The Pharma Innovation Journal 2023; 12(8): 223-227

www.ThePharmaJournal.com

The Pharma Innovation

**ISSN (E): 2277-7695**
**ISSN (P): 2349-8242**
**NAAS Rating: 5.23**
TPI 2023; 12(8): 223-227

www.thepharmajournal.com
Received: 22-05-2023
Accepted: 26-06-2023

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# Millets: Nutritional importance, health benefits, and bioavailability: A review

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**Abstract**
Millet, a type of pseudocereal predominantly grown in Africa and Asia, is gaining popularity in North America due to its increasing consumption among South Asian and African diaspora communities. India, at the forefront of millet production, cultivates significant varieties like Pearl millet, Finger Millet, and Sorghum. Millets offer several advantages, including resistance to pests and diseases, shorter maturation periods, and productivity in arid conditions compared to other cereals. Notably, they exhibit superior nutrition, boasting higher levels of calcium, dietary fibre, and protein. Moreover, millets are gluten-free, making them highly beneficial for individuals with celiac disease or gluten intolerance. Remarkably, millets are rich in antioxidants and phytochemicals, conferring numerous health benefits such as reducing blood pressure, preventing heart disease, cancer, and diabetes, and bolstering the immune system. Traditional processing methods further enhance the nutritional properties of millets, rendering them suitable for large-scale utilization and the creation of diverse value-added food products. This paper aims to highlight the exceptional qualities of millets, shedding light on their potential as a highly nutritious and sustainable food source, especially within the North American market.

**Keywords:** Millets, nutritional, health benefits, bioavailability

## Introduction
Millet, a type of pseudocereal, is predominantly grown in Africa and Asia. However, its significance in growing at North America, especially among the South Asian and African diaspora communities (Singh *et al*., 2012) [25]. India serves as the primary producer of millet, including major varieties like Sorghum, Pearl millet and Finger millet. Millet exhibits strong impregnability to pests and diseases, has a short growing season, and can thrive in drought conditions, setting it apart from other major cereals. Globally, millets rank as the 6th most produced cereal crop (Devi *et al*., 2011) [6]. In terms of nutrition, millets surpass rice and wheat, offering higher levels of calcium, dietary fibre, and protein. Additionally, millets are rich in polyphenols and flavonoids, demonstrating powerful antioxidant activity. Their gluten-free nature has led to interest in their potential benefits for managing type 2 diabetes and reducing the glycaemic index of foods (Devisetti *et al*., 2014) [7]. Millets have a rich heritage of undergoing diverse processing techniques such as husk removal, germination, fermentation, toasting, flattening, and milling. These methods not only enhance their flavour and sensory characteristics but also elevate their nutritional profile. Due to their advantageous physicochemical and nutritional properties, primary millets are highly suitable for extensive incorporation in the food industry. This adaptability enables the development of an extensive array of value-added food products, including infant foods, dietary items, and convenient ready-to-eat snacks. Of particular interest is their utilization in extruded products, either in their whole grain form or as finely ground flour (McSweeney *et al*., 2017b) [17]. The numerous health benefits and nutritional advantages of millets have sparked considerable interest among consumers seeking gluten-free options or those managing chronic diseases. Their versatility and potential to address nutritional challenges position millets as a promising crop for promoting overall well-being worldwide. Their growing popularity in various culinary applications suggests a potential shift towards millets becoming a staple food source in the future (McSweeney *et al*., 2017a) [18].
Millet is a gluten-free grain that promotes alkalinity in the body. Millets are abundant in phytochemicals and essential micronutrients that play crucial roles in bolstering the immune system. They present nutraceutical attributes in the shape of antioxidants, protecting against various health issues such as hypertension, heart disease, cancer, and diabetes, while also reducing the occurrence of tumours (Shobana *et al*., 2018) [24].

Additionally, millets aid in gastric emptying and provide essential roughage for the gastrointestinal system. Promoting an alkaline-based diet is commonly advised for attaining optimal health. However, in developing countries, there are concerns about limited mineral bioavailability, particularly concerning iron and zinc, in cereal-based foods. This issue is especially critical for infants and young children. To tackle these issues, food processing methods are employed to improve the nutritional quality, enhance digestibility, and boost nutrient bioavailability, while also reducing the presence of anti-nutrients (Krishnan *et al*., 2012) [11].

**Table 1:** Millets: scientific names, common names, family, origin, production states, and utilization

| Millets | Scientific names | Common names | Family | Origin | State in terms of production | Utilization | Reference |
|---|---|---|---|---|---|---|---|
| Sorghum | *Sorghum bicolor* (L.) | Jowar, Cholam, Jola | Poaceae | Africa, Asia | Maharashtra, Karnataka | Millet can be prepared and consumed in a similar manner to rice. Its flour is commonly used in making chapattis, various snacks, porridge, and sweets. | (Gaikwad *et al*., 2021) [8], (Chaudhary *et al*., 2020) [4], (Thakur & Tiwari, 2019) [26] |
| Finger millet | *Eleusine coracana* (L.) | Ragi, Mandua, Nagli | Poaceae | Uganda | Karnataka, Uttarakhand | Millet can be used as a rice substitute, and its flour is commonly employed in making chapati. Additionally, millet is utilized in preparing porridge and pudding. | |
| Pearl millet | *Pennisetum glaucum* (L.) | Bajra, Bulrush, Cattail | Poaceae | Tropical West Africa | Rajasthan, Haryana | Millet serves various purposes, including being used as a food source and in malt making. It also finds application as forage crops. Additionally, millet straw is valuable for thatching, fuel, and as a building material. Moreover, millet is utilized in ethanol production. | |

**Nutritional importance of major millets**

Sorghum is a highly nutritious millet with several health-promoting properties. It is an excellent source of dietary fibre, which aids in digestion and helps regulate blood sugar levels. Additionally, sorghum is rich in antioxidants, such as phenolic compounds, which may help protect the body against oxidative stress and chronic diseases. Finger millet is highly regarded for its exceptional nutritional content. It is an excellent source of calcium, providing about 10 times more calcium than rice or wheat. This makes it beneficial for bone development, particularly in growing children and preventing bone-related disorders like osteoporosis. Pearl millet is a highly nutritious millet, providing an array of essential nutrients. It is rich in protein, dietary fibre, and micronutrients like iron, magnesium, and calcium.

**Table 2:** Nutritional composition of Sorghum, Pearl millet, Finger millet

| Parameters | Sorghum | Finger Millet | Peral millet |
|---|---|---|---|
| Moisture | 12.1 | 13.1 | 12.4 |
| Protein | 10.4 | 7.3 | 6.2 |
| Fat | 3.1 | 1.3 | 2.2 |
| Ash | 1.6 | 3.5 | 2.2 |
| Fibre | 2 | 1.5 | 1.3 |
| Carbohydrates | 70.7 | 72.0 | 67.5 |
| Energy | 329 | 328 | 361 |

**Health Benefits of Major Millets**

**1. Sorghum (Jowar)**

a) **Heart Health:** Sorghum is known for its heart-protective properties. It contains antioxidants like phenolic compounds and policosanols, which may help reduce cholesterol levels and lower the risk of cardiovascular diseases (Rajendra Prasad *et al*., 2015) [27].

b) **Digestive Health:** The dietary fibre present in sorghum promotes healthy digestion, helps prevent constipation, and supports gut health by feeding beneficial gut bacteria (Rajendra Prasad *et al*., 2015) [27].

c) **Blood Sugar Regulation:** Sorghum has a low glycaemic index, meaning it causes a slow and gradual increase in blood sugar levels. This quality makes it beneficial for individuals with diabetes or those aiming to manage blood sugar levels (Rajendra Prasad *et al*., 2015) [27].

d) **Antioxidant Properties:** Sorghum is abundant in antioxidants, specifically phenolic compounds and flavonoids, which play a crucial role in neutralizing harmful free radicals within the body. By doing so, these antioxidants effectively reduce oxidative stress and inflammation, thereby potentially lowering the risk of chronic diseases like cancer and cardiovascular disorders (Rajendra Prasad *et al*., 2015) [27].

e) **Weight Management**: The dietary fibre in sorghum promotes satiety, helping individuals feel fuller for longer periods. Including sorghum in the diet can aid in weight management by reducing overall calorie intake and curbing unhealthy snacking (Rajendra Prasad *et al*., 2015) [27].

f) **Celiac-Friendly:** Being gluten-free, sorghum is an excellent grain option for individuals with celiac disease or gluten intolerance. It allows them to enjoy a wide variety of dishes without experiencing adverse reactions (Rajendra Prasad *et al*., 2015) [27].

**2. Finger Millet (Ragi)**

a) **Bone Health:** Finger millet is exceptionally rich in calcium, which is essential for maintaining strong and healthy bones. It is particularly beneficial for growing children, pregnant women, and the elderly in preventing conditions like osteoporosis (Rao *et al*., 2017) [21].

b) **Management of Anaemia:** Ragi is a good source of iron, which helps in preventing and managing iron-deficiency anaemia. It is especially important for individuals with increased iron requirements, such as pregnant women and menstruating women (Rao *et al*., 2017) [21].

c) **Diabetes Management:** The low glycaemic index of finger millet helps in regulating blood sugar levels, making it suitable for individuals with diabetes (Rao *et al*., 2017) [21].

d) **Diabetes Prevention and Management:** Finger millet has been shown to have a positive impact on managing diabetes. Its low glycaemic index and high dietary fibre content help regulate blood sugar levels, making it a suitable choice for individuals with diabetes or those at risk of developing the condition (Rao *et al*., 2017) [21].
e) **Skin Health:** Ragi contains essential amino acids, particularly methionine and lysine, which are vital for collagen formation. Collagen supports skin elasticity and promotes healthy skin, contributing to a youthful appearance (Rao *et al*., 2017) [21].
f) **Reduces the Risk of Gallstones:** Regular consumption of finger millet has been associated with a reduced risk of developing gallstones. The high insoluble fibre content in ragi aids in better bile flow and reduces the formation of gallstones. (Rao *et al*., 2017) [21].

**3. Pearl Millet (Bajra)**

a) **Iron-Rich:** Pearl millet is an excellent source of iron, a crucial mineral in the formation of haemoglobin and red blood cells. Regular consumption of pearl millet can help prevent iron-deficiency anaemia (Malik, 2015) [16].
b) **Energy Booster:** Being an energy-dense grain, pearl millet provides a good amount, of calories, making it beneficial for individuals with high energy demands, such as athletes and laborers (Malik, 2015) [16].
c) **Gluten-Free Grain:** Like other millets, pearl millet is naturally gluten-free, making it an excellent option for those with celiac disease or gluten sensitivities (Malik, 2015) [16].
d) **Digestive Health:** The dietary fibre present in pearl millet supports digestive health by promoting regular bowel movements and preventing constipation. It also aids in maintaining a healthy gut microbiome, which is essential for overall digestive well-being (Malik, 2015) [16].
e) **Lowers Cholesterol:** Pearl millet has been found to have cholesterol-lowering effects. The soluble fibre in bajra binds to cholesterol in the digestive tract, preventing its absorption and contributing to lower LDL (bad) cholesterol levels (Malik, 2015) [16].
f) **Prevents Anaemia in Pregnancy:** The high iron content in pearl millet makes it a valuable grain during pregnancy to prevent iron-deficiency anaemia. Including bajra in the diet can help meet increased iron requirements during pregnancy and support fatal development (Malik, 2015) [16].

**Nutritional bioavailability of millets**

Bioavailability refers to the quantity of nutrients ingested that can be absorbed and utilized through regular metabolic processes. Consequently, when evaluating the sufficiency of dietary intake, the emphasis lies on the bioavailability of nutrients rather than solely on the nutrient content of the food (Tharifkhan *et al*., 2021) [22]. Millets are acknowledged for being rich in minerals. Nevertheless, the existence of anti-nutrients like phytates, polyphenols, and tannins restricts the accessibility of nutrients for absorption within the human body. Both dietary and physiological factors can impact the bioavailability of nutrients present in millets. Consequently, the aim should be to minimize the levels of anti-nutrients and augment the nutrient content. It is evident that the processing of millets has a substantial impact on the bioavailability of nutrients for human consumption (Schonfeldt *et al*., 2015) [10]. Thus, the effect of various processing techniques on nutritional value and bioavailability is discussed below.

**Effect of Processing of Millets on Nutritional Value and Bioavailability**

Millets are processed using a combination of mechanical and traditional technologies. The mechanical processing techniques include decortication, milling, and sieving. On the other hand, the traditional techniques involve processes like germination, fermentation, malting, popping, and soaking & cooking. These methods are employed to enhance the taste, nutritional value, and overall quality of millets.

**Mechanical Processing Techniques**

Decortication is the process of removing the outer pericarp of the crop, which leads to a decrease in dietary fibre, minerals, and antioxidant activity in pearl millet. This reduction in nutrients and anti-nutrients might limit its potential as a functional food. However, it was observed that decortication significantly reduces phytic acid, polyphenols, and tannins in the pearl millet. Milling, a conventional processing technique, entails using a wooden or stool mortar and pestle to transform dried or moistened grains into flour. Through this method, a reduction in anti-nutrients and an enhancement in the bio-accessibility of minerals were observed in semi-refined pearl millet flour. Furthermore, milling resulted in a significant increase in protein and starch digestibility. Conversely, sieving, another processing method, demonstrated a rise in both nutrients and anti-nutrients in finger millet whole flour.

**Traditional Processing Techniques**

Various processing techniques can significantly impact the nutrient and anti-nutrient contents of millets (Ramashia *et al*., 2019) [23]. Germination has been found to enhance mineral availability by breaking down anti-nutrients, and it increases the *in vitro* bio-accessibility of minerals like calcium, zinc, and iron in pearl millet and finger millet. Fermentation of pearl millet improves protein digestibility, nutritional value, and reduces anti-nutritional and mineral contents. Soaking grains before dehulling and milling reduces phytates (Sarkar *et al*., 2015) [19]. Popping or puffing millets increases dietary fibre content and decreases anti-nutritional factors. Combining germination with fermentation enhances nutrient content and energy density while reducing phytic acid in food products like fura (Singh *et al*., 2017) [3]. Malting is a process that involves a combination of germination, milling, and sieving, which effectively improves the nutritional quality and decreases tannin and phytic acid levels in brown finger millet. Enzymes such as phytases, polyphenol oxidase, tannases, cellulases, xylanases, and proteases can be employed to enhance nutrient bioavailability during the processing of millets (Gabaza *et al*., 2017) [15]. For example, phytase addition enhances zinc absorption, polyphenol oxidases increase iron absorption, tannases reduce tannin content, and cellulases improve protein digestibility and mineral extractability (Shobana *et al*., 2018) [24]. Supplementation of proteases can address the issue of anti-nutritional factors inhibiting protein breakdown and amino acid accessibility in the body. In summary, processing methods like germination, fermentation, soaking, popping, and malting, as well as the use of exogenous enzymes, offer effective ways to improve the nutritional profile and reduce anti-nutrients in millet-based

food products (Durairaj *et al*., 2019) [14].

**Consumption of millet**

Throughout history, millets have served as a primary food source in the diets of Asian and African populations. Millet porridge, in particular, has been a staple traditional food in countries such as India, China, Russia, and Germany (Kumar *et al*., 2018) [1]. Over time, millets have gained widespread acceptance and recognition, leading to their incorporation in various local dishes like idli, dosa, and puttu, gradually replacing commonly used cereals. However, with modernization, dietary patterns have shifted, and the consumption of contemporary food items has increased. Despite this change, researchers have responded to evolving preferences and interests by developing modern millet-based foods, including cookies, bread, biscuits, and snack foods. These innovations aim to meet the demands of the changing times while still utilizing the nutritional benefits and versatility of millets (Ritchie *et al*., 2018) [9].

**Acceptability of Millet Based Products**

The consumption of modern food products depends on their acceptability, which is determined through sensory evaluation. Limited studies have focused on the sensory acceptability of millet-based products, and the results have been mixed (Singh *et al*., 2014) [6]. Certain millet-based products have demonstrated favorable acceptability in terms of taste, color, and texture. Examples include pearl millet and sorghum-based cookies, finger millet-based flakes, vermicelli, khakhra, and proso millet-based pizza. Additionally, the introduction of millet-based South Indian food items like idli, upma, khichdi, and bisibela bath in schools as a replacement for rice was well-received by the children. These instances highlight the potential for incorporating millets into various food items to diversify diets and promote healthier eating choices. However, there are instances where the acceptability of proso millet-based snacks and biscuits decreased with an increase in millet proportion, resulting in a bitter taste. More research is needed to explore the sensory acceptability of millet-based products comprehensively (McSweeney *et al*., 2016) [13].

**Research investigating the mineral bioavailability of millet-based foods.**

Enhancing the bioavailability of minerals in millet-based products can lead to increased acceptability along with improved nutritional value. The presence of anti-nutrients in millets affects mineral bioavailability (Tharifkhan *et al*., 2021) [22]. Iron deficiency anemia, osteoporosis, and zinc deficiency are significant global health concerns affecting various age groups. Millets are known to be good sources of minerals, making them suitable candidates for addressing these health issues through both traditional and modern millet-based foods. *In vivo* studies have shown that interventions with pearl millet, finger millet, and sorghum-based food products have led to increased hemoglobin levels (Moharana *et al*., 2020) [2]. Additionally, interventions with finger millet-based pancakes and ladoo have shown increased calcium absorption, while zinc-fortified millet-based porridges have demonstrated improved zinc absorption. These results suggest that the anti-nutrient content of millets does not significantly impact the bioavailability of minerals in millet-based foods. Therefore, promoting millet consumption at the national and global levels can be a valuable approach to address micronutrient deficiencies (Prasad *et al*., 2016) [20].

**Conclusion**

Major millets, namely Sorghum, Finger Millet, and Pearl Millet, hold immense nutritional importance and health-promoting properties. They offer a range of nutrients and bioactive compounds, making them superior to rice and wheat in terms of nutritional value. The gluten-free nature of millets positions them as a favourable choice for individuals with gluten sensitivity or those seeking gluten-free food options. The traditional processing techniques used for millets can enhance their nutritional quality and bioavailability, ensuring better absorption of essential minerals and nutrients. Moreover, the potential health benefits of millets, such as their impact on heart health, diabetes management, and digestive well-being, make them a valuable addition to the diet. With the increasing awareness of the nutritional benefits and the development of millet-based modern food products, millets have the potential to address global health issues related to nutrient deficiencies. Encouraging the consumption of millets, both in traditional dishes and modern food products, can contribute to improved overall health and nutrition, benefiting communities across the globe. Embracing millets as a staple food source can pave the way for a healthier and more sustainable future for individuals and societies worldwide.

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