



# ***SORGHUM BICOLOR*: NUTRITIONAL POWERHOUSE AND PROCESSING INNOVATIONS – A COMPREHENSIVE REVIEW**

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## **ABSTRACT**

*Sorghum bicolor* is increasingly recognized as a climate-resilient cereal crop with high nutritional value and diverse industrial applications. Rich in dietary fiber, resistant starch, polyphenols, and essential micronutrients, sorghum holds significant promise for enhancing food and nutrition security, particularly in arid and semi-arid regions. Despite its potential, its utilization remains underexplored in comparison to major cereals like wheat and rice. This review adopts a systematic approach to synthesize scientific literature published between 2000 and 2024, using databases such as Scopus, PubMed, ScienceDirect, and Google Scholar. Keywords included "*Sorghum bicolor*," "nutritional composition," "bioactive compounds," "processing technologies," and "functional foods." Studies focusing on compositional analysis, processing innovations, health benefits, and product development were critically assessed and categorized. The review reveals that *Sorghum bicolor* is a rich source of carbohydrates, proteins, phenolic acids, tannins, and antioxidants, which contribute to its health-promoting properties, including anti-diabetic, anti-inflammatory, and cholesterol-lowering effects. Emerging processing technologies such as extrusion, fermentation, germination, and micronization have significantly improved sorghum's bioavailability, functional properties, and sensory characteristics. Furthermore, value-added sorghum-based products are gaining popularity in gluten-free and nutraceutical markets. *Sorghum bicolor* represents a nutritionally rich, sustainable alternative to conventional cereals. Continued research into advanced processing methods and product development is essential for enhancing its global acceptance and marketability. Strategic interventions in food science, policy, and public awareness can unlock its full potential as a nutritional and functional food ingredient in the 21<sup>st</sup> century.

## INTRODUCTION

*Sorghum bicolor*, another name for sorghum, is a common crop in the Gramineae family. Originating in Africa, its cultivation has spread throughout the world, reaching places like Asia, Australia, and America. Its ability to adapt to different soil types and climates helps explain why it is a vital staple food for millions of people globally (Mbulwe & Ajayi, 2020). According to Hariprasanna and Patil (2015), the genus *Sorghum* belongs to the kingdom Plantae, division: *Magnoliophyte*, class: *Liliopsida*, order: *Cyperales*, family: *Poaceae*, subfamily: *Panicoideae*, tribe: *Andropogoneae*, and subtribe: *Sorghinae*, subsp. *bicolor*. Grain, sweet, forage, and biomass sorghum are the four main types of sorghum that fall under this category. According to Mullet *et al.*, (2014), there are notable genetic differences across these groupings, as well as differences in height, characteristics, and uses. Due to its adaptability and ranking as the fifth most popular cereal crop globally in terms of both production volume and area usage, sorghum plays a significant role in the agricultural economy (Habyarimana *et al.*, 2020). Because of its innate resistance to biotic and abiotic stressors, it flourishes in a wide range of settings. Because of its wide root system and ability to withstand salinity, sorghum also contributes to soil conservation from an ecological standpoint, protecting farming systems' biodiversity. Sorghum is a good option for farmers with limited resources because it requires fewer agricultural inputs than other crops. With its annual global output of roughly 58.7 million metric tons, it mainly serves Sorghum (*Sorghum bicolor*), a drought-resistant cereal that is the fifth most important cereal crop globally. This resilient grain is an essential staple in water-scarce places since it grows well in semi-arid climates and uses 30–40% less water than maize and wheat. As a staple meal, it can also be used as a raw material for industrial processes, livestock feed, and an energy crop for sustainable bioenergy (figure 1).

*Moench*, another name for sorghum (Lee *et al.*, 2021). Because of its many uses as a staple grain, bioenergy source, animal feed, and industrial product, sorghum plays a vital role in ensuring global food security (Habyarimana *et al.*, 2020). In contrast to other cereal crops, particularly those of the C3 variety, sorghum is regarded as a hardy crop (Sunoj *et al.*, 2020). In light of climate change, it is the best crop option due to its high energy content and drought resistance (Lee *et al.*, 2021). When it comes to converting solar energy and water utilization, sorghum is one of the most efficient crops (Lee *et al.*, 2022). In terms of composition 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. These components support the grain's many health advantages, such as its strong antioxidant activity, ability to scavenge free radicals, and anti-oxidative, anti-inflammatory, and anti-cancer properties (Chhikara *et al.*, 2018). The pericarp, endosperm, and germ are the three distinct anatomical components of sorghum; in certain species, the testa is the fourth component, located between the pericarp and the endosperm. Lipids, fat-soluble vitamins (especially the B-complex), and vital minerals are abundant in the germ. The endosperm is rich in

minerals, protein, starch, and vitamin B complex, whereas the pericarp and testa are mostly composed of non-starch polysaccharides, phenolic acids, tannins, phenolic compounds, and carotenoids. More than 500 million people in Africa, Asia, and the Americas rely on sorghum for nutrition, making it a major contributor to food security. It is primarily a source of energy, consisting of 65–75% carbohydrates, 10–12% protein, and 3–5% fat. Sorghum-based goods are in high demand in both traditional and modern diets due to the rising incidence of gluten-related diseases. Because of its use in high-fiber foods and gluten-free baking, its consumption has increased in Western markets (Cardoso *et al.*, 2017).

## OBJECTIVES OF REVIEW

The main objective of the current study was to compile a strong and adaptable database of academic publications about the culinary uses, phytochemical components, nutritional content, and functional potential of sorghum. Utilizing the power of reputable bibliometric data sources such as Scopus, Web of Science, Google Scholar, and NCBI, this was achieved. "Sorghum bicolor," "nutritional composition," "processing methods," "dietary benefits," "bioactive compounds," "anti-inflammatory," "phenolic," and "antioxidant" were among the key terms used in this procedure. A total of 104 scientific papers were found using the extensive search parameters, and each one was then carefully evaluated. The subject matter, academic discipline, place of origin of geographically linked research, and year of publication were among the many criteria used to identify these papers. Peer-reviewed literature as well as substantial data-oriented publications and research papers were included in this thorough examination. The purpose of this review is to examine the nutritional makeup, production processes, and health advantages of sorghum. Bioactive substances, processing technology improvements, and macro- and micronutrient profiles are discussed (Barba *et al.*, 2019). It also emphasizes how processing affects nutritional bioavailability and functional food uses. The results shed light on how to maximize the nutritional potential of sorghum for both established and developing food sectors.



**Figure 1**  
**Sorghum plant**

## Plant descriptions: history, origin, cultivation and breeding

*Sorghum arundinaceum's* original origins are in Africa. In the past, the first domestication took place in areas that included Ethiopia, Sudan, and Chad between 3000 and 5000 BCE. It was domesticated using a dual-selection method that was initially based on the pigmentation of the granules in the first millennium BC and then on the density of the panicles in the second millennium AD. Descriptions of sorghum plants and grains. Threshing is the post-harvest method of extracting seeds, indicating the development of non-shattering characteristics (Figure 2). Sorghum spread geographically over well-traveled trade routes, first from Africa to the Near East and then to China and India. According to frescoes on the walls of Sennacherib's palace in Nineveh, the capital of ancient Assyria, sorghum was already widely used in the eighth century BC. Sorghum was introduced to Queensland, Australia, by Americans in the 1900s. Sorghum cultivation was widely practiced in North America by the end of the 19th century, and it eventually moved to South America and Australia. In addition to some parts of Europe, particularly France and Italy, sorghum is currently produced widely in China, Australia, Mexico, Brazil, and the United States (McCarthy *et al.*, 2012). Sorghum has acquired popularity in moderate climates like Germany, Poland, and Ukraine, despite its traditional cultivation in tropical regions. Sorghum variants that can flourish in temperate settings have been created as a result of climate change and improvements in breeding methods. Growing sorghum in temperate climates can have beneficial effects, according to a study on the bioactive chemicals in the crop. Interestingly, it was discovered that sorghum cultivated in temperate regions had bioactive chemicals, suggesting that eating it may have health advantages. According to this study, sorghum grown in temperate regions may be a rich source of bioactive chemicals, which would increase its nutritional content and possible health advantages. The sorghum genome's accessibility has also encouraged more research on the crop, including the development of novel cultivars and the investigation of drought tolerance mechanisms. Breeding attempts have been done to increase this crop's cold resistance in order to adapt it to temperate climates.

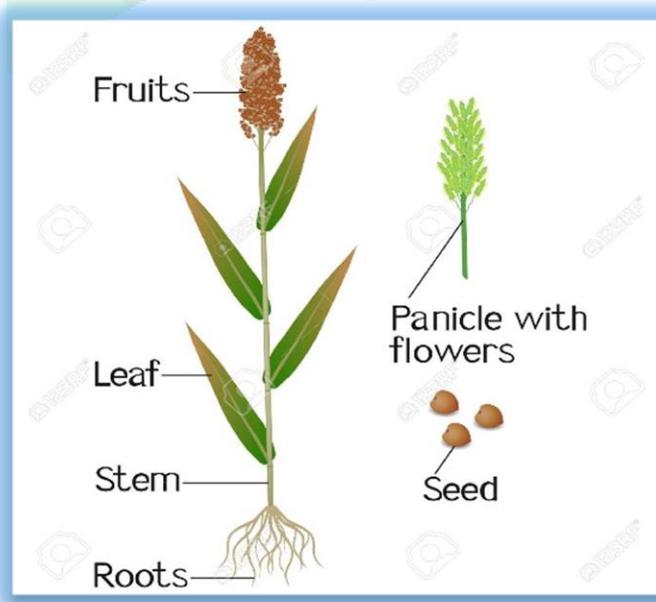


Figure 2

### Description of Sorghum plant

Bicolor, guinea, caudatum, kafir, and durra are the five primary races of farmed sorghum that may be identified. The morphological traits of their mature panicles and spikelets allow these races to be identified. Both *Sorghum bicolor* and *Sorghum arundinaceum* were found in volcanic soil (Beldados *et al.*, 2015). Red non-tannin grain and white grain, which are used for human consumption, make up the majority of sorghum varieties cultivated in India. There is a lot of interest in growing cultivars that also have sweet qualities, but in India today, the emphasis is on creating improved hybrids for both human use and fodder. For optimum development and yield, sorghum cultivation necessitates particular soil, temperature, and climate conditions. Sorghum prefers well-drained, fertile soils when it comes to soil requirements. Loamy and sandy soils are among the several soil types in which this crop can thrive. Soils with a pH between 6 and 7.5 are ideal for its growth. Sorghum grows and develops best at temperatures between 25 and 35 °C. While higher temperatures might cause heat stress and decreased yield, lower temperatures can slow down the growth process. Sorghum may be grown in semi-arid areas because it can respond to a variety of environmental factors and withstand heat stress and drought (Gebeyehu *et al.*, 2019). Table 1 displayed the major producing regions and countries as well as the taxonomy of sorghum.

**Table 1**  
**Sorghum taxonomy and major producing regions/countries and characteristics of sorghum varieties\* (Taylor, 2019)**

English Name	Common Names	Taxonomy	Major Producing Countries	Production in 2022 (Tonnes)	Characteristics	Forage Sorghum	Sweet Sorghum	Grain Sorghum	Biomass Sorghum
Sorghum	Sorghum (India), Mtama (East Africa), Mabele (South Africa), Kaoliang (China)	Subfamily: Panicoideae, Tribe: Andropogoneae, Sorghum bicolor (L.) Moench subsp. bicolor	Africa, Western Africa (Nigeria, Niger, Mali), Sudan, Ethiopia, Cameroon, India, China, USA, South America (Argentina, Brazil), Australia	5.2 million Tonnes (FAO, 2022)	Height (m)	1.8–3.6	>3	0.6–1.2	3.5–6
					Traits	Single or multi-cut harvest, high digestibility, nutrient content, palatability	High soluble sugar content in stems	Photoperiod sensitive/insensitive, high grain yield	Photoperiod-sensitive, dual-purpose, high lignocellulosic biomass
					Uses	Livestock feed	Syrup and biofuel production, high-sugar forage	Staple food in some regions, livestock feed, biofuel production	Biofuel, biogas, biomaterial

### Nutritional Composition of sorghum

Sorghum contains 65–75% carbohydrates, primarily starch, with amylose and amylopectin ratios influencing its digestibility (Table 2) (Joshi *et al.*, 2023). The glycemic index (GI) ranges from 55 to 77, depending on variety and processing, classifying it as a moderate-GI food beneficial for diabetes management. Resistant starch content improves gut health and regulates blood sugar levels. Sorghum provides 10–12% protein, with prolamins as the dominant fraction (Shinde *et al.*, 2022). Lysine is limited, but sulfur-containing amino acids are present in higher amounts compared to maize. Protein digestibility improves with germination and fermentation. Total fat content ranges from 3–5%, with unsaturated fatty

acids, including oleic (32%) and linoleic acid (54%) (Kostik *et al.*, 2013). Phytosterols in Sorghum contribute to cholesterol reduction, supporting cardiovascular health.

Sorghum is a good source of B-complex vitamins, including thiamine (0.35 mg/100g), riboflavin (0.14 mg/100g), and niacin (2.1 mg/100g). Vitamin E content, mainly tocopherols, provides antioxidant benefits. Iron content ranges from 2.1–4.5 mg/100g, with bioavailability influenced by phytates (Chan *et al.*, 2007). Calcium (13 mg/100g) and phosphorus (220 mg/100g) support bone health, while magnesium (160 mg/100g) and zinc (1.6 mg/100g) contribute to metabolic functions.

**Table 2**

**Nutritional Composition of *Sorghum bicolor*** (Kostik *et al.*, (2013), Joshi *et al.*, (2023))

Nutrient	Amount per 100g	Unit	Nutrient	Amount per 100g	Unit
<b>Macronutrients</b>			<b>Minerals</b>		
Energy	329–360	kcal	Calcium	10–50	mg
Carbohydrates	65–75	g	Iron	2–5	mg
Dietary Fiber	6–10	g	Magnesium	120–160	mg
Protein	8–12	g	Phosphorus	220–280	mg
Fats	1.5–3.5	g	Potassium	220–350	mg
<b>Vitamins</b>			Zinc	1–3	mg
Thiamine (B1)	0.2–0.4	mg			
Riboflavin (B2)	0.05–0.1	mg			
Niacin (B3)	2.5–4.0	mg			
Folate (B9)	20–40	µg			

### Bioactive Compounds and Health Benefits

Phenolic compounds, including tannins, flavonoids, and phenolic acids, exhibit antioxidant activity (Table 3). Total phenolic content ranges from 20–40 mg GAE/g, contributing to free radical scavenging and disease prevention (Nwozo *et al.*, 2023). Sorghum contains 6–8% dietary fibre, with insoluble fibre promoting gut motility and soluble fibre aiding in cholesterol reduction.  $\beta$ -glucans and arabinoxylans enhance prebiotic effects. Ferulic acid and flavonoids in Sorghum reduce oxidative stress and inflammation markers (Yadav *et al.*, 2024). Consumption lowers inflammatory cytokines, aiding in chronic disease prevention.

Table:3

Bioactive compounds and health benefits of sorghum (*Sorghum bicolor*) (Nwozo *et al.*, 2023)

Bioactive Compound	Category	Health Benefits	Reference
Phenolic Acids	Polyphenols	Antioxidant, anti-inflammatory, reduces oxidative stress	Research studies
Flavonoids	Polyphenols	Protects against chronic diseases, cardiovascular benefits	Various studies
Tannins	Polyphenols	Anti-cancer properties, aids in weight management	Scientific papers
Phytosterols	Plant sterols	Lowers cholesterol, supports heart health	USDA, Research data
Anthocyanins	Polyphenols	Anti-diabetic, improves brain function, anti-aging	Clinical studies
Lignins	Polyphenols	Improves gut health, reduces risk of cardiovascular diseases	Research articles
Saponins	Glycosides	Lowers blood sugar, has immune-boosting properties	Various studies
Dietary Fiber	Carbohydrates	Supports digestion, regulates blood sugar, aids in weight loss	USDA, Studies
Resistant Starch	Carbohydrates	Improves gut microbiota, reduces risk of diabetes	Research papers

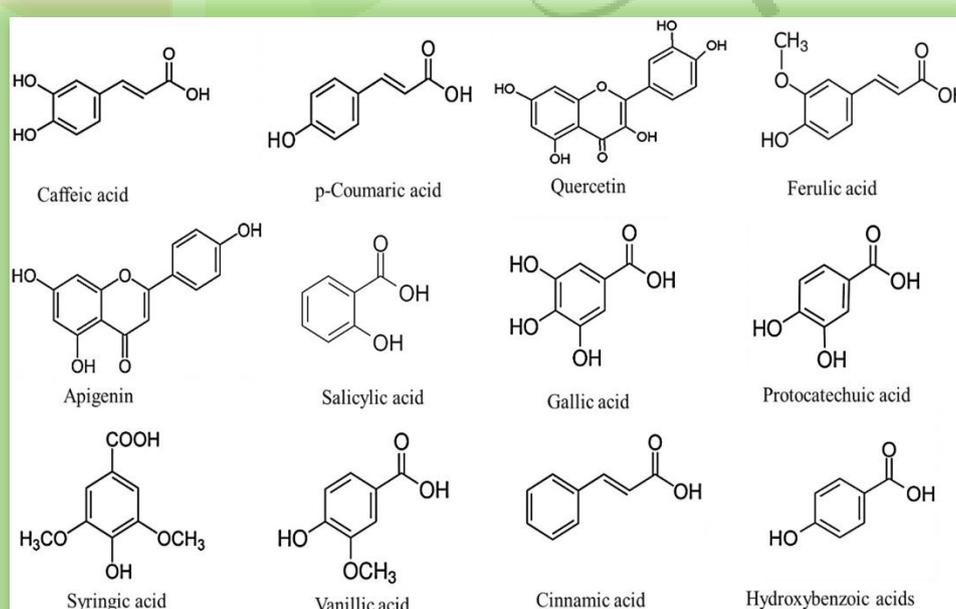


Figure 3

Structure of major sorghum bioactive compounds (Heba *et al.*, 2022)

## Health Benefits of Sorghum

Sorghum has a high fiber content (6–8%), promoting satiety and reducing overall calorie intake. The presence of resistant starch enhances fat oxidation and reduces fat accumulation. A study reported that individuals consuming whole-grain sorghum had a 10% lower body mass index (BMI) compared to those consuming refined grains (Muhihi *et al.*, 2012). The glycemic index of Sorghum (55–77) is lower than wheat and rice, making it suitable for diabetes management. Polyphenols, such as tannins and flavonoids, slow down carbohydrate digestion, reducing postprandial glucose spikes (Ayua *et al.*, 2021). A clinical study demonstrated that Sorghum-based diets reduced fasting blood glucose levels by 12% in type 2 diabetes patients. Sorghum contains phytosterols and polyunsaturated fatty acids that lower LDL cholesterol and improve heart health. Studies indicate that regular consumption reduces total cholesterol by 8–10% and triglycerides by 12%. Magnesium (160 mg/100g) in Sorghum aids in blood pressure regulation, reducing hypertension risks (Jalgaonkar *et al.*, 2019). The insoluble fiber content promotes bowel regularity and prevents constipation. Arabinoxylans and  $\beta$ -glucans in Sorghum function as prebiotics, enhancing beneficial gut bacteria growth. Fermented Sorghum products increase short-chain fatty acid (SCFA) production, improving gut barrier integrity (Ojha *et al.*, 2022). Sorghum is naturally gluten-free, making it an ideal alternative for celiac disease management (Masih *et al.*, 2019). A study on celiac patients consuming Sorghum-based products showed improved nutrient absorption and reduced inflammation markers. Bioactive peptides in Sorghum help repair intestinal damage caused by gluten intolerance.

## Traditional and modern processing techniques of sorghum

Sorghum is one of the earliest grains, originating from Africa and India, used today in various types of food. It is a staple ingredient in products like oatmeal, bread, cookies, tortillas, and commercial extruded products worldwide. The process of transforming the grain into an edible form, or processing, typically improves its quality. In the past, millets were decorticated at the domestic level by hand pounding. Nowadays, they are processed using slightly modified rice milling machinery. The husk content in millet ranges from 1.5 to 29.3 % (Yoganandan *et al.*, 2021). It is found that decortication reduces the overall mineral content but increases the bioavailability of calcium, iron, and zinc by 15, 26, and 24 g/100 g, respectively (Dey *et al.*, 2022). Dehulling combined with hydrothermal treatment affects the phenolic content and antioxidant capacity of millet grains. The antioxidant activity of the phenolic extracts is found to increase in the following order: hull, whole grain, dehulled grain, and cooked dehulled grain (Hassan *et al.*, 2021).

## Abrasive decortication and hammer milling

At the Rural Industries Innovation Center in Kanye, Botswana, sorghum milling techniques and seed quality evaluation were carried out. The study's objectives were to appraise the quality of the sorghum seeds utilized in the milling process and the efficacy and efficiency of various sorghum milling techniques. In order to ascertain how each milling technique affected the final flour or grits/semolina, the researchers compared hammer milling with abrasive decortication. The study also took into account how harvesting time affected the morphology and chemical makeup of the sorghum seeds, including their flavonoid, polyphenol, and tannin contents all of which are indicative of antioxidants. According to the study, sorghum

seeds harvested earlier had higher levels of ABTS and DPPH radical scavenging activity. In order to guarantee the best antioxidant qualities, the researchers came to the conclusion that choosing premium seeds for sorghum production is essential. For milling operations, the researchers used a physical research laboratory-style dehuller and hammer mill. Previous research indicates that the best technique for removing the sorghum grain's outer layers is abrasive milling. It has been discovered that this technique works well for maintaining the sorghum's functional qualities and nutritional value. Sorghum flour is still frequently made using the old-fashioned techniques of hand pounding, dehulling, and hammer milling (Yoganandan *et al.*, 2021).

## Primary processing

### Grading:

Sorghum primary processing includes a number of processes, such as packaging and grading. In primary processing, grading is crucial because it guarantees that the sorghum grains fulfill specific quality requirements. Sorghum grading entails utilizing a cleaner-cum-grading machine to clean bulk farm grains. They are divided into three groups by this machine, which grades them according to size: large, medium, and little. In order to guarantee that only pure sorghum grains are gathered, the machine additionally filters undesirable particles from the grains. Both farmers and purchasers value the consistent quality and size of the sorghum grains, which is ensured by this grading process. Grading enables farmers to receive the best price for their sorghum based on its quality by dividing the grains into various sizes. Grading facilitates packaging. Following their grading, the grains are immediately packaged in gunny bags. The grains' quality is preserved during storage and transit thanks to this packing method, which also shields them from outside pollutants (Song *et al.*, 2022).

### Destoning:

Destoning, which entails removing debris, stones, and glumes from the grain, is an essential stage in the processing of sorghum. Enhancing sorghum grains' storage capacity and consumer acceptability requires this procedure. Destoning improves the grain's quality and value by removing undesirable elements. It assists in preventing damage to processing and milling equipment by eliminating any foreign objects that might interfere with or malfunction. It has been discovered that destoning sorghum grains increases the effectiveness of other processing stages, like decortication. The pericarp, the outermost covering of the grain, is removed during decortication. It implied that sorghum's apparent protein quality and digestibility might be significantly enhanced by decortication. In comparison to conventional roller milling methods, it was discovered that the employment of a decorticator-degerminator in the processing of sorghum produced a higher starch recovery. According to these results, decortication which is made possible by destoning is essential for getting the grain ready for additional processing and improving its overall quality and nutritional content. Since many African sorghum-based dishes are made from decorticated grain, decortication of sorghum grains is particularly crucial. By removing non-fermentable components like fibers by decortication—which is made easier by destoning the outer layers are removed, improving protein quality and digestibility (Wahyuningsih *et al.*, 2019).

Pearling or dehulling sorghum: Pearling and polishing sorghum by dehulling can significantly improve the grain's look and market value. The pericarp, or outer coat of the grain, is removed by the abrasive process of dehulling, often referred to as pearling. This technique produces a visually beautiful product by reducing the quantity of insoluble fiber, dirt, and germs on the bare grain in addition to eliminating the bitterness associated with the pericarp. Blackening problems that can arise in grain sorghum cultivated during the Kharif season are also addressed by dehulling. Grain sorghum cultivated during wet seasons may turn black owing to mold and fungal infestations, even though the yield is higher. By removing the discolored outer layer, dehulling or pearling can lessen this problem, enhancing the product's overall look and possibly raising its market value. The nutritional and functional qualities of sorghum grains have been found to be significantly impacted by dehulling. For instance, because the majority of phenolic chemicals are localized in the pericarp and aleurone layer, decortication of sorghum results in a decrease in the quantity of total phenols in the flour (Salazar-Lopez *et al.*, 2018).

### Secondary processing

When making any kind of food product, the grain should be processed into a form that can be used, such as flour. Various machines that process grain produce flour, fine and coarse rawa, flakes, and pops. Sorghum is ground in a pulverizer, and the resulting flour is sieved to the appropriate level of fineness. Cakes, biscuits, and roti are all made with fine flour. There are two varieties of sorghum semolina, referred to locally as rawa or suji, with different particle sizes: coarse (1.18 mm) and fine (0.6 mm). On the open market, both varieties of rawa are sold commercially. Both varieties of rawa are commercially available for sale on the open market. The pericarp is separated separately as bran in a Brabender semolina machine, and rawa is made only from the endosperm (Ratnavathi *et al.*, 2016).

### Traditional and modern processing methods

Traditional milling removes outer layers, improving texture but reducing fibre and micronutrient content (Singh *et al.*, 2024). Stone grinding retains more nutrients than roller milling, preserving 75–80% of bran and germ components (Table 4). Soaking increases mineral bioavailability by reducing phytates, improving iron absorption by 20–30% (Afify *et al.*, 2011). Fermentation enhances protein digestibility and increases folate levels by up to 50%. Malting improves amino acid composition and enhances vitamin B levels (Ochanda *et al.*, 2010). Germination increases antioxidant capacity by 30–40% and boosts enzyme activity, aiding digestion.

Extrusion improves protein digestibility by 15–25% and enhances resistant starch content, beneficial for glycemic control (Luo *et al.*, 2024). High-temperature processing reduces anti-nutritional factors while maintaining essential amino acids. Parboiling retains 80–90% of minerals by preventing leaching losses. Roasting enhances sensory properties and increases phenolic content, improving antioxidant activity by 25%. Iron and zinc biofortification increase mineral content by 40–60% without compromising grain quality (Ramzan *et al.*, 2020). Fortified Sorghum products show improved anemia prevention in populations with micronutrient deficiencies.

## Effects of processing on nutritional quality

Processing affects nutrient retention, with dehulling causing a 20–30% loss of fiber and minerals (Decker *et.al.*, 2014). Fermentation preserves amino acids and increases vitamin B2 content by 40%. Enzymatic treatments and soaking reduce phytic acid by 50–60%, enhancing mineral absorption (Luo *et.al.*, 2009). Heat processing improves vitamin retention, particularly niacin and folate. Germination and roasting enhance polyphenol content by 20–30%, boosting antioxidant activity (Ahmed *et.al.*, 2021). Extrusion reduces flavonoid levels but improves bioavailability through structural modifications.

**Table 4**

### Traditional and modern processing techniques for sorghum (Singh *et.al.*, 2024)

Processing Technique	Method Description	Purpose & Benefits
<b>Traditional Milling</b>	Stone grinding or hand pounding to produce flour.	Retains bran and fiber, enhances nutrient content but has lower shelf life.
<b>Decortication</b>	Removal of outer bran layer using hand or mechanical methods.	Improves texture and digestibility but may reduce fiber content.
<b>Soaking &amp; Germination</b>	Soaking grains in water followed by sprouting.	Enhances nutrient bioavailability, reduces anti-nutrients, improves protein quality.
<b>Fermentation</b>	Naturally fermenting batter for foods like sorghum dosa or porridge.	Improves digestibility, enhances probiotics, increases vitamin levels.
<b>Popping &amp; Puffing</b>	Roasting at high temperatures to make puffed sorghum.	Improves taste and texture, enhances antioxidant activity.
<b>Traditional Roasting</b>	Dry roasting or sand roasting of whole grains.	Develops a nutty flavor, reduces moisture for better storage.
<b>Modern Roller Milling</b>	Industrial milling with controlled particle size.	Produces fine flour with consistent quality, increases shelf life but may remove some fiber.
<b>Extrusion Processing</b>	High-temperature, high-pressure processing to make products like pasta and snacks.	Enhances texture, improves digestibility, suitable for ready-to-eat products.
<b>Micronization</b>	Infrared heat treatment to modify starch properties.	Improves cooking quality, enhances digestibility, reduces anti-nutrients.
<b>Fortification</b>	Adding essential vitamins and minerals during processing.	Improves nutritional value, addresses micronutrient deficiencies.

## Enhancing the dietary benefits of sorghum through processing

### Strategies for improving protein quality

Sorghum lacks lysine but is rich in sulphur-containing amino acids. Combining it with legumes like chickpeas or lentils increases lysine intake, enhancing protein quality (King *et.al.*, 2024). Protein efficiency

ratio improves by 25–30% when Sorghum is blended with pulses. Fermentation increases essential amino acids, improving protein digestibility by 15–20%. Enzymatic hydrolysis with proteases enhances the bioavailability of peptides, increasing antioxidant activity by 30% (Power *et.al.*, 2013).

### **Increasing digestibility and reducing anti-nutritional factors**

Soaking and germination reduce tannin content by 40–60%, improving iron and zinc absorption (Mehanni *et.al.*, 2021). Phytate degradation through fermentation enhances mineral bioavailability by 50%. Resistant starch and dietary fiber in processed Sorghum promote gut microbiota growth, increasing beneficial bacteria by 20–25% (Dega *et.al.*, 2023). Fermented Sorghum products enhance short-chain fatty acid production, improving digestive health.

### **Functional food development**

Sorghum flour is widely used in gluten-free bakery products, with blends improving texture and sensory properties (Menaka *et.al.*, 2024). Sorghum-based bread fortified with hydrocolloids exhibits 30% better volume and softness retention compared to traditional gluten-free bread. Sorghum enriched with bioactive compounds is used in functional foods targeting metabolic disorders (Das *et.al.*, 2016). Fortified Sorghum products with added micronutrients improve iron and folate intake, reducing anemia risk by 20–30%.

### **Applications of sorghum in the food industry**

Sorghum flour is widely used for rotis, contributing 60–70% of daily energy intake in certain rural diets (Misra *et.al.*, 2009). Porridges made from Sorghum are rich in fiber and serve as staple weaning foods. Fermented Sorghum-based beverages, such as traditional sorghum beer, contain probiotics beneficial for gut health. Different regions incorporate Sorghum into staple diets, with variations in cooking techniques (Joshi *et.al.*, 2009). In parts of Africa, Sorghum is used for flatbreads and couscous. In Southeast Asia, Sorghum noodles and steamed cakes have gained popularity as gluten-free alternatives. Sorghum-based extruded snacks have expanded in commercial markets due to their high fiber and antioxidant content (Rao *et.al.*, 2014). Fortified Sorghum breakfast cereals provide 10–15% of daily iron and protein requirements. Sorghum flour is widely used in gluten-free baking, improving the nutritional profile of cookies, cakes, and bread (Menaka *et.al.*, 2024). The addition of hydrocolloids enhances dough elasticity and improves bread volume by 20–30%. Sorghum protein isolates are increasingly used in plant-based meat alternatives, offering 10–12% protein content (Choubey *et.al.*, 2024). Sorghum protein hydrolysates improve emulsification properties, making them suitable for dairy substitutes.

Table

Sorghum Type	Food Applications	Impact	References
<b>Black Sorghum</b>	Bakery products	Proanthocyanidin reduced and flavonoid remains constant.	Dunn <i>et al.</i> , 2015
<b>Brown Sorghum</b>	Pasta products and Porridges	High phenolic compound	Cercamondi <i>et al.</i> , 2014
<b>Yellow Sorghum</b>	Healthy snacks and Noodles	High flavones with antioxidant properties	Dykes <i>et al.</i> , 2014
<b>Red Sorghum</b>	Fermented products, Beer, Extruded products	High antioxidant capacity	Svensson <i>et al.</i> , 2010
<b>White Sorghum</b>	Noodles and Biscuits preparation	High resistant starch	Mehboob <i>et al.</i> , 2015

### Challenges and Future

Sorghum has a hard outer layer, making milling and flour refinement less efficient than wheat, leading to lower extraction rates (Dekka *et al.*, 2023). Traditional processing methods result in nutrient losses of up to 30%, requiring advancements in milling and fortification techniques. The absence of standardized extrusion techniques affects product consistency in commercial applications (Patil *et al.*, 2016). Sorghum-based products often have a coarse texture and reduced elasticity compared to gluten-containing alternatives, impacting consumer preference. The incorporation of hydrocolloids and enzymatic treatments has improved sensory appeal by 20–30%, but further optimization is needed for widespread adoption (Gasparre *et al.*, 2024).

### Future Research

Biofortification strategies have increased iron and zinc content in Sorghum by 40–60% without affecting yield (Singh *et al.*, 2024). Advanced breeding techniques aim to enhance protein digestibility and amino acid balance, addressing nutritional limitations. Germination and fermentation have increased the bioavailability of key nutrients by 50%, making them promising techniques for functional food development (Singh *et al.*, 2015). Nanotechnology-based nutrient encapsulation is under research to improve the stability of Sorghum's bioactive compounds. Sorghum-based gluten-free products have seen a 25% market growth in recent years due to increasing demand for alternative grains (Rao *et al.*, 2014; Taylor, 2019). Further investment in processing infrastructure and product innovation is required to compete with mainstream cereals in international markets.

## Conclusion

Sorghum is a nutritionally rich, gluten-free grain with significant potential in health-focused diets. Its high fibre, polyphenol content, and moderate glycemic index make it beneficial for weight management, diabetes control, and cardiovascular health. Traditional and modern processing techniques enhance its bioavailability and sensory appeal, with fermentation improving protein digestibility and germination boosting antioxidant levels. Challenges such as milling inefficiencies, consumer acceptance, and nutrient losses in processing need to be addressed through advanced technologies like biofortification and extrusion. The growing global demand for gluten-free and functional foods presents an opportunity for Sorghum-based innovations in bakery, snacks, and plant-based protein products. Future should focus on genetic improvements, novel processing methods, and large-scale commercialization to fully utilize Sorghum's dietary benefits and establish its role as a sustainable, health-promoting cereal in global markets.

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