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REVIEW ARTICLE

Millets for Health: Nutritional Treasures for a Balanced Diet

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ABSTRACT

Millets, often referred to as ancient grains, have regained considerable attention in recent years due to their exceptional nutritional content and potential health benefits. This review provides an overview of a comprehensive exploration into the health advantages associated with the consumption of millets and their applications in contemporary nutrition and wellness. This review dives deep into the nutritional composition of millets, highlighting their rich sources of essential macronutrients, micronutrients, and dietary fiber. Millets have proven to be a valuable source of vital nutrients, such as vitamins, minerals, and antioxidants, which are integral to promoting overall health and preventing a range of chronic diseases. Furthermore, this manuscript reviews the potential therapeutic effects of millets in managing prevalent health concerns, including diabetes, obesity, cardiovascular diseases, and gastrointestinal disorders. It investigates how millets, with their low glycemic index and high satiety-inducing properties, can play a pivotal role in maintaining blood sugar levels, aiding weight management, and improving heart health. Millets are known for their resilience to adverse environmental conditions and their low water and resource requirements, making them a promising candidate for sustainable agriculture and food security. This review encourages individuals, health professionals, and policymakers to consider millets as a valuable component of a healthy and sustainable diet, ultimately contributing to improved public health and environmental conservation.

Keywords: *Antinutrients, Barnyard millet, Composition of millets, Foxtail millet, Finger millet, Millets, Nutrition, Pearl millet*

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INTRODUCTION

Millets represent a diverse family of diminutive and highly variable grasses that primarily serve as cereal crops or grains for both human consumption and animal feed. They are categorized based on their functionality and agronomic properties rather than taxonomical distinctions. The majority (97%) of millet cultivation occurs in developing nations, particularly in Asia and Africa's semi-arid tropical climates, with India and Nigeria as prominent examples. These regions appreciate millets for their remarkable productivity and rapid growth in arid and hot environments.[1] Belonging to the Poaceae grass family, millets are among the earliest cultivated crops. Finger millet *Eleusine coracana* (L.) Gaertn. and Pearl millet *Pennisetum glaucum (*L.) R.Br are the two primary millet types used for both sustenance and animal fodder. Their origins trace back to the sub-humid uplands of East Africa and Sub-Saharan Africa, respectively.[2] These two countries account for the majority of global millet consumption and trade.[3] Millets are a dietary staple for over a third of the world's population and rank as the sixth most important cereal crop in terms of global agricultural production. Various types of millets, including jowar (sorghum), kutki (little millet), ragi (finger millet), korra (foxtail millet), and variga (proso millet), are used in daily diet. Millets are prominently incorporated into rural diets and hold significant nutritional value. They constitute an integral component of traditional meals in numerous regions and are employed diversely among various Indian tribes. In comparison to widely consumed rice and wheat, all millet varieties offer three to five times greater nutritional content.[4] Millet's moniker as the "famine grain" emerges from its capacity to yield generously even in challenging conditions while demonstrating resilience against pests and diseases.[5] Comparable to primary cereals such as rice and wheat, these crops demand minimal fertilizer application for optimal growth.[6] Rajasthan leads millet production in India, accounting for more than 25% of global output. Remarkably, despite this prominence, only a fraction of the Indian population is knowledgeable about the nutritional value and health benefits offered by millets. [7]

Iron, magnesium, zinc, and B vitamins are just a few of the vital vitamins and minerals that millets are a great source of. Additionally, millet includes bioactive substances that have been demonstrated to offer a variety of health advantages, including as polyphenols, flavonoids, and phytosterols.[8] Millets have a number of health advantages, including lowering blood glucose levels, lowering cholesterol, lowering the risk of tumor growth, and lowering cardiovascular diseases. Millets potent antioxidant qualities aid in the prevention of cancer.[9] Millets provide dietary fiber that slows down stomach emptying and helps to reduce the weight.[10]

Millets are naturally gluten-free, making them a crucial component of diets for individuals with celiac disease or gluten sensitivities. They provide a safe alternative to wheat and other gluten-containing grains. [11][12] Millets are versatile and can be used in various culinary applications. They can be cooked as porridge, used in salads, substituted for rice in pilafs, incorporated into baked goods, and more. Their adaptability makes them suitable for a wide range of recipes. [13][14] The fact that the world is in urgent need of feeding its growing population makes it essential to examine crops such as millets which are produced on a local level and used locally by poor households in areas like India and the Sahel region.[15] Cereals in general are considered to be of widespread availability around the world and remain part of a majority of Africa's diet, particularly millet-based foods and beverages. [16][17] As more people become health-conscious and seek whole, minimally processed foods, millets are gaining popularity for their natural and wholesome attributes.

Millets:

Small-seeded meadows that are commonly referred to as Nutri-cereals or dryland cereals encompass a variety of grains such as sorghum, pearl millet, finger millet, little millet, foxtail millet, proso millet, barnyard millet, and Kodo millet, among others. Millets exhibit resilience in low soil conditions, demanding minimal water resources, and avoiding the necessity for extensive pesticide or fungicide applications. Their capacity to endure high temperatures positions them as ideal climate-resilient grains.

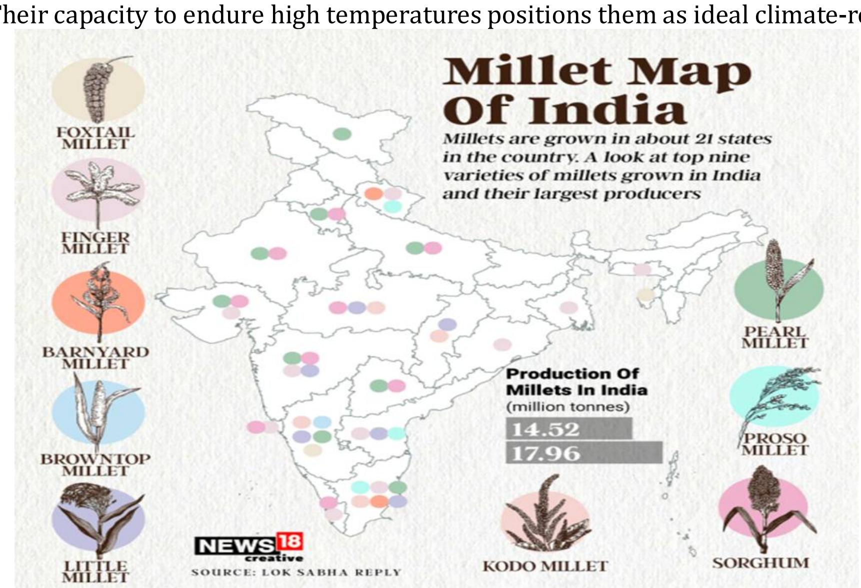


Fig 1: Millet Map of India (Ref. News 18 & LokSabha)

Benefits of Millets:

- Millets are free of gluten, low in glycemic index and contain dietary fiber and antioxidants which can help with a number of health issues such as obesity, diabetes and lifestyle problems.
- For their high nutrient content, which is composed of proteins, essential fatty acids, dietary fibre, B vitamins and minerals such as calcium, iron, zinc, potassium, magnesium; the millet are considered to be nutraceuticals.
- Especially for children and women, it can provide nutritional stability and act as a safeguard against nutritional inadequacies.
- It will play a vital role in initiatives aimed at mitigating the effects of climate change in dryland areas, while also holding significance for smallholders and marginal farmers.

Types of millets:

Table 1: Types of millets

Sr. No.	Millets	Biological Name
	Major millets	
1	Finger millet	*Eleusine coracana* (L.) Gaertn.
2	Proso millet	*Panicum miliaceum* L.
3	Pearl millet	*Pennisetum glaucum* (L.) R.Br.
4	Foxtail millet	*Setaria italica* (L.) P.Beauv.
	Minor millets	
1	Adlay millet (Job's tears)	*Coix lacryma-jobi* L.
2	Polish millet (Fonio)	*Digitaria sanguinalis (L.) Scop.*
3	Indian barnyard millet	*Echinochloa frumentacea Link*
4	Japanese barnyard millet	*Echinochloa esculenta (A.Braun) H.Scholz*
5	Little millet	*Panicum sumatrense Roth*
6	Kodo millet	*Paspalum scrobiculatum L.*
7	Browntop millet	*Pleurothallis millei Schltr.*

Data adopted from: [13][15]

Finger millet:

Eleusine coracana (L.) Gaertn often known as finger millet, is thought to have originated in Ethiopia and was first brought to India some 4000 years ago. In India, ragi is the most common name for it, but other regional names like Koda, Mandal, Mandua, Nachani, or Nagli are also common throughout the nation. It is a super cereal that can be utilized to create functional foods due to its high nutritional value and phytochemical content. It has a well-balanced amino acid profile and is a rich source of proteins.[18] It is an excellent source of important amino acids like lysine, cystine, and methionine. It has little fat (1–1.5 g/100 g), however over 74.4% of the fatty acids are unsaturated. Oleic, palmitic, and linolenic acids are the main fatty acids found in finger millet. It has the highest calcium content of any cereal and is a good source of nutrients. Additionally, it is a good source of potassium, phosphate, iron, and vitamins B1, B2, and B3. Additionally, it has a lot of nutritional fiber. The two most significant soluble polysaccharides in ragi are arabinose and xylose. Additionally, seeds are a good source of phytochemicals such phytic and ferulic acids. [19]

Asthma, high blood pressure and heart problems are just some of the affections that millet can help with. It's also an excellent diet for diabetes because it slows down digestion and the release of glucose into the blood. Besides the fact that finger millet increases hemoglobin and helps fight malnutrition and habitual conditions. [20]

Proso millet:

Common millet, hog millet, broom millet, yellow hog, black seed Proso millet, and white millet are other names for Proso millet *Panicum miliaceum* L.[21] This ancient cereal crop, with its origins in Africa and Asia, holds significant cultural and dietary importance in many societies. Proso millet stands out for its remarkable adaptability to diverse environmental conditions, thriving in low-quality soils with minimal water requirements, and requiring fewer pesticides or fungicides compared to some other crops. Its ability to withstand high temperatures makes it a valuable climate-smart cereal, offering food security in regions prone to climate variability. It contains 70g of carbohydrates per 100g. The 4.0g/100g fat content is the second highest among millets, and the linoleic, oleic, and palmitic acids make up the majority of the free lipids. Proso millet has an overall higher amino acid content than wheat protein in its basic amino acids, leucine, isoleucine and methionine. [22] Proso millet contains 10.6 g of protein per 100 g. This protein is gluten-free, making it suitable for individuals with gluten intolerance or celiac disease.

Niacin, a potent form of vitamin B3 abundantly present in proso millet, plays a crucial role in preventing pellagra, a debilitating skin condition. Moreover, proso millet is rich in calcium, supporting the overall health of teeth and bones. It boasts a wealth of essential minerals and vitamins, making it a nutritious choice. Regular consumption of proso millet can significantly reduce the risk of developing type 2 diabetes. The high magnesium content found in proso millet contributes to maintaining optimal insulin levels and helps regulate blood glucose levels effectively. Furthermore, proso millet's antioxidant properties aid in purging the body of harmful free radicals, promoting overall well-being. [22][23]

Pearl millet:
Pearl millet *Pennisetum glaucum* (L.) R.Br is native to Africa and is widely grown in India. It was initially grown as a forage crop but was eventually adopted as a food crop (4000–5000 years ago). It is currently grown throughout Africa and Asia and goes by a number of common names, including Bulrush millet, Amabele, Bajra, Babal, Nyalothi, Ntweka, Muvhoho, Leotja, and Mhunga. [24] Pearl millet is an excellent source of energy, boasting a calorific value of 361 Kcal per 100 grams, and it is notably rich in dietary fiber, containing 1.2 grams per 100 grams. Furthermore, pearl millet is distinguished by its elevated protein content and serves as a valuable source of essential nutrients, including vitamin-B, vitamin-A, folic acid, and calcium. Among its nutritional components, pearl millet comprises golden yellow fatty oil at a rate of 5.23%, with significant proportions of α-Linoleic acid (45.6%), Oleic acid (28.5%), and Palmitic acid (20.6%). Additionally, it contains minor fatty acids such as Linolenic acid (2.1%) and Stearic acid (1.5%). Notably, Linolenic acid, classified as an essential fatty acid, holds potential in managing conditions like rheumatoid arthritis, cardiac arrhythmias, and depression, while also contributing to a reduced risk of ischemic and thrombotic stroke. In addition to helping ease respiratory problems for asthma patients, magnesium found in pearl millet may help reduce migraine symptoms. The mineral fiber in pearl millet makes it less likely that a gallstone can be formed. Insoluble fiber from pearl millet is helping to decrease that level, because excess bile in the liver may lead to gallstones.[25][26]

Foxtail millet:
Foxtail millet is one of the oldest self-pollinating millet crops in Eurasia, grown since 5000 BC in China and 3000 BC in Europe. China is the original home of foxtail millet *Setaria italica* (L.) P.Beauv. The cultivation of this millet, which is said to be the first to be domesticated, began around 7000 years ago. This millet is also known by other names like foxtail bristlegrass, Italian foxtail, Italian millet, German millet, and Siberian millet. It is cultivated in cold draughtier regions.[27] Foxtail millet is also known as a healthy heart diet and aids in reducing the occurrence of diabetes due to its high magnesium content. A good amount of carbohydrates (60–70 g), protein (12.3 g), fat (4.3 g), fiber (6.7 g), minerals (Phosphorous, calcium, iron, zinc, magnesium, sodium), and phytochemicals (Phenols, Ferulic, chlorogenic acids, and p-coumaric, Flavonoids carotenoids, tocopherol, and tocotrienol) are well revealed in Foxtail millet.[28]

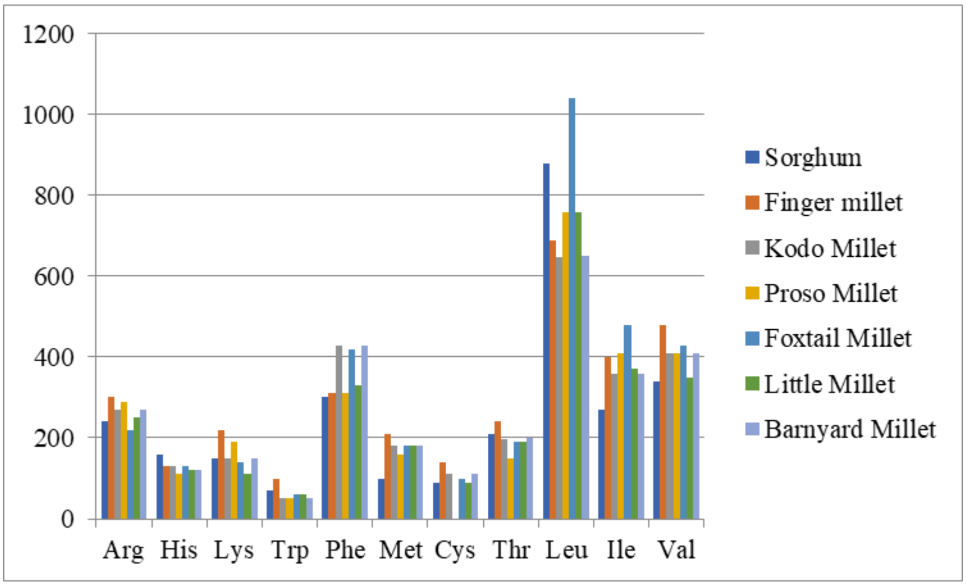
Due to its substantial magnesium content, foxtail millet aids in preventing diabetes by regulating blood glucose levels, supporting weight management, enhancing immune function, and protecting cardiovascular health. Its potential benefits include acting as an antioxidant, reducing blood glucose levels, offering gastrointestinal protection, and potentially having anti-carcinogenic properties. [28]

Barnyard millet:
Echinochloa crus-galli, a species of wild millet grass, is the source of millet, which was domesticated in India and Japan about 4,000 years ago. *Echinochloa frumentacea Link* (Indian millet) and *Echinochloa esculenta* (A.Braun) H.Scholz (Japanese millet) are two types of millet. In terms of nutritive value, barnyard millet is superior to major and minor millets. Barnyard millet grains are a rich source of dietary fiber, iron, zinc, calcium, protein, magnesium, fat, vitamins, and some essential amino acids.[29] Of all the millets, it grows the quickest. Under ideal conditions, the grain matures 45 days after sowing. Although it has adapted to soils with a low pH value of 4.5 and salinities of 2,000–3,000 parts per million, mature millet thrives best in sandy soil with pH values of 4.6-7.4. Among all the millets, it contains the most minerals (4.0g/100g) and crude fiber (14.7g/100g). [18] The resistant starch found in barnyard millet has demonstrated the ability to reduce blood glucose levels, as well as lower serum cholesterol and triglyceride levels, as evidenced in studies conducted with rats. In a clinical study involving human volunteers, regular consumption of barnyard millet meals by individuals with type 2 diabetes resulted in a confirmed reduction in glycemic index (GI).[31] Furthermore, existing research has indicated that barnyard millet contains a relatively higher protein content (ranging from 11.2% to 12.7%) compared to other prominent cereals and millets. The Barnyard millet is the best millet for patients with a condition called celiac disease or sensitivity to gluten.[30][32]

Kodo millet:

Kodo millets are known for their coarse texture and ease of digestion. They have a rich historical background, originating in tropical Africa and later domesticated in India approximately 3000 years ago. This particular millet goes by various names, including Indian Crown Grass, Native *Paspalum scrobiculatum*, Ditch Millet, Rice Grass, Kodra, and Varagu, depending on the region. Kodo millet is cultivated in several countries, including India, Pakistan, the Philippines, Indonesia, Vietnam, Thailand, and West Africa. Notably, it serves as a primary food source in the Deccan Plateau of Gujarat, India. [36] Kodo millets contains high amounts of vitamins and minerals, especially B-complex vitamins, B6, niacin and folic acid, Fe, Ca, Mg, K, and Zn. Kodo millet is very easy to digest and thus can be beneficial for infant and geriatric product formulation. It is also referred as "nutria-cereals". [37] The protein content in kodo millet grain is approximately 8.3%, with the major protein component being glutelin. These millets are also notable for their high crude fiber content, measuring at 9%, which significantly surpasses the fiber content found in wheat (1.2%). In terms of energy, kodo millet provides 353 Kcal per 100 grams of grain. The composition of kodo millet includes 66.6% carbohydrates, 2.4% minerals, 1.4% fat, and 2% ash. The iron content in kodo millet typically ranges from 25.86 ppm to 39.60 ppm. [34]

Kodo millet is a good source of polyphenols, flavonoids, and antioxidant compounds. Due to its richness in nutritional parameters, kodo has many health benefits. Its richness in phytochemicals and phytates makes it anticancerous and helps to reduce body weight and knee and joint pains/arthritis.[35]



Data Adopted from: [35][36][37][38][39][40][41][42][43][45]

Fig. 2: Amino acid content in millets (mg/g)

Table 2: Proximate composition of millets (/100 g)

Millet	Protein (g)	Fat (g)	Dietary Fiber (g)	Mineral (g)	Calcium (mg)	Potassium (mg)	Iron (mg)	Phosphorous (mg)	Thiamine (mg)	Niacin (mg)	Folic Acid
Sorghum	10.4	1.3	14.3	1.6	25	222	4.1	266	0.38	4.3	20.0
Finger millet	7.3	1.3	18.8	2.7	344	283	3.9	283	0.42	1.1	18.3
Kodo Millet	8.3	1.4	15	2.6	27	188	0.5	188	0.15	2.0	23.1
Proso Millet	12.5	1.1	14.2	1.9	14	206	0.8	206	0.41	4.5	_
Foxtail Millet	12.3	4.3	14	3.3	31	290	2.8	290	0.59	3.2	15.0
Little Millet	7.7	4.7	12.2	1.5	17	220	9.3	220	0.30	3.2	9.0
Barnyard Millet	6.2	2.2	13.7	4.4	20	280	5.0	280	0.33	4.2	_

Data Adopted from: [35][36][37][38][39][40][41][42][43][45]

Antinutrients in millets

Antinutrients are a compound that binds to the essential nutrients found in food, hindering their absorption by the human body. These factors are also found in seeds of cereals and legumes, give rise to nutrition-related issues and pose risks to human health. Millets, for instance, contain varying levels of these anti-nutrients, but their impact can be mitigated through several food processing techniques such as fermentation, malting, and germination. These methods enhance the bioavailability of nutrients. Examples of anti-nutrients include phytic acid polyphenols, tannins, dietary fibers and enzyme inhibitors. [36][46][54][55]

Phytic Acid

Antinutritional constituents, such as phytate, can be categorized into phytic acid and myoinositol. Phytic acid, chemically known as 1,2,3,4,5,6-hexa dihydrogen phosphate, stores about 1–5% of phosphorus by weight in cereals, nuts, and legumes. Additionally, a substantial portion of phosphorus (approximately 50–85%) is externally incorporated into plants. Phytic acid exists in a crystalline globular form within the protein bodies found in the cotyledon of oilseeds and legumes, as well as in the bran fraction of cereals. These compounds carry a negative charge, which causes them to attract positively charged substances like minerals (e.g., Zn and Ca), forming insoluble complexes that cannot be readily digested or absorbed. In raw sorghum, pearl millet, and finger millet, the phytic acid content stands at 8.6 ± 0.15, 4.77 ± 0.07, and 5.69 ± 0.19 mg/g, respectively. [46]

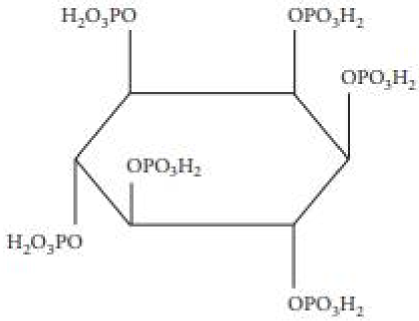


Fig. 3: Chemical Structure of Phytic acid

Furthermore, phytic acid indirectly interacts with protein molecules by binding to positively charged mineral ions, rendering a portion of the protein indigestible. Numerous studies have demonstrated that phytate is not digestible by humans or nonruminant animals, making it an inadequate source of inositol or phosphate when consumed directly. Phytates also form chelates with di- and trivalent metallic ions, including Cd, Mg, Zn, and Fe, resulting in the formation of poorly soluble compounds. These compounds are not absorbed in the gastrointestinal tract; leading to reduced bioavailability due to this reason phytate is categorized as an antinutritive agent. When high concentrations of cereals are consumed, phytates have been shown to interfere with mineral bioavailability in general and may negative impacts are observed on newborns, pregnant or lactating women. [47]

Lowering the amount of phytic acid in millets is important. One can do this by using traditional ways of preparing and cooking millets. This helps make important minerals in millets easier for our bodies to absorb.

Tannins

Tannin is a type of bitter and astringent polyphenolic substance found in plants. It has a relatively high molecular weight, typically between 500 to 3000 Da. Tannins can exist in both organic and inorganic forms, and they serve as protective compounds in plants. When tannins bind to proteins, especially those rich in essential amino acids, they can have a negative effect on protein digestion. [47] This can reduce the efficiency of food, hinder growth, and interfere with the absorption of iron. However, the impact of tannins on different proteins varies, with proteins that have a lot of the amino acid proline, such as collagen in animal tissue and certain plant reserve proteins, being less affected by tannins. [49]

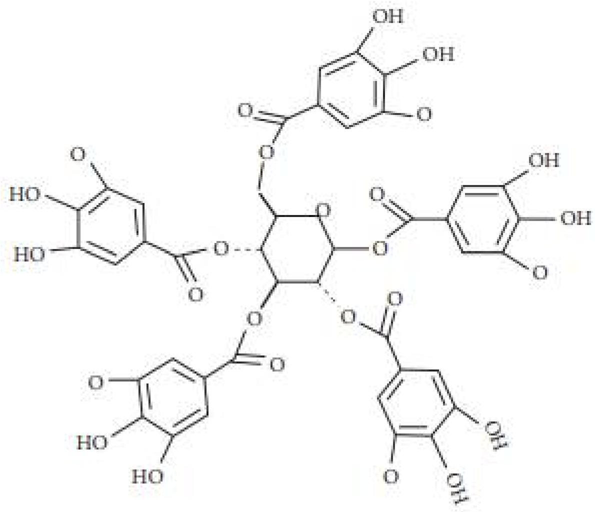


Fig. 4: Chemical Structure of Tannin

Tannins come in two distinct forms based on their susceptibility to hydrolysis through hot water, acids, alkalis, or enzymatic processes: condensed tannins and hydrolysable tannins. Tannins have the property of inhibiting the digestion of proteins. Hydrolysable tannins are prone to digestive hydrolysis, potentially leading to the formation of toxic compounds, whereas condensed tannins are not subject to hydrolysis and remain unabsorbed during the digestion process. Most condensed tannins fall into two categories: flavan-3-ols (catechins) and flavan-3:4-diols (leucoanthocyanidins). In contrast, hydrolysable tannins include compounds like glucose or polyhydric alcohols esterified with gallic acid (gallotannins) or hexahydrodiphenic acid (ellagitannins). Ellagic acid is the stable dilactone of the latter. [51]

Tannin compounds are widely distributed in various plants and are used for purposes such as insecticides, plant growth regulators, and defense against predators. Traditionally, tannins have been considered antinutritional; however, recent research suggests that their effects, whether favorable or antinutritional, depend on their chemical structure and dosage. Condensed tannins are abundant in fruits, vegetables, forage plants, red wine, and specific grains like sorghum, millets, and legumes. [52]

Based on dietary analysis, the average daily tannin intake in India falls within the range of 1500-2500 mg. consuming less than 1.5 to 2.5 grams of tannin daily is generally considered safe and doesn't result in any negative effects. However, exceeding this range can lead to health issues such as anemia, osteoporosis, and may worsen the condition of cancer patients. This is because tannins can bind to starch, which is a precursor to serotonin, potentially reducing serotonin levels and increasing the severity of migraines. [54] While tannins have the ability to inhibit the growth of cancer cells, it's important to note that some carcinogenic molecules can induce cancer and cause damage to liver cells. Additionally, when tannins bind with proteins, they create an astringent sensation, which can decrease the overall taste appeal of food products. As a result, tannins may be considered a disadvantage in the beverage industry and for the palatability of certain foods. [55][56]

Tannins have various industrial applications as they have anti-oxidant and anti-bacterial properties. Therefore, they are used in the food industry, preventive medicine, and the leather and chemical industry. [56]

Polyphenols

Polyphenols are recognized as essential contributors to overall health, playing a significant role in maintaining the well-being of the body over a lifetime. While they may not directly contribute to nutrition, they offer a plethora of health benefits. These compounds exhibit a wide range of properties, including antimutagenic, anticarcinogenic, antiestrogenic, anti-inflammatory, antiviral, and platelet aggregation inhibition, all of which contribute to the prevention and mitigation of various diseases. [51]

Epidemiological studies conducted on both animals and humans have demonstrated that diverse polyphenols possess antioxidant and anti-inflammatory capabilities.[54] They have the potential to prevent and even treat conditions such as obesity, cancer, neurodegenerative diseases, and heart diseases. However, it's important to note that polyphenols can also impact the body in other ways. They can influence the transport of thiamine and folic acid, modify drug activity by interacting with drug carriers or enzymes involved in metabolic reactions, and, in some instances, enhance the inhibition and bioavailability of certain compounds. [55][56]

One aspect to be cautious about is the inhibitory effect of polyphenols on iron absorption, which can lead to suboptimal iron levels. Furthermore, excessive intake of polyphenols in the colon may disrupt the growth of beneficial microbes. It's worth mentioning that at high doses or concentrations, certain polyphenols may have carcinogenic or genotoxic effects.[57] In modern times, polyphenols are recognized as crucial for maintaining overall health and well-being as we age. Millet polyphenols, in particular, consist of a diverse combination of cinnamic acid derivatives and benzoic acid. These compounds play a significant role in inhibiting enzymes and have the potential to prevent cataracts.[59]

Enzyme Inhibitors

Various types of enzyme inhibitors play essential roles in plant defense mechanisms. These include protease inhibitors, alpha-amylase inhibitors, and trypsin inhibitors. These inhibitors serve as protective mechanisms for plants, safeguarding them against pests and microbial threats. Plants possess a diverse array of protein inhibitors, primarily stored in seeds and tubers, earning them the name "storage proteins." These proteins typically constitute between 6% to 10% of the seed's composition.[46]

Protease inhibitors are a class of compounds that play a vital role in regulating protein digestion. These inhibitors function by binding to protease enzymes, which are responsible for catalyzing the hydrolytic cleavage of peptide bonds within proteins. By doing so, protease inhibitors effectively hinder the breakdown of proteins into smaller peptides and amino acids, which is essential for proper digestion and nutrient absorption. Protease inhibitors exert their influence by regulating protease activity, thereby disrupting a range of essential biological processes, including apoptosis, blood clotting, fibrinolysis, inflammation, and hormonal pathways in mammals. Consequently, there arises a necessity to minimize or substantially reduce the presence of protease inhibitors in food products. Nevertheless, it's worth noting that protease inhibitors hold significant biotechnological promise, with potential applications as insecticides, anticancer agents, and antibacterial agents.[58]

Trypsin inhibitors, for instance, specifically inhibit trypsin proteins, which are responsible for binding to peptides after lysine and arginine residues. By doing so, they play a significant role in impeding the digestion of proteins by trypsin and chymotrypsin enzymes. Various previous studies have shown that seeds, which are rich in trypsin inhibitors may increase the satietogenic hormone i.e. cholecystokinin (CCK) and cause reduction in food intake and body weight.[59]

Inhibiting α-amylase activity is recognized as a potential strategy for addressing conditions related to carbohydrate metabolism, such as lowering insulin levels and preventing dental caries and periodontal diseases. Amylase inhibitors are substances that effectively bind to alpha amylases, rendering them inactive. These inhibitors serve dual purposes: firstly, they play a crucial role in safeguarding seeds against harmful microorganisms and pests, and secondly, they contribute to the inhibition of endogenous α-amylase activity. However, it's important to note that these inhibitors exhibit instability within the gastrointestinal environment and are highly susceptible to heat, which limits their effectiveness as starch blockers. Nonetheless, they have found utility in managing type 2 diabetes in humans and offer various applications within the food industry.[60]

Health benefits of millets:

Obesity

One of the prominent health concerns in India and all over the world is obesity, which is associated with various chronic diseases such as diabetes and cardiovascular conditions. Recent research indicates that the prevalence of obesity can be reduced by consuming a diet rich in dietary fiber. [41] By slowing down digestion and absorption, dietary fiber-rich foods improve gastrointestinal function and lower the risk of developing chronic diseases.[42] Millets have emerged as a valuable dietary option as they contain an average dietary fiber content of 22%, significantly higher than other cereals like wheat (12.6%), rice (4.6%), and maize (13.4%). Finger millet, in particular, has been found to have 1.4% soluble and 15.7% insoluble dietary fiber, contributing to an overall dietary fiber content of 21.4% (19.7% insoluble and 2.5% soluble). [38,45] Different types of fiber in the diet can be categorized based on their solubility. Including fiber-rich foods in the diet has been shown to improve intestinal function, aid in weight management, and reduce the risk of chronic diseases by promoting optimal digestion and nutrient absorption. In addition to curbing hunger, millets support weight management and help prevent obesity by alleviating issues like constipation, gas, bloating, and abdominal cramps.

Clinical data obtained from multiple research studies suggested that the consumption of foxtail millet over a period of 12 weeks led to a notable increase in blood leptin levels. Specifically, the levels increased from an average of 8.3 ± 6.4 to 9.6 ± 7.0 nanograms per milliliter (ng/ml). Normal blood level of leptin in adult is 0.5 - 15.2 nanograms per milliliter (ng/mL). This rise in leptin levels is indicative of potential hunger suppression and a reduced intake of energy. It is believed that these effects are achieved by modifying signals in the nervous system and influencing blood glucose metabolism. Additionally, the feeling of fullness associated with foxtail millet consumption can be attributed to two factors. Firstly, it is linked to a delay in the time it takes for the stomach to empty after a meal, a characteristic that has been documented at the time of studies. Secondly, foxtail millet is recognized for its high fiber content, which can contribute to a prolonged feeling of satiety. This combination of effects may contribute to the prevention of sudden spikes in blood glucose levels. A stable blood glucose profile can, in turn, result in reduced availability of glucose for the synthesis of triacylglycerol, potentially leading to a decrease in triacylglycerol levels. [61][62][63]

High levels of lipids in the blood, a condition known as hyperlipidemia, are linked to inflammation, which can lead to lipotoxicity and the advancement of cardiovascular disease (CVD).[74] Some substances that may contribute to the malfunctioning of blood vessel linings, a condition called endothelial dysfunction, include leptin, interleukin-6 (IL-6), and adiponectin. To assess the risk of these complications, potential diagnostic tools include measuring serum high-sensitivity C-reactive protein (hs-CRP), fasting insulin, tumor necrosis factor-α (TNF-α), IL-6, leptin, and adiponectin levels. A study conducted over a 12-week period involving the consumption of foxtail millet revealed a noteworthy outcome: a reduction in the levels of the inflammatory markers IL-6 and TNF-α. [42][61]

Diabetes

As per the International Diabetes Association, the prevalence of diabetes is on the rise globally, affecting all regions. India, China, and the USA are the countries with the highest diabetic populations. Projections indicate that Africa is expected to witness the most significant increase, with a staggering 143% rise from 2019 to 2045, followed by the Middle East and North Africa at 96%, and South East Asia at 74%. In light of these alarming trends, the authors of the study advocate for the incorporation of millets into staple diets, particularly in Asia and Africa, as a means to manage diabetes. Furthermore, the study reinforces the case for re-establishing millets as dietary staples.[63]It reveals that millets exhibit a notably low average glycemic index (GI) of 52.7, which is approximately 30% lower than the GI of milled rice and refined wheat, and significantly lower by 14-37 GI points compared to maize.[49] The glycemic index serves as an indicator of how quickly and to what extent a food item raises blood sugar levels. The comprehensive review concludes that even after undergoing common cooking methods such as boiling, baking, and steaming, millets maintain a lower GI compared to rice, wheat, and maiz. [50]

Numerous studies have provided compelling evidence that millets possess unique attributes contributing to a low glycemic index (GI) and their potential in regulating blood glucose levels. The formation of resistant starch in millets, alongside their high fiber content, plays a pivotal role in retarding starch breakdown, resulting in a lower GI and the potential to reduce blood glucose levels. Furthermore, millets exhibit a significantly greater presence of non-starch polysaccharides, particularly dietary fiber, compared to wheat and rice. This abundance of fiber in millets reduces the activity of enzymes in the gut, leading to incomplete digestion of carbohydrates, proteins, and fats present in millet-based diets.[51][52] Consequently, the absorption of starchy polysaccharides is delayed, and the rate at which mono and disaccharides are absorbed is reduced, resulting in a lower glycemic response. The substantial formation of resistant starch in millets can be attributed to the presence of amylose, a component known to encourage the retrogradation of starch and the subsequent formation of resistant starch. This resistant starch is challenging for digestive enzymes to break down, contributing to the observed low glycemic response. Additionally, millets are characterized by a higher protein and fat content in comparison to milled rice. This elevated protein and fat content, combined with other factors, serves to slow down the digestion process in the small intestine, leading to incomplete digestion and, consequently, a lower GI. Moreover, the protein content in millets brings an added advantage of enhancing insulin sensitivity, thereby supporting improved glycemic control. [64]

Millets have shown promising effects by reducing the activity of glucosidase and pancreatic amylase enzymes. This action helps inhibit the breakdown of complex carbohydrates and postprandial hyperglycemia. Additionally, millets contain aldose reductase, an enzyme that helps prevent the accumulation of sorbitol and lowers the risk of cataract-related complications associated with diabetes. Therefore, incorporating millets into your diet can aid in regulating blood sugar levels and, due to their antioxidant properties, promote healing of cutaneous wounds. [44] In a study conducted as part of the National Agricultural Innovation Project (NAIP) in 2010, the Glycemic Index (GI) of foods based on sorghum was evaluated by the National Institute of Nutrition (ICMR) and the Indian Institute of Millets Research in Hyderabad. The findings revealed that foods made from sorghum had a low GI, resulting in lower blood sugar levels after meals. This is particularly relevant considering the prevalence of diabetes worldwide. [21] Magnesium is an essential mineral that supports the production of various enzymes involved in carbohydrate digestion, regulates insulin action, and enhances the effectiveness of insulin and glucose receptors. [65][66][67]

Cardio Vascular Diseases
Millets have been found to increase levels of adiponectin and H3 lipoprotein cholesterol, which can have a positive impact on plasma lipid levels. Additionally, millets serve as an excellent source of magnesium, a mineral known to reduce the risk of heart attacks. The presence of phytochemicals like phytic acid and high-fructose corn syrup (HFCS) in millets can help lower cholesterol levels and mitigate the risk of cardiovascular diseases by reducing plasma triglycerides.[68] Regular consumption of whole millet grains has been linked to a decreased risk of cardiovascular ailments, making millets an ideal choice for maintaining heart health. The abundance of magnesium in millets is particularly beneficial for controlling blood pressure and preventing heart attacks and strokes, especially in individuals with coronary artery disease. Furthermore, millets provide a rich source of potassium, which acts as a vasodilator and aids in lowering blood pressure, contributing to an improved circulatory system and enhanced cardiovascular well-being. Another advantage of millets is their content of plant-based lignans, which serve as prebiotic fibers and undergo fermentation by bacteria in the digestive tract. The conversion of these lignans into animal lignans by gut microflora offers protection against various chronic diseases. One such lignan, enterolactone, has been found to prevent heart disease and certain types of breast cancer.[69] Overall, millets offer multiple cardiovascular benefits, including lipid regulation, blood pressure control, and protection against chronic diseases through the presence of lignans and other beneficial compounds.
Celiac Disease:
Celiac disease arises from a genetic susceptibility to gluten, but non-gluten-containing millets can alleviate the discomfort caused by gluten found in common cereal grains, potentially reducing the prevalence of this condition.[11][47] Maintaining optimal digestive health is vital for preserving essential nutrients within your body and reducing the likelihood of more serious gastrointestinal problems, such as gastric ulcers or colorectal cancer. Millets, due to their abundant fiber content, play a role in alleviating conditions like constipation, excessive gas, bloating, and cramps. Celiac disease, an immune-related enteropathy, is usually activated by the ingestion of gluten in susceptible individuals. A gluten-free diet primarily involves reducing the intake of grains containing gluten, such as wheat, barley, and rye. As a suitable alternative, millets offer great potential in various food and beverage applications, catering to the increasing demand for gluten-free options. Being gluten-free, millets serve as a viable choice for individuals with celiac disease and contribute to the expanding market for gluten-free products. [70]
Cancer
Excessive free radical generation and lipid peroxidation are major contributors to chronic diseases such as diabetes, cardiovascular disease, cancer, cataracts, and aging. Millets contain phenolic compounds that have the potential to prevent lipid oxidation, offering protection against these conditions. In addition, millet grains have been found to inhibit the growth of human colon cancer cells, indicating their potential in cancer prevention. The presence of flavones, including kaempferol, apigenin, luteolin, and quercetin, in millets has demonstrated antiproliferative activity in laboratory studies. These flavones have shown the ability to induce apoptosis, a tightly controlled process characterized by cell shrinkage, membrane blebbing, chromatin condensation, and the formation of DNA fragments. Anthocyanins, another class of compounds found in millets, have been shown to significantly slow the growth of various tumor cells, including human cervical cancer, leukemia, and prostate cancer cells. In one study, sorghum anthocyanins were evaluated for their antiproliferative activity on human breast cancer cells (MCF-7). The study observed morphological changes in the form of apoptotic bodies and concentration-dependent fragmentation of DNA, indicating the induction of apoptosis. Based on these findings, it can be concluded that sorghum anthocyanins have an antiproliferative effect on human breast cancer cells (MCF-7). The presence of these bioactive compounds in millets suggests their potential in combating chronic diseases and inhibiting tumor growth. [71][72][73]

CONCLUSION
This comprehensive review paper has illuminated the remarkable nutritional values of millets and their significant impact on human health. These ancient grains, often overshadowed by more widely consumed cereals, have emerged as nutritional powerhouses, offering a plethora of benefits that can positively influence health outcomes and mitigate the risks associated with various diseases. The findings presented in this review underscore the diverse and substantial nutritional content of millets, encompassing dietary fiber, vitamins, minerals, and antioxidants. Their unique attributes, including low glycemic index, gluten-free nature, and rich nutrient profile, position millets as valuable components of a health-conscious diet. Through their consumption, individuals can effectively manage and prevent a range of health conditions, including diabetes, heart disease, and obesity. Furthermore, the sustainability of millet cultivation cannot be overstated. These hardy crops thrive in diverse climatic conditions with minimal environmental

impact, making them crucial for ensuring food security and mitigating the challenges posed by climate change.
Also the food processing industry presently has various opportunities to manufacture millet-based products of exceptional quality, which are gaining broader acceptance among consumers due to enhanced post-harvesting and value addition techniques. Consequently, there exists a significant potential for conducting comprehensive research aimed at developing superior millet products that are not only affordable for consumers across income brackets but also flavorful and health-enhancing. The review also focuses on the richness of millets in minerals and phytochemicals that contain several antinutrients which may reduce the absorption of some important nutrients in the body and leads to several diseases. Overall, the nutritional values of millets are pivotal in influencing health status, offering a natural and accessible means to combat a spectrum of diseases. Millets stand as a testament to the potential of ancient grains in modern diets, presenting a sustainable, nutritious, and culturally rich solution to the health challenges of our time. As we further explore their potential and expand their adoption, millets have the potential to lead us toward a healthier and more resilient future.

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CONFLICT OF INTEREST
The authors declare that there are no conflicts of interest regarding the publication of this review article.

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