, offering new economic growth opportunities for related industries.

In summary, as a natural resource rich in antioxidant components, SOB holds substantial potential for development and application. Through further research and technological advancements, SOB is expected to find widespread use in food additives, functional foods, and natural antioxidants, thereby promoting efficient resource utilization and environmental sustainability.

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