



Millets and edible seeds: From traditional foods to modern functional nutrition

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Abstract

Edible seeds and millets have historically played a significant role in human diets, especially in areas that need crops that are both nutritious and climate-resilient. These foods' great nutritional density and variety of bioactive components have sparked a fresh interest in science in recent years. Millets that offer complex carbohydrates, proteins, dietary fiber, minerals, vitamins, and phenolic compounds include pearl millet, finger millet, foxtail millet, tiny millet, kodo millet, barnyard millet, and proso millet. Edible seeds like chia, flax, sesame, pumpkin, sunflower, and hemp include concentrated amounts of protein, unsaturated fatty acids, fiber, minerals, tocopherols, phytosterols, lignans, and polyphenols. These components have been linked to cardioprotective, hypoglycemic, hypolipidemic, anti-inflammatory, and antioxidant properties. The potential of millet-based diets to enhance glycemic responses and some metabolic risk factors is well supported by evidence, and seeds may help regulate blood pressure, improve lipid profiles, and increase food intake. Nutrient bioavailability and functional characteristics can be altered by processing techniques such as soaking, germination, fermentation, roasting, and milling. As a result, the combination of millets and seeds presents significant potential for the creation of convenient goods like ready-to-cook premixes and functional foods. The nutritional makeup, bioactive components, health-promoting potential, processing, bioavailability, and possible uses of millets and edible seeds in contemporary nutrition are all covered.

Keywords: Millets, edible seeds, functional foods, dietary fibre, phytochemicals, omega-3 fatty acids, glycaemic control, lifestyle disorders

Introduction

The burden of obesity, type 2 diabetes, hypertension, dyslipidemia, and cardiovascular illnesses has increased due to shifting dietary habits and a greater reliance on refined and highly processed foods. As a result, traditional foods that can supply nutrients along with physiologically advantageous food components are gaining popularity. Because they combine nutritional density with functional and bioactive qualities, millets and edible seeds are especially attractive.

Small-seeded cereals called millets have been grown for ages, particularly in Asia and Africa. Pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), foxtail millet (*Setaria italica*), small millet (*Panicum sumatrense*), kodo millet (*Paspalum scrobiculatum*), barnyard millet (*Echinochloa* spp.), and proso millet (*Panicum miliaceum*) are significant species. They are adapted to drought, heat and relatively low-input agricultural systems, making them important from both nutritional and food-security perspectives. According to recent reviews, millets are nutrient-rich grains with fiber, vitamins, minerals, and phytochemicals that may be important for metabolic health (Samtiya *et al.*, 2023; Jacob *et al.*, 2024) [14, 15]. Another significant category of plant foods in terms of nutrients is edible seeds. Significant levels of protein, unsaturated fatty acids, fiber, minerals, and bioactive chemicals can be found in chia, flax, sesame, pumpkin, sunflower, and hemp seeds. While Raza *et al.*, (2026) [21] stressed their potential contribution to

cardiovascular, metabolic, and immunological health, Alasalvar *et al.*, (2021) [8] evaluated specialty seeds and highlighted their presence of polyphenols, fat-soluble bioactives, and antioxidant chemicals. The resurgence of interest in these foods signifies a shift from their conventional use as staple items to their current use as functional food additives. They can offer a chance to enhance dietary quality while satisfying the contemporary need for convenience by being incorporated into multigrain products, bakery goods, drinks, and ready-to-cook formulations.

Nutritional Profile of Millets

Carbohydrates, proteins, dietary fiber, fats, minerals, and vitamins are all present in millets. The species, cultivar, growing environment, and processing conditions all affect their nutritional composition. Whole millet grains typically retain more fiber and minerals than highly refined cereals.

1. Carbohydrates and Dietary Fibre

Although the majority of millet grains are made up of carbohydrates, their physiological reaction varies depending on the processing, particle size, and starch structure. Different amounts of resistant, slowly digested, and quickly digestible starch can be found in millets. Improved fullness and delayed digestion are extra benefits of dietary fiber. According to Anitha *et al.*, (2021) [9], millets have a mean glycemic index of roughly 52.7, which is significantly lower than the values for refined wheat and milled rice. Longer-

term millet eating also improved fasting and postprandial glucose levels, according to their meta-analysis. The metabolic significance of millet-based diets is still supported by recent research, albeit the outcome varies depending on the specific millet and processing technique. For instance, adults who consumed particular millet preparations showed improvements in some glycemic and lipid outcomes (Naik *et al.*, 2026).

2. Protein

Plant protein can be found in moderate amounts in millets. While different species have different protein concentrations, pearl millet is generally thought to be a reasonably high-protein millet. While cereal proteins may be deficient in some critical amino acids, millet proteins provide essential amino acids to the diet.

A food's overall amino acid balance can be enhanced by combining millet with seeds or legumes. Because of this, millet-seed blends are especially appealing for creating plant-based and vegetarian diets that are higher in nutrients.

3. Minerals and Vitamins

Minerals like iron, magnesium, phosphorus, potassium, and zinc can be found in significant amounts in millets. While pearl millet is a significant source of iron and zinc, finger millet is especially known for its calcium content. B-group vitamins are also found in a number of millet species.

The mineral, vitamin, fiber, and phytochemical richness of Indian millets was highlighted by Gatkhal *et al.*, (2026) ^[20], who also stressed the significance of processing for enhancing nutrient availability.

Nutritional Profile of Edible Seeds

Edible seeds are nutritionally concentrated foods containing varying proportions of protein, fat and fibre. Their lipid fraction is generally rich in unsaturated fatty acids.

1. Essential Fatty Acids

Alpha-linolenic acid (ALA), a necessary omega-3 fatty acid, is especially abundant in chia and flaxseed. Although composition varies depending on cultivar and environmental conditions, chia seeds may contain about 60% ALA in their lipid fraction (Ullah *et al.*, 2016; Grancieri *et al.*, 2019) ^[2, 6]. Flaxseed is a vital functional seed for metabolic and cardiovascular nutrition since it contains fiber, lignans, linoleic acid, and ALA. Clinical reviews have examined the connection between flaxseed and metabolic syndrome, diabetes, dyslipidemia, obesity, and cardiovascular disease (Parikh *et al.*, 2019) ^[7].

2. Protein

Significant amounts of protein can be found in seeds like sesame, sunflower, hemp, and pumpkin. During digestion or processing, seed proteins can produce bioactive peptides in addition to providing amino acids.

According to a systematic study by Zhao *et al.*, (2023) ^[13], oilseed proteins and derived peptides may be used in dietary regimens that target metabolic and cardiovascular risk as well as have potential physiological and nutritional uses.

3. Dietary Fibre

Dietary fiber is especially abundant in flaxseed and chia. When chia is hydrated, it produces a mucilaginous layer and

contains both soluble and insoluble fiber. This characteristic may affect satiety, digestion, and viscosity.

Because seeds include fiber, protein, and unsaturated fats, they can be used to create dishes with higher nutritional richness.

Bioactive Components of Millets

Millets' nutritional value goes beyond their macronutrient makeup. Phenolic acids, flavonoids, tannins, phytosterols, carotenoids, and other phytochemicals are present in them.

Antioxidant activity is influenced by phenolic molecules including ferulic acid, caffeic acid, p-coumaric acid, and related flavonoids. Additionally, certain millet phytochemicals may affect pathways linked to inflammation and lipid metabolism as well as enzymes that break down carbohydrates. According to Sadh *et al.*, (2024) ^[16], millets have a variety of bioactive chemicals that may have antioxidant, antidiabetic, anti-inflammatory, anti-obesity, cholesterol-lowering, and other useful qualities.

According to recent evaluations, millet foods' functional qualities are largely attributed to phenolics and other phytochemicals (Sahu & Sahu, 2025; Ray *et al.*, 2026) ^[18, 22].

Bioactive Components of Edible Seeds

Polyphenols, lignans, phytosterols, tocopherols, carotenoids, peptides, and essential fatty acids are only a few of the many bioactive components found in seeds.

While sesame includes lignans like sesamin and sesamol, flaxseed is notable for its lignans, particularly secoisolariciresinol diglucoside (SDG). These substances' anti-inflammatory, lipid-modulating, and antioxidant qualities have been studied. Chia contains mucilaginous fiber, ALA, and phenolic compounds. Tocopherols, phytosterols, minerals, and phenolic compounds are all found in pumpkin seeds. These substances may affect oxidative stress, inflammation, glucose metabolism, blood pressure, and lipid metabolism, according to Raza *et al.*, (2026) ^[21].

Millets and Glycaemic Health

Glycemic control is one of millets' health-related qualities that has drawn a lot of scientific interest. A reduced postprandial glycemic response may result from their fiber, resistant starch, slowly digesting starch, and polyphenols.

Anitha *et al.*'s (2021) ^[9] systematic review and meta-analysis, which looked at 65 trials, found that millet foods had lower glycemic indices than a number of popular refined grain staples. Long-term use was linked to improvements in HbA1c in prediabetic people and decreases in fasting and postprandial glucose in diabetic subjects.

Jacob *et al.*, (2024) ^[15] emphasized the low glycemic properties and phytochemical content of millet while describing its possible relevance to metabolic diseases and prediabetes.

Seeds and Metabolic Health

Because edible seeds have fiber, protein, and unsaturated fats, they may be a good addition to low-glycemic diets. These elements may affect postprandial metabolism and slow the emptying of the stomach and the absorption of carbohydrates.

Although the effects on insulin resistance were less consistent, a systematic review of sesame research found

positive effects on blood glucose measurements (Sohouli *et al.*, 2022) ^[11]. The impact of chia on blood pressure, inflammatory markers, hyperglycemia, and lipid profiles has also been investigated.

Blood pressure, total cholesterol, LDL cholesterol, triglycerides, waist circumference, and C-reactive protein all showed slight improvements in a 2025 comprehensive evaluation of chia supplementation; however, the certainty of evidence varied from low to moderate for a number of outcomes.

Role in Obesity and Weight Management

Satiety and appetite control depend on dietary fiber. Without using processed foods, a variety of seeds and millets can boost the fiber density of meals.

Because millets' intact grain structure and fiber content can slow digestion and improve satiety, they may help with weight management when substituted with refined cereal items. Additional protein and good fats from seeds may increase meal satisfaction.

Hernández-Pérez *et al.*, (2022) ^[10] examined ancient food crop seeds, including flax, chia, sesame, sunflower, and pumpkin, and found that fiber, fatty acids, sterols, and phenolic compounds may have anti-obesity qualities.

Cardiovascular Health

A number of components related to cardiovascular nutrition can be found in millets and seeds. Millets' phytochemicals, potassium, magnesium, and dietary fiber may support better metabolic profiles. Antioxidants, fiber, phytosterols, and unsaturated fatty acids are all found in seeds.

The ALA, fiber, and lignan levels of flaxseed make it particularly intriguing. Reviews of clinical trials have indicated possible advantages for cardiovascular risk factors, albeit individual and formulation responses differ (Parikh *et al.*, 2019) ^[7].

In recent evidence syntheses, chia has also shown encouraging effects on lipid markers and blood pressure.

Antioxidant and Anti-inflammatory Potential

Numerous non-communicable diseases are influenced by oxidative stress and persistent inflammation. While seeds supply polyphenols, lignans, tocopherols, and other antioxidant substances, millets contain phenolic acids and flavonoids that support antioxidant action.

Millet-seed formulations are appealing as sources of plant-derived antioxidants due to the combination of these chemicals. Among the new pharmacological characteristics of millets, Sahu and Sahu (2025) ^[18] emphasized their anti-inflammatory and antioxidant qualities.

In a similar vein, Alasalvar *et al.*, (2021) ^[8] highlighted the bioactive components and antioxidant properties of specialized seeds.

Micronutrient and Bone Health

Mineral intake can benefit from the use of millets and seeds. While pearl millet, sesame, chia, and pumpkin seeds provide iron, magnesium, zinc, phosphorus, and other nutrients, finger millet is a significant source of calcium.

These nutrients are involved in immunology, energy metabolism, enzyme function, oxygen transport, and bone formation.

Antinutritional Factors and Bioavailability

When using millets and seeds, it is crucial to consider the presence of phytate, tannins, oxalates, and enzyme

inhibitors. These substances may interact with digestive enzymes or minerals.

Certain antinutritional agents can be reduced by processing methods such as soaking, germination, fermentation, dehulling, and suitable heat treatment. In their assessment of antinutrient-reduction strategies in Indian millets, Gatkal *et al.*, (2026) ^[20] concluded that processing can significantly affect nutrient availability and functional quality. Grinding seeds can increase their access to nutrients that could otherwise be trapped inside their structure. Nutrient and phytochemical profiles may be further altered by germination.

Food preparation should therefore be planned to maximize nutritional bioavailability while maintaining sensory quality and shelf stability rather than only focusing on convenience.

Processing and Functional Properties

The palatability and digestibility of grains and seeds have traditionally been enhanced by traditional processing techniques such as soaking, roasting, germination, fermentation, and milling.

Germination and fermentation in millets can alter phenolic availability and decrease some antinutrients. Protein functionality and starch digestibility can be changed by thermal processing. Excessive processing, however, can potentially result in unfavorable alterations or the reduction of heat-sensitive nutrients. Because interactions between starch, protein, fiber, fats, and phytochemicals affect digestion and nutritional absorption, the millet food matrix is especially significant. Food-matrix interactions can change starch retrogradation, pasting, nutritional bioaccessibility, and digestive behavior, according to a review by Ponnampalam *et al.*, (2022) ^[12].

Millets and Seeds as Functional-Food Ingredients

The combination of millets and seeds offers a chance to create functional foods that are nutritionally balanced. While seeds can enhance protein, essential fatty acids, fiber, and bioactive content, millets can provide complex carbs, fiber, and minerals. Possible products include:

- Multigrain flour
- Dalia and porridge mixes
- Uttapam and dosa premixes
- Cheela premixes
- Breakfast cereals
- Nutritional bars
- Bakery products
- Instant beverage mixes
- Snack products
- Ready-to-cook foods

Such products can be designed according to specific nutritional objectives, including higher fibre, lower glycaemic response and improved micronutrient density.

16. Modern Functional Nutrition and Future Applications

It is not necessary to give up traditional eating habits in order to switch from traditional foods to contemporary functional nutrition. Alternatively, modern food technology can be used to reformulate traditional ingredients for better convenience, consistency, and nutritional value.

Opportunities to create standardized ready-to-cook products are presented by the growing availability of millet flour and seed ingredients. Working populations and customers looking for healthier substitutes for refined cereal-based

convenience snacks may find these goods very helpful. Standardized formulations, nutrient bioavailability, glycemic response, sensory acceptability, shelf life, and long-term human health effects should be the main topics of future research. To find the effective amounts of specific millets and seeds, more randomized controlled studies are also needed.

Conclusion

Edible seeds and millets are important links between traditional food systems and contemporary functional nutrition. While edible seeds offer rich quantities of protein, unsaturated fatty acids, fiber, minerals, and bioactive compounds, millets supply complex carbohydrates, dietary fiber, proteins, and a variety of phytochemicals. Promising roles in glycemic regulation, cardiovascular health, lipid metabolism, weight control, antioxidant defense, and overall dietary quality are indicated by scientific research. While seeds like chia, flax, and sesame show encouraging cardiometabolic effects, the strongest data currently supports the inclusion of millets in dietary recommendations for enhancing glycemic quality. These foods should not be used as alternatives to medical care, but rather as parts of a well-balanced diet.

Millets and edible seeds have a lot of potential to create wholesome, practical, and useful foods. Their nutritional value can be further increased by careful formulation, processing, and absorption. As a result, millet-seed mixtures offer a viable avenue for further study, the creation of food products, and contemporary preventive nutrition.

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