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

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ABSTRACT

Sorghum is a valuable source of bioactive compounds with a variety of health benefits. Its bioactive components include phenolic acids, flavonoids, tannins, and dietary fiber, all of which contribute to its functional food properties. Some of the key bioactive compounds in sorghum and their health benefits: Sorghum contains high levels of phenolic acids, such as caffeic, p-coumaric, and ferulic acids. These compounds act as powerful antioxidants, helping to reduce oxidative stress in the body, which is linked to inflammation, cancer, and cardiovascular disease. Sorghum is particularly rich in flavonoids such as luteolin, apigenin, and their derivatives. These compounds are known for their anti-inflammatory, anticancer, and neuroprotective properties that help improve cardiovascular health by reducing the risk of plaque formation in the arteries. Certain varieties of sorghum, especially the pigmented ones, contain condensed tannins also known as proanthocyanidins. Sorghum is rich in both soluble and insoluble fiber. The dietary fiber in sorghum aids digestion, supports gut microbiome health, and contributes to better blood glucose control. Regular fiber intake may reduce the risk of colorectal cancer and aid in weight management. These long-chain alcohols are thought to help lower LDL cholesterol levels, which is beneficial for cardiovascular health. The polycosanols in sorghum have been found to improve lipid metabolism and may aid in weight management. Specific phytochemicals with antioxidant properties, such as phytic acid, polyphenols, tannins, and sterols, have been shown to reduce the incidence of chronic diseases and play a role beyond just food.

INTRODUCTION

Sorghum bicolor, another name for sorghum, is a common crop in the Gramineae family. Africa is where it all began, but now it's grown all across the world, reaching America, Asia, and Australia. Its adaptability to various soil types and climates helps explain why millions of people throughout the world rely on it as a vital source of basic food [1]. The genus *Sorghum* belongs to the kingdom *Plantae*, division *Magnoliophyte*, class *Liliopsida*, order *Cyperales*, family *Poaceae*, subfamily: *Panicoideae*, tribe *Andropo goneae*, and subtribe *Sorghinae*, subsp. *bicolor* [2].

Four primary types of sorghum exist: grain sorghum, sweet sorghum, forage sorghum, and biomass sorghum. Some groups showed notable genetic variants as well as differences in height, characteristics, and applications [3]. Due to its adaptability and ranking as the fifth most important cereal crop in the world in terms of production volume and area utilization, sorghum plays a significant role in the agricultural economy [4].

It is an underutilized cereal grain, exhibits significant potential for functional application during unexpected times such as pandemics. The production of this crop is a means of both economic sustainability and subsistence, as well as an enhancement of the nutritional value and overall health. Several empirical investigations have delved into the greater functional potential of sorghum, explaining its nutritional equivalence with widely-consumed grain like maize.

This review focuses mainly on exploring sorghum's nutritional benefits, therapeutic potential and its role in sustainable agriculture.

Advantages of Sorghum over other grains

Sorghum contributes to soil conservation from an ecological standpoint as well because of its wide root system and ability to withstand saline, which protects biodiversity in agricultural systems. Sorghum is a good crop for farmers with limited resources because it takes less input in the agricultural process than other crops. Its natural resistance to biotic and abiotic stressors allows it to flourish in a wide range of habitats. Although it is mainly used as a staple food, it can also be used as a raw material for industrial purposes, cattle feed and an energy crop for sustainable bioenergy. Because it may be used as a staple grain, a source of bioenergy, animal feed and an industrial product, sorghum plays a vital role in ensuring the security of food worldwide [4]. When compared to other cereal crops, particularly those of the C3 kind, sorghum is thought to be a resilient crop [5]. In light of climate change, it is the best crop option due to its high energy and drought-resilient qualities [6]. Sorghum has a carbohydrate content similar to maize, making it a substantial energy source. However, its carbohydrate digestibility is often lower, which may aid in blood sugar control due to a slower release of glucose. Sorghum contains about 10-12% protein, slightly higher than rice but comparable to wheat and maize. However, its protein quality is often limited by low levels of lysine, an essential amino acid. Sorghum is relatively low in fat (2-4%), similar to rice and wheat but slightly lower than maize. Sorghum has a higher dietary fiber content compared to polished rice and maize. Its fiber profile, which includes insoluble fiber, can support digestive health and has benefits for cholesterol management. Compared to wheat, sorghum's fiber content is similar but offers unique types of dietary fiber, such as certain arabinoxylans, which contribute to its prebiotic effects.

Sorghum is among the most efficient crops in terms of converting solar energy and using water [7]. When it comes to protein, fat, carbs, and non-starch polysaccharides, as well as bioactive elements like vitamin B and fat-soluble vitamins (D, E, and K), micronutrients, macronutrients, and non-nutrients like carotenoids and polyphenols, sorghum is comparable to other cereals in terms of nutritional value. Sorghum is similar to other cereals in terms of its nutritional value when it comes to protein, fat, carbohydrates and non-starch polysaccharides; it also contains bioactive elements like vitamin B and fat-soluble vitamins (D, E, and K); micronutrients, macronutrients, and non-nutrients like carotenoids and polyphenols. According to one report, these components contribute to

the grain's numerous health benefits, which include its strong antioxidant activity, capacity to scavenge free radicals, anti-inflammatory, anti-cancer, and anti-oxidative qualities [8].

The production of this crop is a means of both economic sustainability and subsistence, as well as an enhancement of the nutritional value and overall health. Numerous empirical investigations have explored the enhanced functional potential of sorghum, clarifying its nutritional parity with grains like maize that are widely ingested. Due to dietary preferences, sorghum can be considered a gluten-free alternative in many areas, including the US and the Mediterranean, which increases its demographic appeal [9]. Since sorghum is gluten-free, it's a healthy choice for anyone with celiac disease or gluten sensitivity. Its application extends across food groups, ranging from drinks and pastries to cereals and snacks, confirming its adaptability. This grain has a unique richness in a variety of bioactive components, which is not usually found in other cereals. The range of bioactive substances mostly consists of phenolic chemicals, which have several health benefits. Of the phenolic chemicals found in sorghum, flavonoids are the most noteworthy for their potential to promote health. Moreover, sorghum has a high concentration of phenolic compounds, including vanillic, gallic and ferulic acids, which have been shown to have anti-inflammatory and antioxidant effects in addition to many other health advantages. Even though sorghum is a major grain and has a significant concentration of phytochemicals, research on the impact of sorghum consumption on human health, namely on inflammation and other pathogenic processes, appears to be lacking. Sorghum grains exhibit a variety of bioactive components in addition to phenolics, which supports their potential as functional ingredients [10].

These include iron, zinc, phytosterols, policosanols, dietary fibers and polyunsaturated fatty acids. It is essential to increasing the production of bioenergy. The sugary kind of sorghum is particularly effective at creating biofuel; the grain is used to make biodiesel and the stalk is used to produce ethanol. Sorghum farming has significant and far-reaching social implications. It is a key resource for many small-scale farmers and agriculturally oriented businesses, supporting rural economies. As such, sorghum's importance is not limited to guaranteeing food security; it also has a strong bearing on encouraging sustainable farming methods and promoting rural development [11].

Grain sorghum has been traditionally used in many civilizations for a variety of purposes. Commonly used as a maize alternative in traditional recipes like ugali, sorghum grain is processed. To make wholesome meals, it is frequently combined with other grains such green grams, amaranthus, and cowpeas [12]. Worldwide, sorghum millet-based nonalcoholic drinks are a popular choice. Lesotho's traditional meal, motoho, is made using sorghum. It is created by first producing thin slurry using warm water and sorghum grain. After that, this slurry is injected with tomoso, a conventional starting culture. The fermentation process, which is essential to the making of motoho, is started by the tomoso starter culture [13].

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

Nutrient/Component	Sorghum	Wheat	Rice	Maize	Barley
Protein (%)	10-12	10-13	6-8	8-11	10-12
Carbohydrate (%)	70-75	70-75	77-80	72-73	73-75
Fibre (%)	6-7	10-12	2-3	6-8	10-17
Iron (mg/100g)	4-5	3-4	1-1.5	2-3	2-3
Calcium (mg/100g)	20-30	30-40	10-15	5-10	30-40
Antioxidants	High	Moderate	Low	Moderate	Moderate
Gluten Content	None	Present	None	None	Present
Glycemic Index	Low to Moderate	Moderate to High	High	Moderate	Moderate

Composition of Sorghum

Carotenoids, including β-Carotene, zeaxanthin, and lutein, are present in sorghum grain, however their concentrations may be lower than in other grains. Furthermore, trace levels of antioxidants including α-Tocopherol and α-Tocotrienol, which are measured in micrograms per 100 g of sorghum grain, are present in sorghum grain. The bioactive profile of sorghum grain is further enhanced by the presence of phytosterols (β-Sitosterol, Campesterol, Stigmasterol) and polyamines (Spermidine, Spermine, Putrescine, Cadaverine). The bioactive profile of sorghum grain is further enhanced by the presence of these polyamines. Sorghum grain contains phytosterols such β-Sitosterol, Campesterol, and Stigmasterol in addition to carotenoids and polyamines. Whereas campesterol and stigmasterol are measured in mg/g of lipids, β-Sitosterol is measured in mg/kg. Phenolic substances, such as flavonoids, 3-deoxy anthocyanins, phenolic acids, and tannins, are also abundant in sorghum grain.

Numerous physiological functions, including antioxidant activity, anti-inflammatory qualities, antidiabetic benefits, antibacterial activity and even anticancer potential, have been demonstrated for these phenolic compounds. Important elements like iron and zinc, as well as dietary fibers, phytosterols, polyunsaturated fatty acids, and policosanols, can be found in sorghum grain [10]. All varieties of sorghum include phenolic compounds, which are the main bioactive ingredients. Sorghum has a more varied phenolic chemical profile and a higher concentration of phenolic compounds than rice, oats, rye, corn, wheat, barley, and maize.

The flavonoids found in sorghum grain can be converted into anthocyanins, flavanones, flavanols, and condensed tannins, or proanthocyanins. P-coumaric acid, caffeic acid, cinnamic acid, ferulic acid, gallic acid, salicylic acid, and vanillic acid make up the majority of the phenolic acids present in sorghum grains [7]. The primary flavonoids found in sorghum are luteolin, apigenin, eriodictyol, and naringenin [14].

Therapeutic significance

1. Antioxidant activity

An imbalance between antioxidants and free radicals leads to oxidative stress, which is a major factor in a number of chronic illnesses. Because of their antioxidant properties, the phenolic compounds in sorghum appear to be important for promoting health and preventing disease. Sorghum grain has the highest level of phenolic compound antioxidant activity when compared to other cereal grains. Antioxidant activity and total phenolic levels—more especially, condensed tannins—have a strong relationship [15]. By preventing chronic illnesses like nitric oxide (NO), synthetase, and xanthine oxidases, as well as by lowering inflammation in conditions like cardiovascular diseases, tannins have been shown to improve human health. Moreover, they inhibit prooxidative enzymes [16]. The addition of sorghum flour resulted in a considerable improvement in the cellular antioxidant activity of Chinese steamed bread. Moreover, phenolic extracts of brown and black sorghums without bran showed the strongest antioxidant activity [17]. Brown and black sorghums also showed strong antioxidant activity. Compared to NO radicals, sorghum extracts showed higher DPPH scavenging action [18].

2. Anti-diabetic activity

Numerous studies have reported the effectiveness of sorghum extracts in the treatment of diabetes, with particular attention paid to the effects these extracts or products have on the enzyme's glucosidase and amylase. According to these investigations, sorghum extracts significantly inhibit these enzymes [19]. Sorghum extracts or products have considerably reduced the incidence of hyperglycaemia and decreased glucose absorption by modifying sugar metabolism [20]. As a result, sorghum contributes significantly to glucose homeostasis, which is an essential strategy for effectively managing diabetes. Drinking a sorghum drink fortified with proanthocyanidins and deoxyanthocyanins significantly reduced excess glycemia when compared

to a non-sorghum drink [21]. Therefore, it has been determined that the functional starch, proanthocyanidins, and deoxyanthocyanins present in whole-grain sorghum may have a beneficial effect on human glucose metabolism as functional food ingredients [22].

3. Antimicrobial activity

Antimicrobial substances prevent the growth of germs and obstruct physiological functions related to metabolism and reproduction. Food's chemical load is decreased when natural antimicrobials are used [23]. Phenolic extract from sorghum is a natural antibacterial substitute that works well and has been shown to have several medicinal uses. Sorghum has a higher concentration of tannin and phenolic compounds due to genetic variations, which strengthens its antioxidant effect. A rise in phenolic compounds is also linked to enhanced antimicrobial and anticarcinogenic characteristics. Highly active phenolic chemicals can be extracted from fresh sweet sorghum stalks using a technique that combines acidic ethanol extraction and ion precipitation [24]. *Salmonella, E. Coli, Staphylococcus aureus, Salmonella spp., Klebsiella pneumoniae, Listeria monocytogenes*, and *Campylobacter jejuni* are among the pathogenic microorganisms that can contaminate food. Foodborne illnesses are mostly caused by fungi such as Penicillium, Aspergillus, Fusarium, Rhizopus, and Candida [25]. Bacteria such *as E. Coli, Salmonella species, Shigella species,* and *S. aureus* are common causes of diarrhoea [26]. Sorghum rich in procyanidins can reduce dental caries, a chronic condition caused by Streptococcus bacteria, hence preventing tooth cavities [27]. Significant microbiological activity has been shown by tannins derived from sorghum grain against a variety of fungi, yeasts and bacteria, including *Salmonella typhimurium* and *S. aureus* [28].

4. Anti-cancer activity

Globally, cancer is the biggest cause of mortality. Sorghum has anti-cancer properties associated with bioactive compounds such as flavonoids and phenolic acids that target multiple cancer symptoms. Among other polyphenols, sorghum contains tannins, policosanols, anthocyanins, phytosterols, and phenolic acids. Black sorghum's 3-deoxy anthocyanins have anti-inflammatory and anti-tumor properties. Flavones found in sorghum have estrogenic characteristics and have demonstrated anticancer effects in vitro [29]. Redox signals, in spite of mutations, cause cancer cells to become more oxidatively stressed, which increases oxidative stress and deactivates tumor suppressor genes like p53. They also activate proteins involved in signaling pathways, such as NF-B and AP-1. Long-term oxidative damage promotes ongoing inflammation and aids in the development of cancer. Traces of reactive oxygen species promote the development of cancer cells. Eating a diet rich in antioxidants is therefore essential to avoiding diseases brought on by oxidative stress. Damaged or infected cells can die by a process called apoptosis that prevents inflammation and mutations in neighbouring cells, protecting surrounding cells and guaranteeing tissue survival. The disruption of apoptotic cell death can cause tumor cells to proliferate and give rise to a variety of malignant cells [30].

5. Anti-obesity activity

Sorghum provides benefits against obesity. Sorghum extracts are essential for the lipid metabolism of pancreatic lipase enzymes and prevent the accumulation of triglycerides. Studies on rats have demonstrated that a diet high in sorghum lowers blood triglyceride levels [31]. Extruded sorghum affects overweight men's body composition, anthropometry and clinical measurements, according to another study. Consuming extruded sorghum was observed to encourage weight loss,

as well as decrease waist circumference and body fat percentage [32]. The main cause of obesity is an excessive buildup of fat. The peroxisome proliferator, a crucial regulator of adipogenesis, activates the peroxisome proliferator-activated receptor, which controls the expression of particular adipogenic genes such fatty acid synthase (FAS) and lipoprotein lipase (LPL) [33].

6. Anti-atherosclerotic activity

By preventing and controlling the synthesis, absorption, and excretion of cholesterol, sorghum lipids and phenolics lower the risk of CVD. A crucial enzyme in the synthesis of cholesterol, 3 hydroxy-3-methyl-glutaryl-coenzyme A (HMG-CoA) reductase, is inhibited by lipids derived from sorghum [34]. According to one study, ingesting hydrophobic sorghum extracts lowered plasma non-HDL cholesterol and the efficiency of cholesterol absorption in hamsters [35]. Bifidobacterium and plasma HDL cholesterol are elevated following ingestion of sorghum grain lipid extract, suggesting that these bacteria have a beneficial role in maintaining cholesterol homeostasis. Sorghum phenolics' effects on platelets were investigated using blood samples from healthy people. A phenolic-rich sorghum extract was applied to the samples. Increased dosages of treatment dramatically decreased platelet aggregation, suggesting that sorghum phenolics can prevent thrombosis.

7. Anti-inflammatory activity

Prolonged oxidative stress can result in chronic inflammation, which can then cause chronic diseases. Prostaglandin E2 (PG-E2), tumor necrosis factor (TNF), cyclooxygenase (COX)–2, and interleukin (IL) are among the inflammatory chemicals that are produced in response to inflammation. Numerous phenolic compounds found in sorghum have the ability to prevent the synthesis of these pro-inflammatory molecules [36]. Together with extracts from cowpea and sorghum that are high in quercetin, flavone apigenin and flavanol quercetin have strong synergistic anti-inflammatory properties that increase their bioavailability in cells. According to one report, quercetin, apigenin, and the conjugation C2 = C3 can greatly increase anti-inflammatory action [37]. According to recent research, consuming whole-grain sorghum biscuits for a 12-week period dramatically lowered levels of TNF, IL-1, IL-6, and IL-8, which are pro-inflammatory chemicals [38]. Phenolic extraction from sorghum bran inhibits hyaluronidase, an enzyme linked to chronic joint inflammation. By reducing the expression of particular genes in lipopolysaccharides (LPS), tocopherols, carotenoids, triacylglycerols, and unsaturated fatty acids obtained from sorghum also shown an inhibitory effect on the inflammatory response [39].

8. Antidiarrheal activity

The symptoms of diarrhoea, a common gastrointestinal ailment, include loose or watery stools, increased frequency of bowel movements, and abdominal pain. It's a global health concern, particularly in developing nations where access to sanitary facilities and clean water may be restricted. Research in this area is ongoing as a result of the World Health Organization's recognition of the need for efficient treatments and preventative measures for diarrheal illnesses. The application of sorghum, a vital food crop in Asia, Europe, and Africa, is one possible research topic. Known by another name, Zengada (Poaceae family), it provides a variety of nutritional advantages, including calories, protein, and minerals. According to current research, it may be useful in treating and preventing diarrheal illnesses [40]. A number of illnesses, including diarrhoea, malaria, stomach-aches, cancer, and epilepsy, have been treated using the seeds. It was shown that sorghum can lower the risk of cardiovascular diseases and has anti-inflammatory, anticancer, antioxidant, and cholesterol-lowering qualities. According to one report sorghum had antibacterial action against S. aureus and E. coli. Some scientific research suggests that sorghum may be used as an antidiarrheal medication [41]. Researchers assessed the acute toxicity and in-vivo antidiarrheal effectiveness of sorghum using artificially caused acute diarrhoea in mice

because medications used to treat diarrhoea can have several negative effects [42].

CONCLUSION

The review casts doubt on sorghum millet's enormous potential in terms of nutrition, health, and food security. Its strong nutritional profile—which includes a high fiber content, a high protein content, and a wide range of important minerals—makes it an excellent naturally gluten-free food source. Additionally, its antioxidant qualities and potential diabetic advantages underscore its utility in tackling crucial health conditions.

Sorghum millet, which is adaptable and resistant to drought, holds great promise for improving food security, especially in regions that are sensitive to climate change. Many goods made from sorghum have emerged as a result of changes in eating habits and health-conscious diets, such as flour, syrup, porridge, bread, and drinks. An interdisciplinary method combining agronomy, genetics, biochemistry, food science, and environmental science is used to produce biofuel and improve nutrition, adapt to climate change, improve genetic quality, improve health, and find industrial uses. In the future, there will be plenty of chances to improve sorghum millet's qualities. Utilizing genetics and cutting-edge food processing methods is crucial to maximizing its nutritional profile and organoleptic properties. Further research may examine its potential as a crop that is bio-fortified, so augmenting nutritional security. With these potential benefits, sorghum millet is at the forefront of sustainable agriculture and nutrition, highlighting the ongoing interest and financial support from academics, decision-makers, and the agro-industry. In conclusion, among the nutrient-dense food crops, sorghum millet is an exceptional option.

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