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"Exploring the Nutritional Profiles, Health Benefits and Culinary Versatility of Sorghum, and Buckwheat"

Alakananda P
Department of Food Technology and Nutrition, Lovely Professional University, Phagwara, Punjab, India

Abstract
Sorghum and buckwheat are gluten-free grains with unique nutritional profiles, offering a variety of uses in the industry. This review explores the resurgence of millets and buckwheat as valuable crops for food security and sustainable agriculture. Millets, such as finger millet and sorghum, are highly nutritious, offering ample protein, fiber, vitamins, and minerals. They thrive well in challenging environmental conditions and are gluten-free, making them suitable for individuals with celiac disease or gluten intolerance. Buckwheat, a pseudo-cereal, boasts a similar nutritional profile with the added benefit of high-quality protein rich in lysine. Both millets and buckwheat contain significant amounts of antioxidants like phenolic compounds, contributing to various health benefits. Sorghum consumption has been linked to reduced inflammation, lower chronic disease risk, and improved blood sugar control. Buckwheat excels in promoting heart health, digestion, and blood pressure regulation. Processing techniques like fermentation can further enhance their nutritional value and mitigate the presence of antinutrients. Additionally, both offer diverse culinary applications, with sorghum being used in breads, cookies, and porridges, while buckwheat features prominently in soba noodles, pasta, and pancakes. As awareness of their nutritional and agricultural advantages grows, millets and buckwheat are poised to have a major impact in promoting healthy diets and sustainable food systems.

Keywords: sorghum, buckwheat, nutritional profile, health benefit, culinary application

Introduction

Millets are a group of grasses with small seeds that are extensively cultivated as cereal crops for both human and animal consumption. They have been a crucial part of diets for millennia, particularly in the semi-arid regions of Africa and Asia. Their resilience to adverse weather conditions and poor soil fertility makes them vital for ensuring food security in these areas (Hassan et al., 2021).

Millets come in several varieties, such as pearl millet, finger millet,foxtail millet, proso millet, and sorghum. Despite their differences in size, color, and nutritional content, all types are rich in fiber, protein, minerals, and vitamins. Being gluten-free, millets are an excellent option for individuals with celiac disease or gluten intolerance (Yousaf et al., 2021). Millets offer numerous nutritional benefits and

can be used in a wide range of culinary applications. They can be boiled whole as a grain or ground into flour for making bread, porridge, and other baked goods. Additionally, millet grains can be used as a base for fermented beverages like beer or popped like popcorn(Kumar et al., 2021).

From a sustainable agriculture perspective, millets play a crucial role in promoting biodiversity and combating climate change. They are more eco-friendly than other cereal crops, as they need less water and fewer inputs (Saleh et al., 2013). Millets are gaining popularity due to their high nutritional value, resilience to climate change, and potential to enhance food security. Governments, NGOs, and agricultural organizations are promoting millet cultivation as part of efforts to diversify food production and address global challenges such as malnutrition and climate change. As awareness grows about the benefits of millets, they are becoming increasingly recognized as valuable crops for sustainable agriculture and food systems worldwide(Kumar et al., 2021).

Sorghum millet

Sorghum or jowar is considered the king of millets.Technically known as Sorghum bicolor, this cereal grain belongs to the Poaceae family of grasses.It is commonly referred to as sorghum and is grown worldwide for its grain, forage, and syrup(Djameh et al., 2015).Sorghum millets, known as jowar in India, are among the most important cereal crops globally. They thrive in dry and semi-arid regions due to their heat and drought tolerance. Sorghum millets are characterized by tall, upright stalks with large panicles filled with seeds that come in a variety of colors, including shades of red, brown, black, as well as white, cream, and yellow (Abah et al., 2020). Sorghum millets are gluten-free, making them suitable for individuals with celiac disease or gluten intolerance. They are rich in carbohydrates, dietary fiber, and essential minerals like iron, phosphorus, potassium, and magnesium. While they contain less lysine than other cereals, they still provide a significant amount of protein. Additionally, sorghum millets are an excellent source of antioxidants, particularly phenolic compounds, which are associated with various health benefits, including a reduced risk of chronic diseases. (Ofosu et al., 2021).

Although sorghum proteins are unlikely to trigger autoimmune allergic reactions, consuming sorghum grains, especially the pigmented varieties, can be challenging due to the presence of antinutritional factors such as tannins, phytic acid, trypsin inhibitors, and protein cross-linkers. These compounds can negatively impact the nutritional efficiency of the grain for both human and animal consumption (Abdualrahman et al., 2019). Various technological processing techniques, such as soaking, cooking, fermentation, steaming, and germination, can reduce the levels of these antinutritional substances. Additionally, these methods not only mitigate the negative effects but also enhance the overall quality of sorghum grains and products made from them, such as starch, porridges, cakes, and bread. These processes also allow for the

use of sorghum grains and their derivatives as food additives (Mohapatra et al., 2019) .

Buckwheat

Buckwheat, scientifically termed Fagopyrumesculentum, is a versatile and nutritious pseudo-cereal prized for its edible seeds. Despite its name, buckwheat does not belong to the wheat family but rather to the Polygonaceae family, akin to rhubarb and sorrel. Originating in Southeast Asia, buckwheat has expanded globally and is now cultivated in various temperate regions(Yilmaz et al., 2018). Known for its rapid growth and adaptability to poor soil conditions, it proves valuable in challenging agricultural environments. Its distinctive triangular seeds, often called groats, boast a rich nutritional profile including complex carbohydrates, dietary fiber, protein, vitamins, and minerals. Importantly, due to its gluten-free nature, buckwheat can be consumed by individuals with celiac disease or gluten sensitivity (Zenkova & Examination, 2021). Buckwheat flour, ground from the seeds, is commonly used in Japanese soba noodles, pancakes, bread, and baked goods, enhancing dishes with its unique nutty flavor(Solanki & Singh, 2023).

Buckwheat serves multiple purposes beyond its seeds. Its leaves are a source of rutin, used in pharmaceuticals and tea for treating hypertonia, while its flowers attract bees for nectar production. In cuisine, buckwheat is widely utilized; its grains, whole or dehulled, are boiled and eaten, and its flour is a staple ingredient in various traditional dishes, meeting diverse dietary requirements(Prakash & Yadav, 2016). Additionally, buckwheat grain forms the base for brewing beer and distilling spirits. Notably, its protein, particularly globulin, is high-quality and rich in lysine, setting it apart from common cereals. Buckwheat hulls are reused as fillers in items like pillows, and the amylases found in buckwheat aid in starch processing industries by breaking down starch into simpler sugars. Finally, buckwheat straw provides nutritious fodder for livestock (Zhang et al., 2012).

Nutritional profile

Buckwheat and sorghum have similar nutritional profiles, being low in fat and moderate in protein content. Both are rich in dietary fiber, complex carbohydrates, and essential minerals such as phosphorus, iron, and magnesium (I. Kreft et al., 2020). However, they each offer distinct nutritional benefits. Sorghum provides significant amounts of B vitamins like niacin, thiamine, and riboflavin, which are essential for energy production. However, buckwheat stands out among grains for its high protein content, making it a valuable plant-based protein source for vegans and vegetarians. It is rich in essential amino acids, particularly lysine, which is often deficient in other cereals (Zhang et al., 2012) (Table.1).

Table.1 Nutritional composition of sorghum and buckwheat

Type Of Millet	Parameters	Compounds	Composition	Reference
Sorghum (Sorghum bicolor)	Moisture		11.06-12.06(%)	(Tamilselvan & Kushwaha, 2020)
	Carbohydrate	Starch	55.60 – 75.20(%)	
		Amylose	21.20 – 30.20(%)	
		Soluble sugar	0.70 - 4.20(%)	
		Reducing sugar	0.05 – 0.53(%)	
			4.40 - 21.10(%)	(Abah et al., 2020)
	Protein	Total protein	1.06 – 3.64(%)	
		Lysine	11.1-1.18(%)	
		Leucine	1.6-2.3(%)	
		Methionine	4.2-4.5(%)	
		Phenylalanine	8.31-9.26(%)	
	Fat	Total fat		
	Vitamins	Thiamine(B1)	0.002-0.023(mg/100g)	(Etuk et al., 2012)
		Pyridoxine(B6)	0.0010.004(mg/100g)	
		Niacin(B3)	0.009-0.17(mg/100g)	
		Thiamine	0.24 – 0.54(mg/100g)	
		Riboflavin		
	Minerals		0.10 – 0.20(mg/100g)	
		Calcium		
		Phosphorus		
		Iron	11.0 – 586.0(mg/100g)	
	Fiber			
		Total fiber	167.0 – 751.0(mg/100g)	
			0.90 – 20.0(mg/100g)	
			2.0 – 2.08 (%)	
Buckwheat(Fagopyrumesculentum)	Carbohydrate	Starch	68-73(%)	(Yilmaz et al., 2018)
		Amylose	19 – 34(%)	
		Amylopectin	54 - 70(%)	
		Total protein	9.40-10.6(%)	
	Protein	Non-essential amino acids	3.83-4.0(%)	(Chauhan & Sarita, 2018)

		Essential amino acids	1.68-2.0(%)	
	Fat	Total fat	2.0-3.08(%)	
	Vitamins	Vitamin A	14.3-21.7(mg/kg)	
		Thiamine (B1)	0.31-0.38(mg/100g)	
		Riboflavin (B2)	0.07-0.08(mg/100g)	
		Vitamin E	1.45-2.35(mg/g)	(Zenkova & Examination, 2021)
	Minerals	Iron	1.75-17.21(%)	
		Manganese	0.08-2.27(%)	
		Calcium	30.0-331(mg/100g)	
		Copper	0.64-2.81(%)	
	Fiber	Dietary fiber	6.4-7.0(%)	

Health benefits of sorghum

Sorghum is a type of cereal grain that contains a rich source of antioxidants, primarily phenolic compounds and flavonoids. These compounds offer many health benefits, such as reducing inflammation and lowering the risk of chronic illnesses like heart disease and cancer. Phenolic acids, tannins, and flavonoids are the key bioactive components found in sorghum(Rashwan et al., 2021). Recent research indicates that sorghum varieties resistant to biotic and abiotic challenges have higher levels of proanthocyanidins, 3-deoxyanthocyanidins, and flavan-4-ols compared to susceptible varieties. These phenolic compounds, including 3-deoxyanthocyanidins and tannins, contribute to sorghum's antioxidant properties and potential health benefits (Etuk et al., 2012).

Antioxidant activity

An unbalanced concentration of free radicals and antioxidants can lead to oxidative stress, is the main cause of various chronic diseases. Sorghum is known for its antioxidant properties, which can promote health and prevent diseases. The antioxidant activity of sorghum can be measured using various methods, including ferric reducing antioxidant power (FRAP), 1,1-diphenyl-2-picrylhydrazyl (DPPH), and 2,2-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) free radical scavenging assays (Xiong et al., 2019). The condensed tannin content in sorghum is significantly correlated with its total phenolic content and antioxidant activity. Black and brown sorghums, which have higher levels of condensed tannins, consistently exhibit strong antioxidant activity in vitro, especially in the bran where phenolics are concentrated. Among all sorghum

types, Sumac SU99 brown sorghum bran shows the highest in vitro antioxidant activity, with ORAC = 3,124 µmol TE/g, ABTS = 768 µmol TE/g, and DPPH = 716 µmol TE/g (Xu et al., 2021).

Anti-inflammatory activity

Chronic inflammation, caused by prolonged oxidative stress, can lead to various chronic diseases. During inflammation, the body produces several pro-inflammatory substances, including prostaglandin E2 (PG-E2), tumor necrosis factor (TNF)-a, cyclooxygenase (COX)-2, and interleukin (IL). Various phenolic components in sorghum grain have been found to inhibit the production of these pro-inflammatory substances. Phenolic acids, such as gallic and ferulic acids, have been shown to reduce the COX-2 enzyme, with ferulic acid specifically inhibiting the synthesis of TNF-a (Iyabo et al., 2020). Additionally, the flavones luteolin and apigenin have been found to inhibit the synthesis of COX-2 and nuclear factor kappa B, the transcription factor that activates the production of pro-inflammatory chemicals. Recent research has demonstrated that apigenin and the flavonolquercetin, along with apigenin-rich sorghum extract, exhibit a potent synergistic anti-inflammatory effect. This effect is achieved by increasing their bioavailability through the inhibition of pro-inflammatory compounds of phase II metabolism and the function of the ATP-binding cassette membrane transporter in cellular models(Oliveira, 2024).

Anti-diabetes

Sorghum whole grain is an excellent option for diabetics due to its very slow starch digestion. This is because the sorghum endosperm contains a high concentration of resistant, slowly digesting starch. As a result, sorghum whole grain can be a healthy dietary choice for individuals with diabetes and obesity(Xu et al., 2021). For individuals with obesity and diabetes, the resistant and slowly digesting starch complexes in sorghum can help limit calorie intake, promote satiety, and result in a low glycemic response. A recent study found that people who consumed sorghum whole grain biscuits felt more satisfied and experienced less hunger compared to those who ate wheat biscuits (de Morais Cardoso et al., 2017).

Anticancer

Sorghum's phenolic compounds have demonstrated promising anticancer properties, and consuming whole grain sorghum may lower the risk of certain cancers. These anticancer effects are primarily attributed to sorghum's strong antioxidant capacities and the activation of phase II enzymes by its phenolic components, particularly three-deoxyanthocyanidins. These compounds and sorghum extracts rich in them have shown efficacy against various cancer cell types, including colon, liver, esophageal, intestinal, leukemia, breast, and stomach cancers (Oliveira, 2024). They function by inducing programmed cell

death, or apoptosis, and inhibiting the growth and metastasis of cancer cells. Additionally, condensed tannins from sorghum are believed to play a significant role in cancer prevention. Studies suggest that these tannins can inhibit the enzyme aromatase, which is involved in breast cancer, thereby preventing the production of cancer-promoting stimuli. Notably, brown sorghum bran extracts high in condensed tannins have demonstrated strong aromatase inhibition at low concentrations, outperforming 3-deoxyanthocyanidin-rich extracts from tannin-free black sorghum bran. This suggests that condensed tannins may have even greater anticancer effects compared to 3-deoxyanthocyanidins(de Morais Cardoso et al., 2017).

Health benefits of buckwheat

Improving blood sugar control and blood lipid profile is crucial to reduce the risk of heart disease. Heart disease risk factors are well-known and include having a poor lipid profile. Notably, this particular food has a low to medium glycemic index, making it safe for most people with type 2 diabetes. It is also an excellent source of fiber, which slows down or delays the breakdown of table sugar. The health benefits of this food include improved heart health, lower blood pressure, assistance with weight loss, protection against certain cancers, diabetes management, better digestion and cholesterol levels, and a stronger immune system. Reducing the risk of heart disease involves enhancing blood lipid profile and controlling blood sugar levels (M. Kreft, 2016). One well-known risk factor for heart disease is a poor lipid profile. It is important to note that this specific food has a low to medium glycemic index, making it safe for most patients with type 2 diabetes. Additionally, it is a great source of fiber, which slows down or prevents the absorption of table sugar. This food offers many health benefits, including improved digestion and cholesterol levels, a stronger immune system, reduced blood pressure, assistance with weight loss, protection against certain cancers, and diabetes management (Li et al., 2018).

Antioxidant activity

Antioxidant activity is a vital property that helps prevent various health issues in humans. Buckwheat contains antioxidants like hyperin, quercetin, and rutin, which have numerous biological properties, including anti-aging, anti-carcinogenic, and anti-mutagenic effects. Researchers have utilized various methods, such as microwave irradiation or water baths at different temperatures (23–150°C) for 15 minutes, to examine the antioxidant activity of buckwheat. Regardless of the heat source, the full ethanol extract exhibited the highest antioxidant activity, ranging from 5.61 to 5.73 μmolTroloxequivalents/g at 100 and 150°C (Podolska et al., 2021).

Rutin: Rutin, the main polyphenol antioxidant in buckwheat, has been demonstrated to lower blood pressure, improve blood lipid profiles, and reduce the risk of cancer.

Quercetin: The antioxidant quercetin, found in numerous plant foods, may provide several health benefits, including a reduced risk of heart disease and cancer.

Anti-nutritional

Buckwheat contains several anti-nutritional elements, including a-amylase inhibitors, phytates, trypsin, and tannins. According to a study, these anti-nutritional elements can be reduced or eliminated through processing methods such as steaming, boiling, baking, and se-enrichment germination. Boiling was found to have the highest inhibitory effect, followed by steaming, while baking had the least inhibitory impact. Additionally, the Se-enrichment germination method was found to reduce the content of these anti-nutritional factors(Solanki & Singh, 2023).

Improving digestion

Buckwheat is a nutritious food that is high in dietary fiber. This fiber is a type of carbohydrate that cannot be broken down completely by the body's digestive enzymes. It helps with digestion and encourages food to move efficiently through the digestive system. Additionally, dietary fiber has many benefits, including promoting intestinal health, assisting with weight management, and reducing the risk of cardiovascular disease. Moreover, buckwheat has significant amounts of niacin, also known as vitamin B-3. Niacin is vital in converting carbohydrates, fats, and proteins into energy that the body's cells can use. With its high fiber and niacin content, buckwheat is an excellent food choice for promoting digestive health and overall well-being(Yilmaz et al., 2018).

Hypotensive Effect

Due to its high rutin and quercetin content and its ability to regulate the renin-angiotensin system, buckwheat is regarded as a functional food with potential antihypertensive benefits. It is also used in the development of certain functional foods. Buckwheat sprouts, in particular, have a higher phenolic content and antioxidant activity compared to other grain sprouts. Managing salt intake and dietary habits is crucial in preventing and treating hypertension, as high dietary salt intake often causes high blood pressure. A study on hypertensive rats examined the effects of a high-salt diet, with one group fed buckwheat and the other given a control diet. The results showed that rats fed buckwheat sprouts had increased levels of natural vasodilators, such as nitric oxide and bradykinin, leading to reduced blood pressure and enhanced antioxidant capacity compared to rats fed other grains (Luthar et al., 2021) (Table.2).

Table.2 Health benefits of sorghum and buckwheat

Type of millets	Health benefits	Reference
Sorghum	Tannins from sorghum show powerful antioxidant activity Reduces the risk of certain types of cancer, colon, liver, esophageal, intestinal, leukemia, breast, and stomach cancers Apigenin-rich extract from sorghum has a strong synergistic anti-inflammatory Sorghum has a relatively low starch digestibility, it prevents obesity and diabetes Phenolic compounds from sorghum have shown anticancer activity Anthocyanins, flavanols, flavones, isoflavones, flavanones, flavonols, and the polymeric proanthocyanidins are present	(Xiong et al., 2019) (Xu et al., 2021)
Buckwheat	Antioxidant properties of buckwheat were found to be due to the richness of the phenolic compound Buckwheat sprouts contain various flavonoids such as orientin, isoorientin, vitexin, isovitexin, rutin and quercetin Quercetin, an antioxidant in plant foods, may reduce cancer and heart disease risk Rutin, the primary antioxidant in buckwheat, may lower cancer risk and improve inflammation, blood pressure, and lipid profile. Buckwheat as a cholesterol-lowering functional food is becoming widespread Show antihypertensive effect by regulating the renin-angiotensin system due to its high polyphenol content Low glycemic index diets regulate blood glucose, prevent obesity, and reduce heart disease risk Consumption of buckwheat prevented the deterioration of neurological functions	(Yilmaz et al., 2018) (Luthar et al., 2021) (Podolska et al., 2021)

Culinary application

Soba noodles

Soba noodles are thin Japanese noodles made from buckwheat flour, wheat flour, or a combination of both. They are often enjoyed cold with dipping sauce or served hot in broth as a noodle soup, known for their distinct nutty flavor. A staple in Japanese cuisine, soba noodles are appreciated for their unique taste and texture. Beyond their excellent flavor, soba noodles are valued for their

nutritional benefits. They contain more protein and fiber and fewer calories than regular wheat noodles, making them a healthier option. Additionally, soba noodles are a good source of complex carbohydrates, thiamine, and manganese.
In Japanese culture, soba noodles are often consumed on special occasions such as New Year's Eve, where they symbolize longevity and prosperity. They are also enjoyed year-round in various dishes, including salads, stir-fries, and hot noodle soups(Johnson et al., 2021).

Buckwheat pasta

Buckwheat pasta, made from buckwheat flour, offers a gluten-free alternative to traditional pasta, which is typically made from durum wheat semolina. This makes it an excellent option for those who are sensitive to gluten or following a gluten-free diet.Buckwheat pasta has a distinct nutty flavor and a slightly grainy texture, which sets it apart from wheat-based pasta(Man et al., 2016).

Buckwheat sourdough

Buckwheat sourdough is a type of bread made primarily with buckwheat flour instead of or in addition to wheat flour. The bread is made through a natural fermentation process using lactic acid bacteria and wild yeast. This method gives the bread its characteristic sour flavor and light texture.Buckwheat sourdough bread is a popular choice for those looking for a gluten-free or wheat-free alternative to regular sourdough bread. The dough is shaped into loaves, proofed, and then baked until golden brown and crusty. The resulting bread has a distinctive nutty flavor, a slightly sour taste, and a dense yet tender crumb (Vombergar et al., 2021).

Sorghum cookies

Sorghum cookies are cookies that are primarily made using sorghum flour. Sorghum flour, derived from the gluten-free whole grain sorghum, is widely used in various cuisines around the world. Sorghum cookies are a popular choice for those who are gluten intolerant or on a gluten-free diet. These cookies are renowned for their high phenolic content and strong antioxidant activity, especially those made with sorghum tannin, which can have up to twenty times the antioxidant activity of wheat cookies.
Sorghum cookies are made by combining sorghum flour with gluten-free flour such as rice, almond, or tapioca flour. The dough may contain butter/oil, sugar, eggs/egg substitutes, and flavorings like vanilla, cocoa powder, or spices(E. et al., 2017).

Sorghum porridge

Sorghum porridge is a delicious and nutritious dish that is typically eaten for breakfast in many African countries and other parts of the world. To prepare sorghum porridge, sorghum grains are first soaked overnight to soften them and

reduce cooking time. The soaked sorghum is then drained and rinsed before being simmered in water or milk until it becomes tender and creamy. Typically, the porridge is sweetened with sugar, honey, or another sweetener and flavored with ingredients like cinnamon, vanilla, or nutmeg to enhance its taste. It's worth noting that porridge made from decorticated sorghum grain has been shown to have a slower gastric emptying rate compared to other staple foods such as rice, potato, and pasta(Haliza & Widowati, 2021).

Gluten-free Pasta Based on Sorghum and Rice

The pasta was made using a pilot-scale twin screw extrusion method, which involved blending sorghum flour with rice and other ingredients such as corn starch, guar gum, monoglycerides, and salt. Before being fed into the extruder barrel, the dry ingredients were preconditioned with steam and water to partially hydrate and cook them. The pasta dough was then shaped and cut using a rotary knife. When compared to semolina-based pasta, the cooked pasta made from sorghum and rice showed better cooking qualities, including lower cooking loss, comparable or increased water uptake, and a firmer texture after cooking. The addition of corn starch and guar gum in the pasta formulation improved binding, structure, and texture. Various methods, such as assessing cooking loss, water uptake, and firmness, were used to evaluate the pasta's cooking quality. This sorghum and rice pasta offers a promising gluten-free option suitable for individuals with celiac disease or use in food assistance programs(Haliza & Widowati, 2021).

Sorghum Sourdough Bread

Buckwheat sourdough bread is primarily made from buckwheat flour, though it is sometimes mixed with wheat flour. The bread's distinct sour flavor and airy, light texture are achieved through a natural fermentation process using wild yeast and lactic acid bacteria. This fermentation process also enhances the amino acid balance, reduces anti-nutritional components, and improves the digestibility of the bread. Additionally, fermentation increases the protein content and the ratio of essential to total amino acids. While ash and lipid concentrations may decrease during fermentation, trypsin inhibitor activity and tannin content are also significantly reduced (Rashwan et al., 2021).

Conclusion

Millets and buckwheat are regaining attention due to their impressive nutritional profiles, resilience to harsh environments, and ability to support the security of food. Sorghum and buckwheat, in particular, offer a wealth of health benefits. Sorghum boasts strong antioxidant properties, potentially lowering the risk of chronic diseases. Buckwheat excels in its fiber content, promoting gut health and overall well-being. Since both grains are free of gluten, people with celiac disease or gluten sensitivity can benefit from them.Moreover, sorghum and

buckwheat demonstrate versatility in culinary applications. From soba noodles and buckwheat pasta to sorghum cookies and sourdough bread, these grains can be incorporated into various delicious and nutritious dishes. Further research is needed to fully understand the health benefits of these grains and develop strategies to minimize their anti-nutritional elements. Overall, sorghum and buckwheat offer a promising future for sustainable agriculture and the creation of useful and nutrient-dense food items.

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