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Nutritional, Therapeutic, and Functional Applications of Sorghum: A Comprehensive Review

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Abstract

Sorghum is a nutrient-rich cereal grain with bioactive compounds that offer numerous health benefits. Key bioactive constituents include phenolic acids, flavonoids, tannins, and dietary fiber, which contribute to its functional food properties. Sorghum contains phenolic acids like ferulic, p-coumaric, and caffeic acids, which act as antioxidants, reducing oxidative stress linked to heart disease, cancer, and inflammation. Flavonoids such as luteolin and apigenin possess neuroprotective, anti-inflammatory, and anti-cancer properties and support cardiovascular health by reducing arterial plaque buildup. Colored sorghum varieties are rich in condensed tannins (proanthocyanidins), which exhibit antioxidant activity, improve gut health, lower cholesterol, and potentially aid in weight management. Sorghum is high in dietary fiber, promoting healthy digestion, regulating blood glucose, and supporting gut microbiota. Policosanols in sorghum help lower LDL cholesterol and improve lipid metabolism, contributing to cardiovascular health and weight management. Other phytochemicals like phytic acid, polyphenols, and sterols reduce the risk of chronic diseases due to their antioxidant and cholesterol-lowering effects. Nutritionally, sorghum is high in protein (9-13%), dietary fiber (6%), and essential minerals such as magnesium, phosphorus, zinc, and iron. It also contains B-complex vitamins, vitamin E, and essential fatty acids like oleic and linoleic acid. Sorghum's nutritional profile supports growth, metabolism, and disease prevention, particularly in managing cardiovascular health, weight, and cancer risk. Sorghum's hardiness, low input requirements, and nutritional value make it a sustainable crop ideal for addressing food security and climate adaptability. Its resilience to environmental stresses positions it as a critical component in sustainable agriculture, supporting global food systems amidst environmental challenges.

Introduction

One common crop in the Gramineae family is sorghum, sometimes known as sorghum bicolor. It started in Africa, but it has now spread to America, Asia, and Australia for growth. Its capacity to adapt to many soil types and climates contributes to the fact that it is a crucial source of basic food for millions of people worldwide [1]. Plantae, division Magnoliophyte, class Liliopsida, order Cyperales, family Poaceae, subfamily Panicoideae, tribe Andropo goneae, and subtribe Sorghinae, subsp. bicolor are all members of the genus Sorghum [2]. There are four main varieties of sorghum: biomass, forage, sweet, and grain sorghum. In addition to disparities in height, traits, and uses, some groups displayed significant genetic variations [3]. Sorghum contributes significantly to the agricultural economy because of its versatility and its position as the world's fifth most important cereal crop in terms of output volume and area usage [4]. This neglected cereal grain has a great deal of potential for practical use in unforeseen circumstances, such pandemics. This crop's cultivation improves nutritional value and general health while also promoting economic sustainability and subsistence. Numerous empirical studies have explored the broader functional potential of sorghum, elucidating its nutritional parity with commonly ingested grains such as maize.

The primary goals of this analysis are to examine the nutritional advantages, prospective medical uses, and contribution of sorghum to sustainable agriculture.

Advantages of Sorghum over other grains

Because of its extensive root system and resistance to salinity, sorghum also helps to conserve soil from an ecological perspective, preserving biodiversity in agricultural systems. Because it requires less inputs than other crops, sorghum is a useful crop for farmers with minimal resources. It may thrive in a variety of environments due to its innate tolerance to biotic and abiotic stresses. Despite being primarily utilized as a staple food, it can also be used as an energy crop for sustainable bioenergy, cow feed, and a raw material for industrial processes. Sorghum is essential to maintaining global food security since it may be utilized as an industrial product, animal feed, a source of bioenergy, and a staple grain [4]. Sorghum is considered a hardy crop when compared to other cereal crops, especially those of the C3 sort [5]. Because of its high energy content and drought resistance, it is the ideal crop choice in light of climate change [6]. Sorghum is a significant source of energy because it has about the same amount of carbohydrates as maize. However, because glucose is released more slowly, its carbohydrate digestibility is frequently lower, which may help with blood sugar regulation. About 10-12% protein is found in sorghum, which is equivalent to wheat and maize but somewhat higher than rice. However, low amounts of lysine, an important amino acid, frequently impair the quality of its protein. Sorghum has a fat content of 2-4 percent, which is comparable to that of rice and wheat but marginally lower than that of maize. Compared to maize and polished rice, sorghum contains more dietary fiber. Its fiber profile, which includes insoluble fiber, provides advantages for controlling cholesterol and supporting digestive health. Sorghum has a comparable amount of fiber to wheat, but it contains special kinds of dietary fiber, like certain arabinoxylans, which support its prebiotic properties.

When it comes to utilizing water and converting solar energy, sorghum is one of the most effective crops [7]. The nutritional value of sorghum is similar to that of other cereals in terms of protein, fat, carbohydrates, and non-starch polysaccharides, as well as bioactive components like vitamin B and fat-soluble vitamins (D, E, and K), micronutrients, macronutrients, and non-nutrients like carotenoids and polyphenols.

In terms of protein, fat, carbohydrate, and non-starch polysaccharides, sorghum is comparable to other cereals. It also contains micronutrients, macronutrients, and non-nutrients like carotenoids and polyphenols, as well as bioactive components like vitamin B and fat-soluble vitamins D, E, and K. These elements are responsible for the grain's many health advantages, including its potent antioxidant activity, ability to scavenge free radicals, anti-inflammatory, anti-cancer, and anti-oxidative properties, according to one report [8]. This crop's cultivation improves nutritional value and general health while also promoting economic sustainability and subsistence. The increased functional potential of sorghum has been the subject of numerous empirical studies, elucidating its nutritional equality with commonly consumed grains such as maize. In many regions, such as the US and the Mediterranean, sorghum might be regarded as a gluten-free substitute due to dietary preferences, which broadens its appeal to a wider range of consumers [9].

Sorghum is a healthy option for anyone with celiac disease or gluten intolerance because it is gluten-free. Its versatility is demonstrated by the fact that it is used in a variety of food groups, from cereals and snacks to drinks and pastries. Compared to other cereals, this grain possesses a unique richness in a range of bioactive components. Phenolic compounds, which have a number of health advantages, make up the majority of the range of bioactive substances. The most notable phenolic compounds in sorghum for their potential health benefits are flavonoids.

In addition, sorghum has a lot of phenolic compounds, such as ferulic, gallic, and vanillic acids, which have been demonstrated to have anti-inflammatory and antioxidant properties in addition to a host of other health benefits. Despite being a major grain and having a high concentration of phytochemicals, there doesn't seem to be much research on how eating sorghum affects human health, namely inflammation and other pathogenic processes. The potential of sorghum grains as functional ingredients is supported by the presence of a range of bioactive components in addition to phenolics [10].

These consist of dietary fibers, polyunsaturated fatty acids, iron, zinc, phytosterols, and policosanols. Increasing the production of bioenergy requires it. The sweet kind of sorghum is especially useful for producing biofuel; the stalk is used to manufacture ethanol and the grain is used to make biodiesel. Farming sorghum has profound and wide-ranging social effects. It is a vital resource that supports rural economies for a large number of small-scale farmers and enterprises with an agricultural focus. Therefore, the significance of sorghum extends beyond ensuring food security; it also plays a significant role in fostering sustainable agricultural practices and advancing rural development [11].

Many civilizations have long utilized grain sorghum for a number of reasons. Sorghum grain is processed and frequently used as a substitute for maize in traditional recipes such as ugali. It is commonly used with other grains including cowpeas, amaranthus, and green grams to create nutritious meals [12]. Nonalcoholic beverages made from sorghum millet are a common choice all around the world. Sorghum is used to make motoho, the traditional dish of Lesotho. It is made by first making a thin slurry with sorghum grain and warm water. Tomoso, a traditional beginning culture, is then introduced into this slurry. The tomoso starting culture initiates the fermentation process, which is necessary for producing motoho [13].

Serial No.	***Nutrient/Component***	***Sorghum***	***Wheat***	***Rice***	***Maize***	***Barley***
1.	Protein (%)	10-12	10-13	6-8	8-11	10-12
2.	Carbohydrate (%)	70-75	70-75	77-80	72-73	73-75
3.	Fibre (%)	6-7	10-12	2-3	6-8	10-17
4.	Iron (mg/100g)	4-5	3-4	1-1.5	2-3	2-3
5.	Calcium (mg/100g)	20-30	30-40	10-15	5-10	30-40
6.	Antioxidants	High	Moderate	Low	Moderate	Moderate
7.	Gluten Content	None	Present	None	None	Present
8.	Glycemic Index	Low to Moderate	Moderate to High	High	Moderate	Moderate

Table 1: Summary Table of Sorghum's Nutritional Profile Compared to Other Cereals.

Composition of Sorghum

Although sorghum grain contains carotenoids such as lutein, zeaxanthin, and β-Carotene, its quantities may be lower than those of other grains. Additionally, sorghum grain contains trace amounts of antioxidants, such as α-Tocopherol and α-Tocotrienol, which are expressed in micrograms per 100 g of grain. The presence of phytosterols (β-Sitosterol, Campesterol, Stigmasterol) and polyamines (Spermidine, Spermine, Putrescine, Cadaverine) further enhances the bioactive profile of sorghum grain. The presence of these polyamines significantly improves the bioactive profile of sorghum grain. Along with carotenoids and polyamines, sorghum grain contains phytosterols as β-Sitosterol, Campesterol, and Stigmasterol. β-Sitosterol is measured in mg/kg, while campesterol and stigmasterol are measured in mg/g of lipids. Sorghum grain is also rich in phenolic compounds, including flavonoids, 3-deoxy anthocyanins, phenolic acids, and tannins.

These phenolic compounds have been shown to provide a wide range of physiological benefits, including antibacterial activity, anti-inflammatory properties, antidiabetic advantages, antioxidant activity, and even anticancer potential. Sorghum grain contains essential minerals such as iron and zinc, dietary fibers, phytosterols, polyunsaturated fatty acids, and policosanols [10]. Phenolic chemicals, the primary bioactive components of sorghum, are present in all types. Compared to rice, oats, rye, corn, wheat, barley, and maize, sorghum has a higher concentration of phenolic chemicals and a more diversified phenolic chemical profile.

Anthocyanins, flavanones, flavanols, condensed tannins, and proanthocyanins can all be produced from the flavonoids present in sorghum grain. Most of the phenolic acids found in sorghum grains are P-coumaric acid, caffeic acid, cinnamic acid, ferulic acid, gallic acid, salicylic acid, and vanillic acid [7]. Lutein, apigenin, eriodictyol, and naringenin are the main flavonoids present in sorghum [14].

Therapeutic significance

Antioxidant activity

One of the main causes of many chronic diseases is oxidative stress, which is caused by an imbalance between antioxidants and free radicals. The phenolic compounds in sorghum seem to play a significant role in improving health and preventing disease due to their antioxidant qualities. When compared to other cereal grains, sorghum grain exhibits the highest level of antioxidant activity from phenolic compounds. There is a considerable correlation between antioxidant activity and total phenolic contents, particularly condensed tannins [15]. Tannins have been demonstrated to enhance human health by reducing inflammation in circumstances like cardiovascular disorders and preventing chronic illnesses like nitric oxide (NO), synthetase, and xanthine oxidases.

Additionally, prooxidative enzymes are inhibited by them [16]. The cellular antioxidant activity of Chinese steamed bread was improved with the addition of sorghum flour. Furthermore, the greatest antioxidant activity was demonstrated by phenolic extracts of black and brown sorghums devoid of bran [17]. Strong antioxidant activity was also demonstrated by black and brown sorghums. Sorghum extracts shown greater DPPH scavenging activity in comparison to NO radicals [18].

Anti-diabetic activity

Numerous studies have documented the efficacy of sorghum extracts in the management of diabetes, with special focus on the impact these products or extracts have on the enzymes amylase and glucosidase. These studies show that sorghum extracts considerably inhibit these enzymes [19]. By altering sugar metabolism, sorghum extracts or products have significantly decreased the incidence of hyperglycemia and decreased absorption of glucose [20]. Sorghum thus plays an important role in maintaining glucose homeostasis, which is a crucial tactic for successfully treating diabetes. When compared to a non-sorghum beverage, consuming a sorghum beverage enhanced with proanthocyanidins and deoxyanthocyanins dramatically decreased excess glycemia [21]. Thus, as functional food ingredients, it has been established that the deoxyanthocyanins, proanthocyanidins, and functional starch found in whole-grain sorghum may improve human glucose metabolism [22].

Antimicrobial activity

Antimicrobial agents inhibit the growth of microorganisms and interfere with physiological processes involved in metabolism and reproduction. Using natural antimicrobials reduces the chemical load of food [23]. Sorghum phenolic extract has been demonstrated to have a number of therapeutic applications and is an effective natural antibacterial alternative. Because to genetic differences, sorghum contains higher concentrations of tannin and phenolic chemicals, which enhances its antioxidant activity. Increased antibacterial and anticarcinogenic properties are also associated with an increase in phenolic chemicals. Using a method that combines ion precipitation and acidic ethanol extraction, fresh sweet sorghum stalks can yield highly active phenolic compounds [24]. Pathogenic bacteria that can infect food include Salmonella, E. Coli, Staphylococcus aureus, Salmonella spp., Klebsiella pneumoniae, Listeria monocytogenes, and Campylobacter jejuni. Fungi like Penicillium, Aspergillus, Fusarium, Rhizopus, and Candida are the main culprits of foodborne diseases [25]. Diarrhea is frequently caused by bacteria such Salmonella species, Shigella species, E. Coli, and S. aureus [26]. Procyanidin-rich sorghum helps prevent tooth cavities by lowering dental caries, a persistent disorder brought on by Streptococcus bacteria [27]. Tannins from sorghum grain have demonstrated significant microbiological activity against a range of bacteria, yeasts, and fungi, including Salmonella typhimurium and S. aureus [28].

Anti-cancer activity

Cancer is the leading cause of death worldwide. Bioactive substances including flavonoids and phenolic acids, which target many cancer symptoms, are linked to sorghum's anti-cancer qualities. Tannins, policosanols, anthocyanins, phytosterols, and phenolic acids are some of the polyphenols found in sorghum. The 3-deoxy anthocyanins found in black sorghum have anti-inflammatory and anti-tumor effects. Sorghum contains flavones with estrogenic properties that have been shown to have anticancer properties in vitro [29]. Regardless of mutations, redox signals lead to increased oxidative stress in cancer cells, which in turn deactivates tumor suppressor genes such as p53.

Additionally, they activate signaling pathway-related proteins like AP-1 and NF-B. Chronic oxidative damage encourages persistent inflammation and contributes to the growth of cancer. Reactive oxygen species traces encourage the growth of cancer cells. Therefore, avoiding diseases caused by oxidative stress requires eating a diet high in antioxidants. A process known as apoptosis allows damaged or infected cells to die, saving neighboring cells and ensuring tissue life by preventing inflammation and mutations in those cells. Tumor cells can multiply and give rise to a range of malignant cells when apoptotic cell death is disrupted [30].

Anti-obesity activity

Sorghum has anti-obesity properties. Pancreatic lipase enzymes' lipid metabolism depends on sorghum extracts, which also stop triglycerides from building up. A meal rich in sorghum has been shown to reduce blood triglyceride levels in rats [31]. Another study found that extruded sorghum has an impact on the anthropometry, body composition, and clinical measures of overweight individuals. Extruded sorghum consumption has been shown to promote weight loss and reduce body fat percentage and waist circumference [32]. Excessive fat accumulation is the primary cause of obesity. The expression of specific adipogenic genes, including fatty acid synthase (FAS) and lipoprotein lipase (LPL), is regulated by the peroxisome proliferator, a key regulator of adipogenesis, activating the peroxisome proliferator-activated receptor [33].

Anti-atherosclerotic activity

Sorghum lipids and phenolics reduce the risk of CVD by inhibiting and regulating the synthesis, absorption, and excretion of cholesterol. Lipids derived from sorghum inhibit 3 hydroxy-3-methyl-glutaryl-coenzyme A (HMG-CoA) reductase, an enzyme essential to the synthesis of cholesterol [34]. One study found that giving hamsters hydrophobic sorghum extracts reduced their plasma non-HDL cholesterol levels and their ability to absorb cholesterol [35]. After consuming sorghum grain lipid extract, there is an increase in Bifidobacterium and plasma HDL cholesterol, indicating that these bacteria may help to maintain cholesterol homeostasis. Blood samples from healthy individuals were used to examine the impact of sorghum phenolics on platelets. The samples were treated with a sorghum extract that was high in phenol. Platelet aggregation was significantly reduced by higher treatment dosages, indicating that sorghum phenolics may be able to prevent thrombosis.

Anti-inflammatory activity

Chronic inflammation brought on by prolonged oxidative stress can lead to chronic diseases. The inflammatory chemicals that are produced in response to inflammation include cyclooxygenase (COX)-2, interleukin (IL), tumor necrosis factor (TNF), and prostaglandin E2 (PG-E2). Sorghum contains a variety of phenolic compounds that can inhibit the production of these pro-inflammatory chemicals [36]. Flavone apigenin and flavanol quercetin have potent synergistic anti-inflammatory qualities that boost their bioavailability in cells when combined with quercetin-rich extracts from cowpea and sorghum. One report claims that the conjugation C2 = C3, quercetin, and apigenin can significantly boost anti-inflammatory activity [37]. Recent studies have shown that eating whole-grain sorghum biscuits for 12 weeks significantly reduced pro-inflammatory chemicals TNF, IL-1, IL-6, and IL-8 [38]. Hyaluronidase, an enzyme connected to persistent joint inflammation, is inhibited by phenolic extraction from sorghum bran. Sorghum-derived tocopherols, carotenoids, triacylglycerols, and unsaturated fatty acids have also demonstrated an inhibitory effect on the inflammatory response by lowering the expression of specific genes in lipopolysaccharides (LPS) [39].

Antidiarrheal properties

A common gastrointestinal illness, diarrhoea is characterized by loose or watery stools, increased frequency of bowel movements, and abdominal pain. It's a global health issue, especially in developing countries where access to clean water and sanitary facilities may be limited. The World Health Organization has recognized the need for effective treatments and preventative measures for diarrheal illnesses, which has led to ongoing research in this area. One potential area of study is the use of sorghum, an important food crop in Asia, Europe, and Africa. Also referred to as Zengada (Poaceae family), it offers a number of nutritional benefits, such as minerals, protein, and calories. Current research suggests that it could be helpful in both preventing and treating diarrheal illnesses [40]. The seeds have been used to treat a variety of ailments, such as epilepsy, cancer, stomach-aches, malaria, and diarrhoea. Sorghum has been demonstrated to have anti-inflammatory, anticancer, antioxidant, and cholesterol-lowering properties, as well as to reduce the risk of cardiovascular diseases. One report claimed that sorghum had antibacterial properties against E. coli and S. aureus. Sorghum may be used as an antidiarrheal drug, according to some scientific research [41]. Because drugs used to treat diarrhoea can have a number of adverse effects, researchers used artificially induced acute diarrhoea in mice to evaluate the acute toxicity and in-vivo antidiarrheal efficacy of sorghum [42].

Conclusion

The review raises questions about the enormous potential of sorghum millet in terms of food security, nutrition, and health. It is an excellent naturally gluten-free food source because of its strong nutritional profile, which includes a high fiber content, a high protein content, and a wide range of important minerals. Its potential benefits for diabetics and antioxidant properties further highlight its usefulness in treating important medical conditions. Because of its adaptability and drought resistance, sorghum millet has enormous potential to increase food security, particularly in areas that are vulnerable to climate change. Changes in eating habits and health-conscious diets have led to the emergence of numerous products made from sorghum, including bread, drinks, porridge, flour, and syrup. To create biofuel, enhance nutrition, adapt to climate change, enhance genetic quality, enhance health, and discover industrial applications, an interdisciplinary approach combining agronomy, genetics, biochemistry, food science, and environmental science is employed. There will be many opportunities in the future to enhance the properties of sorghum millet. Optimizing its nutritional profile and organoleptic qualities requires the use of genetics and state-of-the-art food processing techniques. Its potential as a crop that is bio-fortified to increase nutritional security may be investigated further. Sorghum millet is at the forefront of sustainable agriculture and nutrition because of these potential advantages, which underscore the continued interest and funding from academics, policymakers, and the agro-industry. In conclusion, sorghum millet is a superb choice among the nutrient-dense food crops. To create biofuel, enhance nutrition, adapt to climate change, enhance genetic quality, enhance health, and discover industrial applications, an interdisciplinary approach combining agronomy, genetics, biochemistry, food science, and environmental science is employed. There will be many opportunities in the future to enhance the properties of sorghum millet. Optimizing its nutritional profile and organoleptic qualities requires the use of genetics and state-of-the-art food processing techniques. Its potential as a crop that is bio-fortified to increase nutritional security may be investigated further. Sorghum millet is at the forefront of sustainable agriculture and nutrition because of these potential advantages, which underscore the continued interest and funding from academics, policymakers, and the agro-industry. In conclusion, sorghum millet is a superb choice among the nutrient-dense food crops.

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