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## Comparative evaluation of the nutraceutical value of nutri-cereals and their benefits concerning a healthy human lifestyle

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### Abstract

Cereals and millets are essential elements of our daily diet. It is essential to investigate their nutritional and health-promoting properties for their incorporation into our meals. This research evaluated the nutraceutical value of nutri-cereals that are frequently part of human consumption. The proximate analyses revealed significant differences, with protein levels ranging from 6.43 to 16.77%, carbohydrates from 48.90 to 69.97%, and fiber from 3.20 to 10.18%. Nutri-cereals are rich in calcium (63.48 to 1211.95 mg/100 g), iron (7.05 to 38.94 mg/100 g), zinc (1.16 to 11.30 mg/kg), phytic acid (1.53 to 124.13 µg/g), and antioxidants (105.90 to 1030.78 µg/g). Among the small millets, finger millet exhibited the highest amounts of antioxidants (1030.78 µg/g), phytic acid (124.13 µg/g), and calcium (1211.95 mg/100 g), while rice had the greatest carbohydrate content (69.97%) and foxtail millet presented the highest iron levels (38.94 mg/100 g). In conclusion, minor millets such as foxtail millet, finger millet, pearl millet, and kodo millet were determined to be nutritionally superior to both rice and wheat. These nutrient-dense millets offer significant opportunities for future breeding initiatives aimed at enhancing cereal quality and possess substantial potential in the food sector for creating high-value functional foods and promoting nutritional security.

### 1. Introduction

Cereal grains have been the foundation of human diets for thousands of years, supplying most daily calories and forming an integral part of cultural food systems. In modern agriculture, however, rice, wheat, and maize have dominated global production, gradually overshadowing traditional grains. Nutri-cereals or minor millets include foxtail millet, little millet, barnyard millet, proso millet, and kodo millet. These small-seeded grains were once staple foods across Asia and Africa, valued for their resilience in harsh climates and their ability to nourish communities during times of scarcity. In recent decades; however, they have regained attention not just as food security crops but as functional foods with immense nutraceutical value and profound benefits for human health and lifestyle. Millets contain complex carbohydrates that release glucose slowly, thereby maintaining steady blood sugar levels (Sayani and Annalkshmi, 2017). Minor millets are rich in dietary fiber, which plays a crucial role in digestion, satiety, cholesterol management, and body weight regulation. The protein content, though moderate, is of excellent quality, with essential amino acids such as methionine and cysteine that are often deficient in rice and wheat-based diets. These grains also provide significant amounts of vitamins, particularly the B-

complex group, which supports energy metabolism and nervous system health, along with minerals such as iron, calcium, magnesium, zinc, and phosphorus, which are indispensable for immunity, bone strength, and metabolic functions (Himanshu *et al.*, 2018; Kamalesh *et al.*, 2024).

Minor millets, apart from major cereals, are not only their macronutrient balance but also by their richness in phytochemicals and bioactive compounds. They are abundant in phenolic acids such as ferulic and caffeic acid, flavonoids like quercetin and luteolin, and tannins and phytosterols that function as powerful antioxidants. These compounds protect cells from oxidative stress, which is implicated in the onset of many chronic diseases, including cardiovascular disorders, cancer, and neurodegenerative conditions. Beyond antioxidant capacity, these bioactive molecules possess anti-inflammatory, antimicrobial, and cholesterol-lowering properties, making millet consumption a natural strategy to prevent multiple health issues simultaneously. Modern nutritional science has increasingly recognized the importance of such functional foods, and minor millets, once considered “poor man’s food,” are now being celebrated as “smart foods” suitable for all sections of society. The health-promoting properties of minor millets have been widely studied in the context of lifestyle-related diseases. For individuals with diabetes, their low glycemic index ensures better glycemic control than refined cereals. Obesity, another global concern linked to sedentary lifestyles and high-calorie diets, can be managed more effectively through the inclusion of millets, as their high fiber content enhances satiety and prevents overeating. Cardiovascular diseases,

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often associated with high cholesterol levels and poor dietary patterns, can be mitigated by the presence of phytosterols and soluble fiber in millets, which help reduce serum cholesterol. Regular millet consumption has also been linked to lower risks of hypertension, improved lipid profiles, and reduced oxidative damage, all of which collectively support heart health. The contribution of millets to bone health, due to their rich calcium and magnesium content, is another important benefit, particularly in combating osteoporosis in ageing populations. Another remarkable feature of minor millets is their gluten-free nature, which makes them a safe and nutritious alternative for people with gluten intolerance or celiac disease. At a time when gluten-free diets are increasingly being adopted not only for medical reasons but also for general wellness, minor millets offer a natural, wholesome solution. Their digestibility, combined with their ability to support healthy gut microbiota through fiber fermentation, adds further to their reputation as digestive-friendly grains. Millet-based diets improve bowel movement, promote beneficial gut bacteria, and enhance overall gastrointestinal health (Anuratha *et al.*, 2024).

The importance of minor millets extends beyond human nutrition to agricultural sustainability. They are naturally hardy crops that thrive under conditions where rice and wheat struggle, particularly in drought-prone, rainfed, and marginal soils. Their short growing season, low water requirement, and resistance to pests and diseases make them invaluable in the context of climate change and food insecurity. Unlike water-intensive rice cultivation, millet farming requires minimal irrigation, conserving natural resources and reducing environmental stress. By reviving millet cultivation, farming systems can become more climate-resilient and environmentally sustainable, while also providing farmers with livelihood security. Thus, millets contribute not only to nutritional security but also to ecological balance. When compared with major cereals, the superiority of minor millets becomes evident. Polished rice, for instance, is starch with negligible fiber and low micronutrient levels, leading to “hidden hunger,” or micronutrient deficiency, even when caloric intake is sufficient. Wheat, while nutritionally better than rice, contains gluten, which poses dietary challenges for sensitive populations. In contrast, minor millets combine energy, nutrients, and bioactive compounds in a single package, offering health, versatility, and safety. By establishing their nutraceutical superiority, these grains can be positioned as mainstream foods in both rural and urban diets. The relevance of minor millets to a healthy human lifestyle lies in their ability to combine nutrition, health promotion, and sustainability in one solution. In an age where non-communicable diseases are the leading cause of mortality, dietary changes play a decisive role in prevention and management. Millets, with their nutraceutical richness, can significantly reduce the burden of such diseases when integrated into daily diets. Moreover, their contribution to satiety and metabolic regulation aligns with modern goals of fitness and weight management. In other words, choosing millets is not merely a personal dietary decision but also an act of environmental responsibility. Their nutraceutical richness, encompassing macronutrients, micronutrients, and bioactive compounds, makes them superior to major cereals for maintaining a healthy lifestyle and preventing chronic diseases. Beyond individual well-being, their ecological resilience ensures that they contribute to food security and sustainable agriculture in an era of climate change. At the same time, their cultivation promotes biodiversity, reduces carbon footprints, and ensures climate resilience,

making them a cornerstone of sustainable diets as defined by the Food and Agriculture Organization. In this context, it is essential to explore a comparative evaluation of their nutraceutical benefits is thus essential for repositioning these grains from neglected crops to global superfoods.

## 2. Material and Methods

### 2.1 Sample collection and preparation

Grains of cereals and millets commonly cultivated in various regions of Tamil Nadu, India, offer numerous health advantages. For the analysis of functional properties, the nutritious grains were thoroughly cleaned and stored at ambient temperature, around 25°C to 28°C. To achieve uniform flour consistency and reduce particle size, dried rice grain samples were milled using a Brabender Quadrumate Senior Mill. Following this, the samples were positioned on infrared plates. The sampling was done with three replications. Then the statistical analysis was performed to calculate standard errors and critical differences by using the software AGRES.

### 2.2 Biochemical analysis

#### 2.2.1 Carbohydrate content

The primary carbohydrates found in plants include monosaccharides, disaccharides, oligosaccharides, and polysaccharides. The overall carbohydrate percentage was calculated using the following equation (James, 1995).

#### 2.2.2 Protein content

The Kjeldahl method was employed to assess crude protein in accordance with the AOAC (2002) guidelines. A 2 g sample was combined with 20 ml of concentrated H<sub>2</sub>SO<sub>4</sub> and a Kjeldahl catalyst, consisting of 9 parts H<sub>2</sub>SO<sub>4</sub> and 1-part CuSO<sub>4</sub>, in a digestion chamber until the solution became clear. A blank test was also performed without the sample. After digestion, the Kjeldahl distillation procedure was used to measure the nitrogen content. The nitrogen value was then multiplied by 6.25 to calculate the crude protein value.

#### 2.2.3 Fiber content

Crude fiber refers to the indigestible portion of carbohydrates, which is measured using diluted alkaline and acid solutions. The leftover materials are classified as crude fiber (Sadasivam and Manickam, 1996).

#### 2.2.4 Fat content

The Soxhlet extraction technique was employed to assess the fat content. The measurement of crude fat was performed following the protocols set forth by the Association of Official Analytical Chemists (AOAC, 2002). First, the weight of the flask was recorded after it had been heated overnight in a hot air oven at 105°C, then allowed to cool in a desiccator. A 5 g sample was subjected to extraction with petroleum ether using a Soxhlet apparatus for about 6 h.

### 2.3 Mineral nutrients

#### 2.3.1 Calcium content

Grain samples were processed using a 9:4 blend of nitric acid and perchloric acid. The sample is then filtered with a Whatman number 40 filter paper. Portions of this solution can be utilized for

the measurement of calcium in addition to magnesium, and for calcium analysis. The calcium content was estimated by the versenate titration method (Govindaraju *et al.*, 2001).

### 2.3.2 Phosphorus content

Grain samples were treated with a 9:4 mixture of nitric acid and perchloric acid. The sample is then filtered using Whatman number 40 filter paper. Portions of this solution can be utilized for measuring phosphorus through a colorimetric approach (Govindaraju *et al.*, 2001).

### 2.3.3 Potassium content

Grain samples were treated with a 9:4 mixture of nitric acid and perchloric acid. The sample is then filtered using Whatman number 40 filter paper. Aliquots of this solution can be used for the determination of phosphorus content by flame photometric method (Govindaraju *et al.*, 2001).

### 2.3.4 Copper, zinc and iron content

Grain samples were treated with a 9:4 mixture of nitric acid and perchloric acid. The sample is then filtered using Whatman number 40 filter paper. Aliquots of this solution can be used for the determination of iron, zinc, and copper. Then the sample was fed into an atomic absorption spectrophotometer to record iron, zinc, and copper content (Govindaraju *et al.*, 2001).

## 2.4 Antioxidant and antinutritional factors

### 2.4.1 Phytic acid

Phytic acid is chemically referred to as myoinositol 1,2,3,4,5,6-hexakis dihydrogen phosphate. It serves as the main storage form of phosphorus, constituting 1-5% of the weight found in cereals, legumes, oilseeds, and nuts. The phytic acid levels in all samples were determined by the technique described by Gao *et al.* (2007) using sodium phytate.

### 2.4.2 Antioxidant activity

The antioxidant properties of the polyphenol extract were evaluated

using the DPPH free radical scavenging method as described by De Ancos *et al.* (2002).

## 2.5 Statistical analysis

The standard error of the means (SEM) was calculated for each factor and its interactions. In cases where the results were significant, the critical difference (CD) was determined at a 5 per cent level of significance.

## 3. Results

### 3.1 Functional properties

The nutritional characteristics were examined in all types of millets, and notable variations in their quality attributes were noted (Table 1). The highest carbohydrate content of 69.97% was found in rice, followed by little millet at 64.80%, finger millet at 61.25% and wheat at 60.4%. Foxtail millet exhibited the lowest carbohydrate level at 48.90%, closely followed by pearl millet at 51.0%. Kodo millet contained 56.35% of carbohydrates, while barnyard millet had 59.53%. The protein levels in millets ranged from 6.43% to 16.77%. Wheat showed the highest protein content at 16.77%, trailed by barnyard millet at 12.18% and foxtail millet at 10.99%. The least protein content was found in finger millet at 5.99%, as well as in kodo millet at 6.43% and pearl millet at 7.08%. Little millet contained 8.43% protein. The fiber content of millets varied from 2.56% to 10.18%. Significant differences in fat content were also observed among the millets. Among the different millets, the highest fiber content was recorded at 9.49% in barnyard millet, followed by little millet at 7.50%, foxtail millet at 6.90% and kodo millet at 5.50%. The lowest fiber content was seen in finger millet at 3.20%, kodo millet at 5.50% and pearl millet at 3.30%. Barnyard millet had the highest fat content at 8.5%, followed by pearl millet at 13.10% and little millet at 6.20%. The lowest fat contents were found in wheat at 1.40% and finger millet at 1.70%. Rice had the highest energy content at 1521 kcal/100 g, followed by pearl millet at 1504 kcal/100 g and little millet at 1457 kcal/100 g. The lowest energy contents were found in foxtail millet (345 kcal/100 g) and barnyard millet at 315 (kcal/100 g)

**Table 1: Comparison of functional properties of cereals and millets**

Cereals and millets name	Carbohydrate (%)	Dietary fiber (%)	Protein (%)	Fat (%)	Energy (kcal/100 g)
Rice	69.97	2.56	9.46	3.20	1521
Wheat	60.40	10.18	16.77	1.40	1398
Kodo millet	56.35	5.50	6.43	2.60	1391
Foxtail millet	48.90	6.90	10.99	5.10	345
Little millet	64.80	7.50	8.43	6.20	1457
Barnyard millet	59.53	9.49	12.18	8.50	315
Pearl millet	51.02	3.30	7.08	13.10	1504
Finger millet	61.25	3.20	5.99	1.70	1342
SEd	6.91	2.92	3.60	4.00	515.23
CD= 0.05%	13.92	5.83	7.22	8.02	1030.51

### 3.2 Mineral compounds

The mineral characteristics were examined across all types of millets, with notable differences in mineral concentrations observed (Table

2). Additionally, the phosphorus content in millets ranged from 172 to 301 mg/100 g, with kodo millet and pearl millet featuring the greatest phosphorus concentration at 301 mg/100 g and 300 mg/100

g, respectively; rice had the least at 172 mg/100 g. Potassium content in finger millet measured 420 mg/100 g, and pearl millet had 312 mg/100 g of phosphorus. The calcium content in millets varied from 63.48 to 1211.95 mg/100 g, with finger millet exhibiting the highest level at 1211.95 mg/100 g. Conversely, kodo millet had the lowest calcium content at 63.48 mg/100 g. Wheat contained 227.18 mg/100 g of calcium, pearl millet had 182.83 mg/100 g, barnyard millet recorded 94.11 mg/100 g, and little millet presented 84.92 mg/100 g of calcium. Additionally, the iron content in millets ranged from 7.05 to 38.94 mg/100 g, with foxtail millet featuring the greatest iron concentration at 38.94 mg/100 g, while kodo millet had the least at 7.02 mg/100 g.

Iron content in wheat measured 32.28 mg/100 g, pearl millet had 37.12 mg/100 g, barnyard millet recorded 29.95 mg/100 g, and little millet contained 24.16 mg/100 g of iron. The zinc levels in millets varied from 1.16 to 11.30 mg/100 g, with rice showing the highest zinc concentration at 11.30 mg/100 g, followed by little millet at 7.50 mg/100 g. Kodo millet had the lowest zinc content at 1.16 mg/100 g. Wheat contained 2.70 mg/100 g of zinc, pearl millet had 3.25 mg/100 g of zinc, and finger millet recorded 2.86 mg/100 g of zinc. The copper levels in millets varied from 0.40 mg/100 g to 1.34 mg/100 g, with rice showing the lowest copper concentration at 0.40 mg/100 g, and foxtail millet had the highest copper content at 1.34 mg/100 g.

**Table 2: Valuation of the mineral content of millets with cereals**

Cereals and millets name	Phosphorus (mg/100 g)	Potassium (mg/100 g)	Calcium (mg/100 g)	Copper (mg/100 g)	Iron (mg/100 g)	Zinc (mg/100 g)
Rice	172	9.12	66.42	0.40	8.49	11.30
Wheat	288	299	227.18	0.59	32.28	2.70
Kodo millet	301	152	63.48	0.40	7.05	1.16
Foxtail millet	299	247	115.63	1.34	38.94	5.60
Little millet	241	135	84.92	0.55	24.16	7.50
Banyard millet	276	20	94.11	0.76	29.95	4.60
Pearl millet	300	312	182.83	0.71	37.12	3.25
Finger millet	292	420	1211.95	0.82	26.83	2.86
SEd	44.69	145.58	390.64	0.30	12.04	3.25
CD = 0.05%	89.42	291.21	781.33	0.62	24.13	6.54

### 3.3 Antioxidant activity and antinutritional properties

Antioxidants are essential for maintaining food quality and promoting human health (Table 3). Effectively addressing oxidative stress may be vital for preventing and managing various diseases. The antioxidant properties were assessed across different millet varieties, revealing significant differences in antioxidant levels. The antioxidant activity in millets ranged from 105.90 to 1030.78 µg/g. The highest antioxidant concentration of 1030.78 µg/g was recorded in finger millet, followed closely by kodo millet at 1019.20 µg/g, barnyard millet at 762.54 µg/g, and pearl millet at 604.08 µg/g. In comparison, rice and wheat showed lower antioxidant levels, measuring at 174.27 µg/g and 165.41 µg/g, respectively. Foxtail millet had the lowest antioxidant level at

105.90 µg/g, while little millet contained 555.10 µg/g. The phytic acid levels in millets varied between 1.53 and 124.13 µg/g. The highest concentration of phytic acid, at 124.13 µg/g, was observed in finger millet. On the other hand, rice had the least phytic acid content at 1.53 µg/g, with little millet registering 9.94 µg/g. Foxtail millet had 37.88 µg/g, barnyard millet contained 36.50 µg/g, kodo millet had 32.90 µg/g, and pearl millet had 20.00 µg/g. The highest concentration of polyphenols, at 495.31 mg GAE/100 g, was observed in kodo millet. Finger millet contained 382.64 µg/g, and pearl millet had 376.85 mg GAE/100 g of polyphenols. On the other hand, rice had the least polyphenols, at 43.81 mg GAE/100 g, with little millet registering 79.43 mg GAE/100 g.

**Table 3: Valuation of antinutritional and antioxidant properties of millets with cereals**

Cereals and millets name	Antioxidant (µg/g)	Phytic acid (µg/g)	Polyphenols (mg GAE/100 g)
Rice	174.27	1.53	43.81
Wheat	165.41	43.50	157.23
Kodo millet	1019.20	32.90	495.31
Foxtail millet	105.90	37.88	124.01
Little millet	555.10	9.94	79.43
Banyard millet	762.54	36.50	143.82
Pearl millet	604.08	20.00	376.85
Finger millet	1030.78	124.13	382.64
SEd	375.25	37.64	167.49
CD = 0.05%	750.54	75.32	335.02

### 3.4 Vitamin

The vitamin B content was examined across all types of millets, with notable differences in vitamin B concentrations observed (Table 4). The thiamine content in millets varied from 0.19 mg/100 g to 0.63 mg/100 g, with foxtail millet exhibiting the highest level at 0.63 mg/100 g. Conversely, rice had the lowest thiamine content at 0.19 mg/100 g. Wheat contained 0.43 mg/100 g of calcium, finger millet had 0.41 mg/100 g, barnyard millet, pearl millet, and kodo millet presented 0.35 mg/100 g of thiamine. Additionally, the riboflavin content in millets ranged from 0.13 mg/100 g to 0.31 mg/100 g, with kodo millet featuring the greatest riboflavin concentration at 0.31 mg/100 g, while

rice and finger millet had the least at 0.13 mg/100 g and 0.19 mg/100 g, respectively. Niacin content measured 4.31 mg/100 g in banyard millet and foxtail millet had 3.41 mg/100 g of niacin, respectively. The pyridoxine levels in millets varied from 0.03 mg/100 g to 0.71 mg/100 g, with kodo millet showing the highest pyridoxine concentration at 0.71 mg/100 g, followed by wheat at 0.39 mg/100 g, rice at 0.35 mg/100 g, and pearl millet at 0.35 mg/100 g. Foxtail millet had the lowest pyridoxine content at 0.03 mg/100 g. Kodo millet contained 41.05 mg/100 g of folate, pearl millet had 37.50 mg/100 g, finger millet recorded 35.94 mg/100 g, and wheat showed 30.10 mg/100 g of folate.

**Table 4: Analysis of vitamin content of millets with cereals**

Millet name	B1 (Thiamine) (mg/100 g)	B2 (Riboflavin) (mg/100 g)	B3 (Niacin) (mg/100 g)	B6 (Pyridoxine) (mg/100 g)	B9 (Folate) (mg/100 g)
Rice	0.19	0.13	2.48	0.35	10.42
Wheat	0.43	0.16	2.45	0.39	30.10
Kodo millet	0.35	0.31	1.52	0.71	41.05
Foxtail millet	0.63	0.13	3.41	0.03	0.03
Little millet	0.29	0.13	1.34	0.09	39.50
Banyard millet	0.35	0.14	4.31	0.06	0.02
Pearl millet	0.35	0.23	0.90	0.35	37.50
Finger millet	0.41	0.19	1.30	0.10	35.94
SEd	0.13	0.06	1.18	0.23	17.83
CD = 0.05%	0.32	0.14	2.42	0.52	35.71

Millet grains were found to be promising for nutritive value and potential health benefits compared to major cereals such as wheat, rice, and maize. Millets are nutri-cereals embedded with a lot of nutrients, minerals, and antioxidants grown in the semiarid tropics of the world used for human food, animal feed, fodder, and fuel.

## 4. Discussion

Millets have re-emerged in recent years as highly valuable “nutri-cereals” because of their rich nutrient composition, bioactive compounds, and functional properties that contribute significantly to human health and disease prevention. Unlike refined cereals such as rice and wheat, which provide starch and limited micronutrients, millets are dense in protein, dietary fiber, minerals, vitamins, and phytochemicals, making them superior for ensuring nutritional security in both rural and urban populations. Convince consumers of the importance of integrating millets into modern diets, accurate nutrient information is essential, as it plays a pivotal role in the popularization of millet-based functional and novel food products (Ratnavathi and Tonapi, 2022). Adequate protein intake, particularly the balance of essential amino acids, is crucial for growth, immunity, and metabolism. Insufficient consumption of protein sources can adversely affect dietary protein quality and may result in conditions such as stunted growth among children. Millets, though moderate in protein, provide important amino acids that can complement legumes to form a balanced diet. The combination of cereals and pulses enhances protein quality by mutual supplementation, ensuring adequate lysine and tryptophan, and is often more cost-effective than relying solely on animal protein (Joshi *et al.*, 2024).

Finger millet is one of the oldest domesticated crops and continues to hold importance in the traditional diets of Africa and South Asia. Among the millets, finger millet is of particular interest as a gluten-free substitute for wheat and rice in the preparation of diverse value-added products, highlighting its significance for food security, nutrition, and the development of functional foods (Jagati *et al.*, 2021). As a gluten-free grain, finger millet is highly suitable for individuals with celiac disease or gluten intolerance. It is rich in calcium, iron, dietary fiber, and essential amino acids, making it nutritionally superior to many commonly consumed cereals (Kothapalli *et al.*, 2024). Calcium content in finger millet is particularly high compared to other cereals, which supports bone health, especially in children, women, and the elderly. Finger millet-based foods are now gaining traction as alternatives in the bakery, snack, and beverage industries, owing to their high nutritional density and wide processing potential. The nutraceutical potential of finger millet lies in its polyphenolic compounds, which exhibit strong antioxidant properties, thereby protecting the body from oxidative stress and reducing the risks associated with lifestyle diseases such as diabetes, cancer, and cardiovascular disorders. The grain has a low glycemic index, making it effective in managing blood sugar levels, while its high fiber content aids in satiety, weight control, and improved gut health. Finger millet can be incorporated into porridge, fermented beverages, malted flours, and ready-to-eat products, further strengthening its appeal as both a traditional and modern food option.

Little millet, though less widely cultivated, holds tremendous promise as a nutrient-dense cereal. It contains high levels of energy, protein, dietary fiber, and essential minerals such as phosphorus, iron, and

calcium. These nutrients contribute to preventing malnutrition and addressing dietary deficiencies, particularly in vulnerable populations. The grain is also abundant in phytochemicals, including phenols, flavonoids, and tannins, which contribute to antioxidant and anti-inflammatory properties (Nishma Singh and Akansha Chaudhry, 2023). From a health perspective, little millet plays a crucial role in managing modern lifestyle disorders. Obesity, overweight, and related conditions such as hypertension and type 2 diabetes are major contributors to morbidity and mortality worldwide, accounting for around 7.1% of global deaths and 4.9% of disability-adjusted life years (DALYs). Cardiovascular diseases, which represent 50% of mortality associated with a poor diet, can be reduced by incorporating fiber and phytochemical-rich grains like little millet. Its low glycemic response and antioxidant properties provide protection against metabolic disorders, while its nutrient density helps improve dietary quality across all demographic groups. Its versatility in processing into flours, porridges, baked goods, and snack products enhances consumer acceptance and supports its reintroduction into mainstream diets.

Kodo millet is another gluten-free cereal with significant nutritional and therapeutic importance. Traditionally grown in India, it is rich in dietary fiber, protein, and essential minerals, while also providing antioxidant compounds. The absence of gluten makes it particularly beneficial for individuals with gluten intolerance. Furthermore, its bioactive compounds, including polyphenols, have been linked with cancer-preventive properties. Kodo millet is beneficial for patients with cardiovascular disorders, diabetes, and obesity due to its hypoglycemic and hypocholesterolemic effects (Mathur *et al.*, 2025). Regular consumption helps regulate blood sugar and lipid levels, thereby improving overall metabolic health. Its high fiber improves digestion and enhances gut health, while the presence of phytochemicals strengthens the body's defence against oxidative stress. The potential of kodo millet for novel product development is significant, particularly in the functional food sector. It can be processed into gluten-free flours for bakery applications, fermented foods, breakfast cereals, and even ready-to-drink beverages. By addressing health and nutritional needs, kodo millet can serve as a key ingredient in value-added food innovations.

Barnyard millet has attracted widespread interest due to its nutrient richness and adaptability. The grain is notable for its high protein content (11.2-12.7%), dietary fiber, and significant levels of micronutrients such as iron and zinc, which are much higher than in other cereals (Saleh *et al.*, 2013). The carbohydrate content in millets ranging from 51.5 to 62 g/100 g, ensuring a lower glycemic index. A clinical study confirmed that regular consumption of barnyard millet resulted in reduced glycemic response among individuals with type 2 diabetes, supporting its role in managing metabolic disorders (Ugare *et al.*, 2014). Barnyard millet flour is used in the preparation of infant foods and beverages due to its digestibility and nutrient profile (Batt *et al.*, 2023). Its bioactive compounds, including polyphenols and carotenoids, are present in higher concentrations compared to finger millet, further contributing to its antioxidant and health-promoting effects. The grain is also suitable for individuals suffering from anaemia, especially women in developing nations, due to its high iron content and enhanced mineral bioavailability after dehulling. The combination of slow-digesting carbohydrates, high dietary fiber, and bioactive compounds makes barnyard millet a superior option for lifestyle disease management. It can be added to porridges,

flatbreads, fermented foods, and processed health drinks, making it versatile for both traditional diets and modern food systems.

Foxtail millet ranks among the earliest domesticated cereals, cultivated widely across Asia and Africa. It contains substantial amounts of protein, fiber, and minerals, along with a wide range of phytochemicals. Its carbohydrate content ranges between 60-65 g/100 g, protein around 12.3 g, and dietary fiber around 6 g, in addition to significant levels of minerals such as phosphorus, calcium, iron, magnesium, zinc, and sodium (Kalsi and Bhasin, 2023). The phytochemicals in foxtail millet include phenolic acids (ferulic, chlorogenic, p-coumaric), flavonoids, carotenoids, and vitamin E compounds like tocopherols and tocotrienols. These bioactive molecules contribute to its antioxidant, anti-inflammatory, anticancer, hypolipidemic, and hypoglycemic properties, providing multiple health benefits (Sharma and Niranjana, 2017). Foxtail millet is particularly valuable in lowering cholesterol levels, reducing oxidative damage, and controlling blood sugar, making it highly relevant in the prevention, and management of non-communicable diseases. The grain also has hypolipidemic effects, which help in lowering triglycerides and LDL cholesterol while improving HDL cholesterol. Processing techniques such as soaking, fermentation, germination, and cooking can reduce anti-nutritional factors like tannins and phytic acid, thereby enhancing the bioavailability of minerals and improving nutritional quality (Rajat Panwar *et al.*, 2016). Aside from its advantageous nutritional and nutraceutical properties, foxtail millet is widely utilized in the food industry. It can be added to pasta, noodles, baked goods, porridges, and even extruded snack that are extruded. Its adaptability to modern processing technologies ensures that foxtail millet can successfully transition from a traditional grain to a mainstream functional food ingredient.

Minor millets, including finger, little, kodo, barnyard, and foxtail millets, represent a unique group of grains that combine superior nutrition, bioactive compounds, and ecological resilience. Each millet variety offers distinct health benefits: finger millet is notable for its high calcium and gluten-free applications; little millet is valuable for its nutrient density and role in managing obesity and cardiovascular risks; kodo millet is recognized for its anti-cancer potential and digestive benefits; barnyard millet is highly beneficial for diabetic patients and those suffering from anaemia, and foxtail millet demonstrates wide-ranging pharmacological properties including antioxidant, hypoglycemic, and hypolipidemic effects. Together, these grains have the potential to significantly improve dietary quality, prevent lifestyle-related diseases, and support global food and nutritional security. Their cultivation also contributes to climate resilience and sustainable agriculture, as they require minimal inputs and withstand harsh growing conditions. By encouraging the use of millet and creating new value-added products, these grains can be incorporated into contemporary food systems, matching consumer interest in health, wellness, and sustainability. The comparative evaluation of their nutrient composition and health-promoting properties highlights their importance not only as traditional crops but as future-ready foods that can transform human diets for improved health and well-being. Governments, researchers, and industries are increasingly collaborating to reintroduce millets into modern diets, ensuring that their health benefits reach wider populations (Aditi Sewak *et al.*, 2025).

## 5. Conclusion

Millets are highly regarded for their rich nutraceutical properties, making them a significant food source worldwide. Recent research was conducted to explore the functional characteristics and health benefits of millets for humans. The results demonstrate that millets have a higher content of carbohydrates, proteins, fiber, fats, antioxidants, vitamins, and minerals, confirming their nutritional superiority and health advantages. The findings show that millets are rich in essential minerals (such as zinc and iron), which are crucial for addressing nutritional disorders or malnutrition in children. In conclusion, the study indicates that incorporating millets into diets might help improve and enhance overall human health. The database on nutritional and phytochemical constituents of nutri-cereals is not adequate, and research studies are required to create awareness among the urban population. To increase the consumption of millets, awareness about the availability of millet-processed food needs to be strengthened. Taking together, these attributes make millet a favorable and reliable food source for contemporary consumers, promoting overall physical and nutritional health. Education campaigns, recipe development, and integration into lifestyle diets such as diabetic-friendly and gluten-free menus are paving the way for their revival. Minor millets represent more than traditional food crops; they are future-ready solutions to global challenges in nutrition, health, and sustainability. By incorporating them into daily diets, promoting their cultivation, and supporting research and innovation, societies can move toward a healthier, more sustainable and nutritionally secure future. The nutraceutical evaluation of nutri-cereals with commonly consumed cereals is therefore essential not only for academic interest but also for shaping nutrition policies, dietary guidelines, and consumer choices.

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## Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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