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Millets as a Sustainable Crop for Nutritional Security: Addressing Malnutrition Challenges

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Abstract

Millets are cereal crops belonging to the Poaceae family, which is the scientific name for the grass family. They are classified into two main groups: major millets which include Sorghum, Pearl, Finger millet, and minor millets, such as Little, Foxtail, Proso, Barnyard, and Kodo millet. India is the chief producer of millets, with an annual production of more than 17 million tonnes. This accounts for 80% of Asia's millet production and 20% of the global supply. Chhattisgarh is one of the states in India where minor millets like kodo millets, finger millets, and little millets are produced. These millets have several health benefits due to their nutrient content, including essential amino acids, antioxidants, dietary fiber, fatty acids like linolenic, oleic, and palmitic acid. Millets contain excellent nutritional value including macronutrients like protein (7–13%), carbohydrates (60–70%), fat (1.5–5%), fiber (2–7%). Little millet contains moisture (13.1%), protein (7.7%), carbohydrate (83.3%), fiber (11.5%), ash (2.7%), and fat (1.5%). Kodo millet contains moisture (11.92%), protein (11.52%), fat (2.89%), crude fiber (1.85%), ash (1.22%), and carbohydrate (70.60%). Finger millet contains carbohydrates (65–70%), fiber (2.5–3.5%), fat (1–1.5%), ash (2.5–3%), protein (5–8%), and moisture (11.75%). Sorghum millet contains moisture (11.9%), protein (10.4%), fat (1.9%), carbohydrate (72.6%), fiber (14.3%), and ash (1.6%). Barnyard millet contains crude protein (11.3–17.2%), fat (3.6–3.8%), ash (4.7–5.0%), crude fiber (5.41–6.87%), carbohydrate (68.8%), and moisture (8.7%). Foxtail millet contains moisture (9.35%), ash (3.10%), protein (10.29%), fat (3.06%), fiber (4.25%), and carbohydrate (69.95%). Pearl millet contains moisture (8.5%), crude protein (13.6%), crude fat (7.8%), crude fiber (2.8%), ash (2.1%), and carbohydrate (63.2%). Proso millet contains moisture (8.04%), crude protein (13.09%), fat (3.35%), crude fiber (2.37%), carbohydrate (77.33%), and ash (1.53%). Millet processing and value addition can offer a wide range of nutritious products to defeat the global issue malnutrition.

Keywords: Millets, malnutrition, nutrients, macronutrients, fiber

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INTRODUCTION

Malnutrition has become a rising global health issue due to various factors like changes in lifestyle, unhealthy eating habits, and consumption of contaminated food, climate change, and increasing food supply uncertainties in both developing and developed nations. Malnutrition occurs when a person's diet does not contain enough nutrients, or the proper balance required for optimum health and growth. When a person's food intake is either insufficient or their diet lacks variety, or if there is a condition preventing their body from absorbing the necessary nutrients, it can lead to severe health issues and affect vital organs. Essentially, malnutrition is an imbalance in the consumption of dietary nutrients.

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Malnutrition can result from consuming either too much or too little food or lacking essential nutrients and minerals. The person suffering from malnutrition may be deficient in vitamins, minerals, and other vital substances necessary for the body's proper functioning. Generally, malnutrition is defined as insufficiency, excess, or imbalance in the input of energy and nutrients. Malnutrition covers two primary categories: undernutrition, defined by stunting (insufficient height for age), wasting (inadequate weight for height), underweight (low weight for age), and micronutrient deficiencies (lack of vital vitamins and minerals); and overnutrition, comprising overweight, obesity, and diet-related noncommunicable diseases, such as heart disease, stroke, diabetes, and cancer [1].

A survey uncovered that around 821 million individuals globally are experiencing chronic food deprivation, highlighting the widespread issue of malnutrition [2]. Globally, there is a significant presence of both nutrient deficiencies and excesses. It has been identified that 1.9 billion adults are overweight, while an additional 462 million are underweight. Additionally, one-third of women of reproductive age are affected by anemia, and about 20 million babies are born anemic each year, passing this condition from one generation to the next [3]. Child malnutrition is still a major issue all over the world. In 2021, 22.3% (148.1 million) children were stunted, 6.8% (45 million) were wasted, and 5.6% (37 million) were overweight [4].

India is a vast and developing country with the population of 1.428 billion. In India, the proportion of malnourished people is quite high among children who are less than 5 years, adolescent girls, pregnant women, and lactating mothers in both rural and urban masses [5]. In India, a significant number of children are impacted by malnutrition. According to a survey it has been estimated that India has the maximum number of malnourished children across the globe and one in every three children is malnourished in the country [6].

Millets are cultivated from ancient times, which is as old as the beginning of sedentism and civilization in the anthropological history of the world around 8000 BC. It is believed that sorghum, finger millet, and pearl millet were of African origin, whereas foxtail millet, proso millet, and kodo millet were Asian in origin [7]. Millets are considered as the first domesticated cereals and categorized by their remarkable facility to survive in less fertile soil, drought resistance, pest resistance, and short growing season usually 45-60 days [8].

Millets belong to minor cereals in the *grass* family with botanical name "*poaceae*." These are small-seeded cereal crops that can be grown in various tropical and desert climates, demonstrating a strong ability to thrive in less fertile soils. They are mostly grown in the dry and semi-dry areas of India [9].

In India, millets are principally grown in the states of Karnataka, Andhra Pradesh, Chhattisgarh, Tamil Nadu, Maharashtra, Odisha, Madhya Pradesh, Rajasthan, and Uttarakhand [10]. The cultivation area for millets has varied between 12.29 million to 15.48 million hectares from 2013–14 to 2021–22. India is a leading producer of millet, contributing over 17 million tonnes, which represents 80% of Asia's production and 20% of the worldwide output. The average yield of millets in India is 1239 kg/ha, slightly higher than the global average yield of 1229 kg/ha [11].

India holds the title of being the leading producer of millet worldwide. An array of millet types cultivated comprises of Sorghum millet (*Sorghum bicolor*), Pearl millet (*Pennisetum glaucum*), Finger millet (*Eleusine coracana*), Kodo millet (*Paspalum scrobiculatum*), Little millet (*Panicum sumatrense*), Barnyard millet (*Echinochloa fumentacea*), Proso millet (*Panicum miliaceum*), and Foxtail millet (*Setaria italica*). Millets are generally classified into two main categories: major millets and minor millets. Sorghum, pearl, and finger millet are considered the primary or major millets, whereas kodo, barnyard, proso, little, and foxtail millet are categorized as minor millets. Moreover, millets stand out from other crops as they can achieve remarkably higher yields even in low-fertility

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soils by employing minimal input farming techniques. That is why millets make them a promising solution for addressing the growing global challenges of population increase, hunger, and food shortages [12].

Chhattisgarh is one of the states in India where minor millets like kodo millets, finger millets, and little millets are produced. Millets are grown in several districts within the state, such as Kanker, Kondagaon, Bastar, Dantewada, Bijapur, Sukma, Narayanpur, Rajnandgaon, Kawardha, Gaurela-Pendra-Marwahi, Balrampur, Koriya, Surajpur, and Jashpur [13].

Millets have several health benefits due to their nutrient content. They are good sources of essential amino acids, fatty acids, and antioxidants. They are also rich in dietary fiber, which regulate blood sugar levels and manage cholesterol, thus lowering the risk of heart disease. These are gluten-free and have potential to battle against malnutrition, celiac disease, or diabetes.

These millets contain excellent nutritional value including macronutrients like protein (7–13%), carbohydrates (60–70%), fat (1.5–5%), and fiber (2–7%). These millets are gluten free and contain large quantities of micronutrients like vitamin B-complex, minerals like potassium, iron, calcium, magnesium, and zinc as well as fatty acids like linolenic, oleic, and palmitic acid [14].

MORPHOLOGICAL CHARACTERISTICS OF MILLETS

Kodo Millet

Kodo millet (*Paspalum scrobiculatum*) have common name Kodo, and called Kodra, Arika, etc. in different Indian languages. In India, kodo millet is primarily cultivated in the states of Madhya Pradesh, Uttar Pradesh, Chhattisgarh, Tamil Nadu, Gujarat, Maharashtra, and Karnataka. Kodo millet is a highly drought resistance crop, therefore, it can be grown in areas where rainfall is light and irregular.

In India, kodo millet was grown on an area of 1.96 lakh hectares in the year 2015–16, yielding a total production of approximately 0.84 lakh tonnes, with a productivity of 429 kg/ha [15].

Morphologically, kodo millet is well-suited for farming in tropical and subtropical areas. Kodo millet flourishes in nutrient-deprived soils and is broadly found in the dry regions of India. Kodo millet is an annual grass species that typically grows up to about 90 cm in height. Kodo millet is a monocot crop and produces minor seeds, measuring 1.5 mm in width and 2 mm in length. The seeds range in color from light brown to dark grey and come enclosed in a tough husk that can be challenging to peel off [16]. Kodo millet has 10-48 basal tillers per plant and the length of the inflorescence varies from 2 to 12 cm. Kodo millet is a highly self-pollinated crop and is relatively a late maturing crop compared to other small millets [17].

Finger Millet

Finger millet (*Eleusine coracana)* have common name Ragi, and called Mandua, Ragulu, etc. in other Indian languages. Finger millet is a vital food crop primarily cultivated in the arid and semi-arid regions of the world. Finger millet holds a unique position in agriculture due to its high nutritional value and remarkable adaptability to various environmental conditions [18]. In India, finger millet is mainly grown in the states of Karnataka, Uttarakhand, Tamil Nadu, Andhra Pradesh, Odisha, Jharkhand, Chhattisgarh, and Maharashtra.

In India, finger millet is important crop among the millets after sorghum and pearl millet which is grown on an area of 2 million hectares with a production of 2.15 million tones, which accounts for 45 % of the world's cultivated area and 55% of the world's production [19].

Finger millet is an annual crop that typically grows to a height of 30–150 cm and has a maturity period ranging from 75 to 140 days. Finger millet has an annual or perennial growth [20].

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Morphologically, finger millet stems are straight, compressed, and glabrous. The leaf blades of finger millet are slender, linear, and come to a sharp point. They are commonly folded, striated, and feature ciliated margins. The flower cluster of finger millet showcases a variety of spikes, varying in number from 3 to 20, elegantly arranged in a pattern resembling that of a bird's foot. Each spike is packed with about 70 spikelets, each holding 4–7 seeds with a diameter between 1 and 2 mm [21].

Little Millet

Little millet, also known as kutki, is often referred to by other names, such as samai, sama, and so on in different languages. Little millet is known for being rich in vitamin B and important minerals like potassium, phosphorus, iron, zinc, and magnesium. Little millet is predominantly cultivated in various regions of India including Karnataka, Tamil Nadu, Orissa, Madhya Pradesh, Chhattisgarh, Jharkhand, Andhra Pradesh, Uttarakhand, Maharashtra, and Gujarat [22].

Little millet is grown in India across 2.34 lakh hectares, yielding approximately 1.27 lakh tones with a productivity of 544 kg/ha in the year 2015–16. India holds the position as the leading producer of little millet, accounting for more than 98% of the total cultivation area and yield. Little millets are tiny, seeded plants that thrive in less fertile soil, tribal communities, rain-fed regions, and hilly terrains while displaying excellent resilience to intense environmental pressures [23].

Little millet is grown to a small extent at elevations reaching up to 2100 meters. Morphologically, the plant of little millet varies in height from 50 to 100 cm. The inflorescence of little millet is compact, and has oblong panicles which are varies in length from 14 to 40 cm. The panicle of little millet is composed of several branches ranging from 10 to 50 cm, each branch is 3–9 cm long. Little millet spikelet are flattened which is 3–4.5 mm long. The seed of little millet is glabrous, which is mostly brown in color and sometimes shiny white to almost black in color. The seeds of little millet are smaller compared to those of proso millet [24].

Pearl Millet

Pearl millet (*Pennisetum glaucum*) is a versatile cereal crop, known by various names in different Indian languages, including Bajra, Bajri, Sajje, Kambu, Kamban, and Sajjalu. In India, pearl millet holds a significant position among the crops, following closely behind rice and wheat in cultivation importance. Pearl millet was cultivated across a vast area of 7.4 million hectares, yielding an average of 9.13 million tonnes in the year 2017–18 [25]. Pearl millet is predominantly cultivated in the Indian states of Rajasthan, Maharashtra, Gujarat, Uttar Pradesh, and Haryana.

Pearl millet is extensively cultivated for both grain and fodder in the dry regions of northwestern and southern India. Pearl millet has the remarkable ability to thrive in environments with low and erratic rainfall, high temperatures, and poor soil fertility [26]. Pearl millet is known as the most drought-tolerant warm-season cereal and is primarily grown as a crucial food grain and a valuable source of feed and fodder. It is one of the most dependable cereal crops in the arid and semi-arid tropical regions [27].

Morphologically, pearl millet is a highly cross-pollinated crop, with wind acting as the primary pollinating agent. The spikes of pearl millet arise in about 10 weeks after sowing, then the styles begin to bulge after 2–3 days, first at the top of the inflorescence and then proceeds further. The pearl millet takes two days to fully develop its entire spike. The exerted stigma present in pearl millet remains open for 12–24 hours. In pearl millet, the anthers typically emerge after the styles have dried. The emergence of the anthers begins in the middle of the spike and then progresses both upward and downward [28].

Sorghum Millet

Sorghum millet (*Sorghum bicolor*) is commonly known as Jowar, and Jowari, Jonna, etc. called in various Indian languages. Sorghum is one of the major cereal crops consumed in India, following rice

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and wheat. The primary production of sorghum occurs in Maharashtra, along with the southern states of Karnataka and Andhra Pradesh, which together contribute nearly 80% of the country's total production. Madhya Pradesh, Gujarat, and Rajasthan are also notable regions for producing sorghum.

In 2007, India ranked as the third-largest sorghum producer globally, with a production of 7.15 million tonnes. Nearly 95% of the country's total sorghum production comes from the regions and states mentioned above [29].

Morphologically, sorghum has adventitious and fibrous roots. The sorghum crop is agronomically suited to hot and dry agroclimatic region where other food grains do not grow easily. The inflorescence of sorghum consists of panicles, which can be either short and compact or loose and open. The rachis of sorghum may be straight, hairy, or glabrous. Sorghum is a type of grain that has a natural partial covering of glumes, which are gently separated during the threshing process. The shape of the seed is oval to round from 4 to 8 mm in diameter and vary in size, shape, and color depending on the cultivar [30].

Barnyard Millet

Barnyard millet (*Echinochloa fumentacea*) is commonly known as Sanwa, and Udalu, Shyama, etc. called in different Indian languages. Barnyard millet is primarily cultivated to be utilized for both human consumption and as feed for livestock. Within the wide variety of cultivated and wild barnyard millet species, the two most renowned ones are the Indian barnyard millet (*Echinochloa fumentacea*) and the Japanese barnyard millet (*Echinochloa esculenta*) [31].

In India, barnyard millet holds the position as the second most crucial small millet following finger millet, boasting a production of 87 thousand tonnes and a productivity of 857 kg/ha. Barnyard millet is mainly grown in two different agricultural regions - the mid-hills of the Himalayan region in Uttarakhand to the north, and the Deccan plateau region of Tamil Nadu to the south [32].

Morphologically, Indian barnyard millet is an annual grass with slightly vertical and straight stems, up to 242 cm tall. The leaf length and arc width of barnyard millet as 15–40 cm long and 1–2.5 cm wide. The barnyard millet plant is primarily green, although violet tinges can also be observed in both the vegetative and reproductive parts of the plant. The leaf blades are smooth and glabrous, culms are slender to strong. The inflorescence of barnyard millet is green to violet in color, and they are typically straight and compact which is 1–28 cm long. The spikelet of barnyard millet is covered with stiff hairs, and the spikelets on the panicle are small, unbranched, and tightly clustered, measuring 2–4 mm in length [33, 34].

Proso Millet

Proso millet (*Panicum miliaceum*) is a cereal crop and commonly called Barre, Cheena, Baragu, etc. Proso millet seeds show a range of colors, including white, cream, yellow, orange, red, black, and brown. They are generally smaller in size compared to pearl millet seeds. Proso millet is a short season crop which is thriving between 6 and 12 weeks [35].

In India, proso millet is cultivated in several states, including Tamil Nadu, Maharashtra, Karnataka, Andhra Pradesh, Bihar, Madhya Pradesh, and Uttar Pradesh. It is grown over an area of 0.41 lakh hectares, with a production yield of 0.22 lakh tonnes [36].

Morphologically, proso millet is a cereal crop that adapts well to different soil and climatic conditions. It is a quick-growing plant that needs very little water to grow. Proso millet can thrive in northern regions beyond other millet varieties, performing exceptionally well in plateau settings and at higher altitudes. The plant commonly grows to a height ranging from 30 to 100 cm, displaying minimal tillers, and possessing an adventitious root system. Proso millet is typically acknowledged as

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a self-pollinating crop, but at times, it is also seen as a crop that can cross-pollinate. Proso millet seeds typically have an oval shape, measuring around 3 mm in length and 2 mm in width [37].

Foxtail Millet

Foxtail millet (*Setaria italica*) presents a pale yellow to orange hue and holds an oval shape [38]. Foxtail millet is known by various names, such as Kangni and Kakum in different Indian languages. Foxtail millet is cultivated in various states across India, including Andhra Pradesh, Karnataka, Telangana, Rajasthan, Maharashtra, Tamil Nadu, Madhya Pradesh, Uttar Pradesh, and to some extent in the northeastern states. The crop is grown across 0.87 lakh hectares, total yielding around 0.66 lakh tonnes. In the year 2015–16, the productivity of foxtail millet reached 762 kg/ha [15].

Morphologically, foxtail millet keeps husk and bran layers like other types of millet. The husk makes up 13.5% (w/w) of the grain, while the bran and germ combined only make up 1.5–2% (w/w). Foxtail millet has a brief growth cycle, taking about 5–8 weeks to reach the flowering stage after planting, and approximately 8–15 weeks to achieve seed maturity. Each flowering can produce hundreds of seeds [39].

Foxtail millet consists of a single stalk with several inflorescences. The whole plant of foxtail millets grows up to height of 120–200 cm which is approximately 2–5 feet. Apart from that fully matured foxtail millet plant has thin, straight, leafy stems, and arc-shaped, silky, hairless leaves. The seed head of foxtail millet is 5–30 cm long, thick, and hairy panicle in appearance with an average diameter of 2 mm. The color of the seeds varies widely between varieties and can be pale yellow to orange, red, brown, or black. Foxtail millet can thrive well in altitudes from sea level of 2000 m and is adapted to wide range of elevations in soil as well as temperature [40].

NUTRITIONAL COMPOSITION OF MILLETS

Kodo Millet

Kodo millets are distinguished among cereals for their significant levels of calcium, dietary fiber, polyphenols, and protein [41]. Kodo millets are known for being rich in magnesium and phosphorus. Kodo millets also boast high levels of magnesium and phosphorus. Magnesium is recognized for its beneficial effects on alleviating migraine symptoms and lowering the likelihood of heart attacks. Phosphorus, on the other hand, plays a vital role in the synthesis of adenosine triphosphate (ATP), an essential factor for enhancing energy levels in the body [42–44].

Kodo millet is a nutrition powerhouse, filled with a variety of vitamins, minerals, and phytochemicals, notably sulphur, which has led to its affectionate name “nutria-cereal.” This millet stands out for its abundance of crucial amino acids like lysine, threonine, valine, and sulphur-based amino acids, while it contains lower levels of tryptophan. Kodo millet offers generous doses of vitamin B3, B6, and folic acid, as well as essential minerals, such as calcium, potassium, magnesium, and zinc. Kodo millet, being gluten-free, is a great option for individuals with gluten sensitivities. In addition to this the regular consumption of kodo millet is beneficial for managing cardiovascular issues, including high blood pressure and high cholesterol [45, 46].

Kodo millet contains moisture (11.92%), protein (11.52%), fat (2.89%), crude fiber (1.85%), ash (1.22%), carbohydrate (70.60%), and energy (353 Kcal/100 g) [47, 16].

Finger Millet

Finger millet is nutrient-rich and has several vital nutrients like carbohydrates, dietary fiber, essential amino acids, and minerals which are present in sufficient amount [48]. Finger millet contains a lot of fiber, which is beneficial for digestion. Finer millet lowers body’s blood sugar levels and converts it to insulin and is helpful for preventing diabetes. Finger millet is rich in calcium, potassium, and essential amino acids like methionine and lysine, along with vitamin E. The dietary fiber and

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polyphenols present in finger millet offer various health benefits, including antidiabetic properties, protection against chronic diseases, reduction in hypercholesterolemia, and antioxidant and antibacterial effects [49].

Finger millet is a great provider of iron, crucial to produce hemoglobin in red blood cells. The plenty of essential nutrients like calcium, potassium, dietary fiber, and polyphenols add exceptional nutritional value to the finger millet. These elements can bestow a range of health advantages, including antidiabetic, antioxidant, and antimicrobial properties. Finger millet, being naturally gluten-free, is a great option for those who are sensitive to gluten as well as for individuals managing diabetes. Finger millet is known for its high calcium content, ranging from 300 to 400 mg, a value approximately ten times higher than that of typical cereals, such as wheat and rice. Moreover, finger millet is rich in various essential micronutrients, such as thiamine, iron, magnesium, zinc, chromium, and iodine. Finger millet is commonly known as a "cool food" because of its rich mineral content, which helps in maintaining the acid-base balance in the human body [50].

Finger millet is a nutritious cereal crop that contains macronutrients, such as carbohydrates (65–70%), fiber (2.5–3.5%), fat (1–1.5%), ash (2.5–3%), protein [29] (5–8%), moisture (11.75%) [51], and energy (328 Kcal/100 g) [52].

Little Millet

Little millet holds a significant position in the Indian diet. Little millet is rich in nutraceuticals and micronutrients, providing valuable medicinal benefits. Little millet is a lesser-known grain that is highly regarded for its various health advantages, due to the presence of beneficial compounds like phenolic compounds, tocopherols, and carotenoids. Additionally, its low glycemic index makes it especially advantageous for individuals with diabetes. Little millet is a beneficial source of phosphorus, while its fiber content aids in lowering body fat levels. The low-calorie content and antioxidant properties found in little millet support a healthy diet and aid in weight management [53].

Little millet contains a good balance of amino acids, including cysteine, methionine, and lysine, which are particularly rich in sulphur [54]. Little millets have lower glycemic index due to presence of rich dietary fiber, resistant starch [55]. Little millet is also a good source of essential micronutrients including iron, potassium, and niacin [56].

Little millet contains moisture (13.1%), protein (7.7%), carbohydrate (83.3%), fiber (11.5%), ash (2.7%), fat (1.5%) [8], and energy (341 Kcal/100 g) [57].

Pearl Millet

Pearl millet benefits from a deep root system that enables enhanced nutrient absorption from the soil, resulting in superior nutritional value when compared to alternative cereal crops, such as wheat, rice, maize, and sorghum. Pearl millet boasts a wealth of vital minerals, including iron, zinc, magnesium, copper, manganese, potassium, and phosphorus [58]. Pearl millet has higher protein content and serves as an excellent provider of vitamin B, vitamin A, folic acid, calcium, and magnesium [59].

Pearl millet is a rich source of several health-promoting nutrients, such as iron, zinc, folic acid, and ß-carotene, which help combat malnutrition caused by mineral deficiencies [60]. The amino acid composition of pearl millet is superior to sorghum and maize, and comparable to that of wheat, barley, and rice. Moreover, pearl millet is rich in niacin. Pearl millet is a gluten-free grain that maintains its alkaline properties even after being cooked, which makes it a great option for individuals who have wheat allergies. While pearl millet is highly nutritious and beneficial, its availability is limited due to the presence of anti-nutritional factors like phytic acid and polyphenols [58].

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Pearl millet grain has a high fat content than other cereals, which cause poor keeping quality of the product. Pearl millet contains moisture (8.5%), crude protein (13.6%), crude fat (7.8%), crude fiber (2.8%), ash (2.1%), carbohydrate (63.2%), and energy (361 Kcal/100 g) [61].

Sorghum Millet

Sorghum millet is a good source of essential macronutrients, including dietary fiber, protein, and key minerals. Although its lipid content is relatively low at around 3%, it contains beneficial fatty acids, such as oleic and linoleic acid. Sorghum millet includes vitamin E and vitamin B complex as thiamine, riboflavin, and niacin. Sorghum millet is rich in essential minerals, such as phosphorus, magnesium, iron, and zinc [62]. Sorghum millet is gluten-free, high in resistant starch, and filled with a wide range of nutrients, including various bioactive phenolic compounds. Sorghum has more diverse and abundant phenolic compounds than other major cereal crops, making it a valuable addition to our diets and a potential powerhouse for health benefits. Sorghum millet contains almost all types of phenolic compounds, including simple phenolic acids, flavonoids, and tannins [63].

Sorghum millets have several health benefits such as high content of dietary fiber, good source of vitamins and minerals, controls weight management, lowers blood cholesterol. Sorghum has antioxidant activity, anti-inflammatory activity as well as cancer, antidiabetic and obesity, dyslipidaemia, and cardiovascular disease prevention properties [64].

Sorghum phenolic compounds may contribute to insulin regulation and could serve as an assistant in the treatment of diabetes. Sorghum is a rich source of antioxidants that have multiple health benefits which help to prevent chronic diseases [65]. Sorghum millets have various types of vitamins and minerals as the important vitamins in sorghum are vitamins B-complex, such as pyridoxine, riboflavin and thiamine, and fat-soluble vitamins including A, D, E, & K as well as iron and zinc. Sorghum is a good mineral source, such as phosphorus, potassium and in sorghum availability of iron varies from 6.6% to 15.7% while zinc availability ranges from 9.7% to 17.1% [66].

Sorghum millet contains moisture (11.9%), protein (10.4%), fat (1.9%), carbohydrate (72.6%), fiber (14.3%), ash (1.6%), and energy (349 Kcal/ 100 g) [67].

Barnyard Millet

Barnyard millet is superior in major and minor millets in terms of nutritive value. Barnyard millet cereal grains provide a rich variety of nutrients, including dietary fiber, iron, zinc, calcium, protein, magnesium, fat, vitamins, and numerous essential amino acids [68–70]. In the barnyard millet the high carbohydrate to crude fiber ratio promotes a slower release of sugars into the bloodstream, helping to maintain stable blood sugar levels. Additionally, the resistant starch in barnyard millet has been shown to lower blood glucose, cholesterol, and triglyceride levels [71].

It is rich in essential fatty acids like linoleic acid, palmitic acid, and oleic acid as well as minerals like iron, calcium, and magnesium, where magnesium and niacin help to lower cholesterol levels and phosphorus minerals, improve the metabolic process and food conversion into energy [72]. Barnyard millet is highly recommended for individuals with cardiovascular conditions and diabetes. Barnyard millet can effectively help lower blood sugar and lipid levels. Additionally, barnyard millet is an ideal choice for those with gluten intolerance, such as people affected by celiac disease [71].

Barnyard millet contains macronutrients like crude protein (11.3–17.2%), fat (3.6–3.8%), ash (4.7–5.0%), crude fiber (5.41–6.87%), carbohydrate (68.8%), moisture (8.7%), and energy (398 Kcal/100g) [12].

Proso Millet

Proso millet possesses valuable nutritional attributes, as rich in protein, starch, dietary fiber, and several elements, such as magnesium, iron, and calcium. Additionally, proso millet is associated to

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various potential health advantages, such as reducing the risk of arteriosclerosis, gastrointestinal cancer, coronary heart disease, and other health issues. In recent years, there has been a growing interest in the use of millet, particularly in food applications as a gluten-free ingredient [36].

Proso millet has high magnesium and niacin content and is rich in essential amino acids like lysine, leucine, isoleucine, and methionine [74]. Proso millet is highly nutritious and comparable to other major cereal grains. Proso millet is rich in essential minerals including calcium, phosphorus, potassium, sodium, magnesium, manganese, iron, and zinc, making it a great dietary choice. Proso millet contains all the crucial amino acids, such as methionine, phenylalanine, tryptophan, valine, and more. The limiting amino acid in proso millet is lysine, which is only 189 mg/g. The essential amino acid index in proso millet is higher (51%) compared to wheat. Additionally, proso millet has a lower glycemic index than rice, wheat, and barley, making it an ideal food choice for individuals with type-2 diabetes mellitus and cardiovascular disease [75].

Proso millet contains moisture (8.04%), protein (13.09%), fat (3.35%), carbohydrate minerals, and high level of protein [76].

Foxtail Millet

Foxtail millet has lower glycemic index and gluten content which makes foxtail adjuvant therapeutic food for diabetic and gluten intolerant individuals [77]. Foxtail millet helps steadily releasing glucose while supporting the body's metabolism. Foxtail millet is also known as a healthy heart diet and aids in reducing the occurrence of diabetes due to its high magnesium content [77].

Foxtail millet is a healthy grain that is gluten-free, highly nutritious, and gentle on the stomach, making it easy to digest. Foxtail millet is a great choice for individuals with celiac disease and diabetes due to its low glycemic index. Additionally, foxtail millet offers several health benefits, including the prevention of cancer and cardiovascular diseases, reducing the risk of heart attacks, aiding in weight loss, and lowering blood lipid levels [78].

Foxtail millet contains moisture (9.35%), ash (3.10%), protein (10.29%), fat (3.06%), fiber (4.25%), carbohydrate (69.95%), and energy (349 kcal/100 g) [79].

Value Added Products from Millets

Millets have been important crop in India for centuries and are essential food for a large portion of the world's population. Malnutrition is a major issue which is increasing day by day which is affected by changing lifestyle, change of food, adulteration food, and change in climate. The value of any food like rice, wheat, maize as well as millets are important because for its easy accessibility to the world. The value addition gives full utilization of all food and promotes zero wastage. Millets were utilized to create value added products, such as bakery items, pasta, popped flakes, and instant food mixes. The millets are incorporated in various food products to enhance their nutritional value and diversity. Millets were incorporated into bakery products like bread, cake, cookies to increase their nutritional content and offer healthier alternatives. Millets were combined with refined wheat flour to create pasta products like vermicelli, noodles, and macaroni, offering a healthier alternative to traditional pasta. Millets are ideal for producing flakes and popped products due to their small size and quick hydration properties. Value added products like aval uppma, kitchadi, payasum, and various flavored flakes were developed using millet flakes and popped millets. Millets are also incorporated in ready to eat products and as well as in instant mixes which provides a convenient and hygienic option for modern consumers looking for quick and easy meal solutions [80].

The value of millets through processing methods enhances their nutritional value, reduces anti-nutritional factors, and ensures food and nutritional security by creating diverse and nutritious food products. The importance of value addition of millets lies in their high nutritional value and potential

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to address food security challenges. Millets are rich in macro and micronutrients, dietary fiber, antioxidants, and proteins, making them crucial for nutritional security [81]. The effective processing methods of millet enhanced the nutritional value of millets which helps to contribute to overall health benefits for people suffered from malnutrition. The value addition of millets product like multi millets namkeens, bakery items, extruded products as pasta, noodles, etc. increases their market value but also offers gluten-free, antioxidant-rich, and nutritionally enhanced options for consumers of all ages, including those with gluten intolerance and diabetic person [31]. Additionally, the incorporation of millets into products like millet bread provides nutritious and gluten-free alternatives, catering to the growing consumer demand for healthy and diverse food options [82]. Thus, the value addition of millets is crucial in enhancing food security, improving health, and driving economic growth.

Business Opportunity in Processing of Millets

India is the leading producer of millets and holds a crucial position in the global millet trade. It ranks among the top 10 exporters of millet worldwide. In 2022, India was 7th in millet export value reaching USD 65.10 million (1.66% of global trade), and 10th in export volume with 1.68 lakh metric tons (0.45% of global trade). There are various government initiatives including financial assistance, the establishment of processing centers, and the formation of FPOs which are playing a crucial role in promoting millet processed industries in India. These initiatives aim to boost the production of millets, create awareness about health benefits of millets, and improve the overall value chain for millets. The promotion of millets and millet-based products not only contributes to the health and well-being of consumers but also holds promise for sustainable agricultural practices and economic growth [83].

Millets are a valuable crop for small farmers due to their low investment and low input cost, as well as their nutritional benefits. Furthermore, millets have a high demand in the market, which makes them a profitable crop for farmers. In recent years, there has been noticeable growth in business opportunities focused on millets in India. This is due to the growing awareness of the nutritional value of millets and its potential to tackle various health and environmental issues. Millets also offer a unique opportunity for farmers to diversify their crop portfolio and enhance their income. Millet processing has several opportunities due to its high nutritional profile. There are several products made with millets like ready-to-cook and ready-to-eat (RTC & RTE) products. The establishing of millet processing units can greatly enhance the value of the crop. Millet processing units can add value to millet grains by converting them into various products. Processing units of millets like millet flour and semolina production, millet-based snacks etc. can ensure consistent quality and safety standards for millet products, which is essential for building trust among consumers. Apart from that, value added millets including millet-based flour blends, ready-to-eat snacks, breakfast cereals, and even specialized millet-based beverages are most distinguished toward business opportunity [84].

CONCLUSIONS

Millets are cereal crops grasses that belong to minor cereals in the *grass* family with botanical name "*poaceae*." Millets are categorized into two groups: major millets (Sorghum, Pearl, and Finger millet) and minor millets (Little, Foxtail, Proso, Barnyard, and Kodo millet). Millets contain excellent nutritional value including macronutrients like protein (7–13%), carbohydrates (60–70%), fat (1.5–5%), and fiber (2–7%). These millets are gluten free and contain large quantities of micronutrients like vitamin B-complex, minerals like potassium, iron, calcium, magnesium, and zinc as well as fatty acids like linolenic, oleic, and palmitic acid. The millets contain a wide range of nutrition in a significant amount and are good source of essential amino acids, fatty acids, dietary fiber, and antioxidants. The value of millets through processing methods enhances their nutritional value, reduces anti-nutritional factors, and ensures food and nutritional security by creating diverse and nutritious food products. The processing of millets gives business opportunity to the people as millets are a valuable crop for small farmers due to their low investment and low input cost, as well as their nutritional benefits. Millets have a high demand in the market, which makes millet a profitable crop for farmers.

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