International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(Review Article)

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Review on classification, nutritional and anti-nutritional profile of a sustainable crop-millet

Dalbir Singh Sogi and Jaismeen Kaur *

Guru Nanak Dev University, Amritsar, Punjab, India.

International Journal of Science and Research Archive, 2025, 15(03), 474-488

Publication history: Received on 25 April 2025; revised on 01 June 2025; accepted on 04 June 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.15.3.1716

Abstract

Millets are sustainable, economical and nutritional rich food crops. Contemporary climatic issues have realized the indispensable role of millets in global food security. The major, minor and pseudo millets are an excellent alternate for traditional crops such as wheat, maize and rice due to rich nutritional profile. Millets are rich in macro and micro nutrients along with antioxidants, phytochemicals and sulphur containing amino acids. Slow digestible carbohydrates are beneficial for diabetic population. Millets consists of good quality and quantity of essential amino acids requires for protein synthesis. Millets are rich in fiber and have low GI that play an excellent role in weight management and treatment of diabetes, constipation, and cardiovascular diseases. Calcium content of finger millet is three times greater than milk. Millets help to meet the nutritional need of population, particularly the vulnerable category. Polyphenols are good source of antioxidant in diet helping body to improve its immune defense system. The phenolic compounds present in millets have antioxidant, anti-aging and anti-inflammatory properties. Anti-nutrient compounds decrease the acceptability of millets especially due to mineral mal-absorption and micronutrients deficiency when present in excessive amount in the diet. Improvement in milling and processing treatments has decrease the antinutritional compounds and increase the nutritive value of millets which improved its acceptability and consumption.

Keywords: Millets; Classification; Nutritive composition; Anti-nutritional components; Germination

1. Introduction

Millets are highly varied group of small -seeded grasses and major crop in the semiarid tropics of Asian and African countries such as India, Mali, Nigeria and Niger. Millets have superior photosynthesis and dry matter production capacities, with low inputs requirement, high disease and insect resistance, minimal synthetic fertilizers and pesticides requirements and crop duration of 60-100 days [1]. Millets release less greenhouse gases and demand less water compared to other cereals such as rice. Paddy demands large quantities of water during their growth which results in significant drop in yield and water table [2]. Millets offer an additional harvest and therefore more food and fodder. The cultivation of millets adds diversity, increases soil fertility and reduces dependence on chemical pesticides and fertilizer. These factors will result in increase in the profit of farmer on long term basis. The millet cultivation can be revolutionized by strengthening conventional agricultural practices and giving support to small-scale farmers including women on national and regional levels.

The data reveals that in 2022, 37 million children under the age of five years were overweight or obese, 45 million were wasted (too thin for height), and 149 million were stunted (too short for age). Under nutrition is linked to nearly half of mortality in children under the age of five [3]. Millets can play an important role in managing these nutrition disorders because of high quality macro and micro nutrients along with anti-appetite compounds. These are gluten free, high fiber content and low glycemic index. The seed coat of millets consists of phytochemicals and polyphenols. Millets contain good quality of essential amino acids except lysine which can be complement by leguminous and animal protein to

* Corresponding author: Jaismeen Kaur

balance the biological value [4]. Millets can be added to a cereal-based diet to help lower micro-nutrients deficiencies as well as the protein-energy malnutrition [5].

Non-communicable diseases (NCDs) accounts for 74% of all deaths worldwide, killing 41 million people annually. Every year, 17.9 million people die from cardiovascular diseases, followed by cancer (9.3 million), chronic respiratory conditions (4.1 million), and diabetes (2.0 million) [3]. The risk of death from an NCD increases with tobacco use, physical inactivity, excessive alcohol intake, unhealthy diets and air pollution. Various clinical studies support the positive role of millets in prevention of NCDs like diabetes mellitus, cardiovascular disease, cancer, delaying gastric emptying, supplying gastrointestinal bulk, Parkinson's disease, and cancer [6,7]. Millets help to reduce reliance on rice and wheat which make them beneficial for environment, farmers and consumers.

Millets contain many anti-nutritional compounds such as tannins, phytates, polyphenols, trypsin inhibitors and dietary fiber. These compounds bind to the nutrients present in the food and make them less available for absorption by the human body. Phytates interfere with the absorption of minerals like calcium and zinc. Tannins are bitter in taste and reduces apparently digestibility of protein. These anti-nutrition factors cause gestational discomfort, reduce bioavailability of other nutrients, retard the enzyme function and disturb thyroid hormone functions. The excessive intake of these anti-nutrients results in micro nutrients deficiency. These factors lead to decline in the demand of millets at consumer level. The way forwards to overcome these drawbacks can be various anti-nutritional reducing methods such as germination and fermentation.

The main focus of this review is to compile information on nutritional and anti-nutritional factors present in the millets which may help to establish it as an alternative food crop. Fig.1 represents the Characteristics of millet crops.

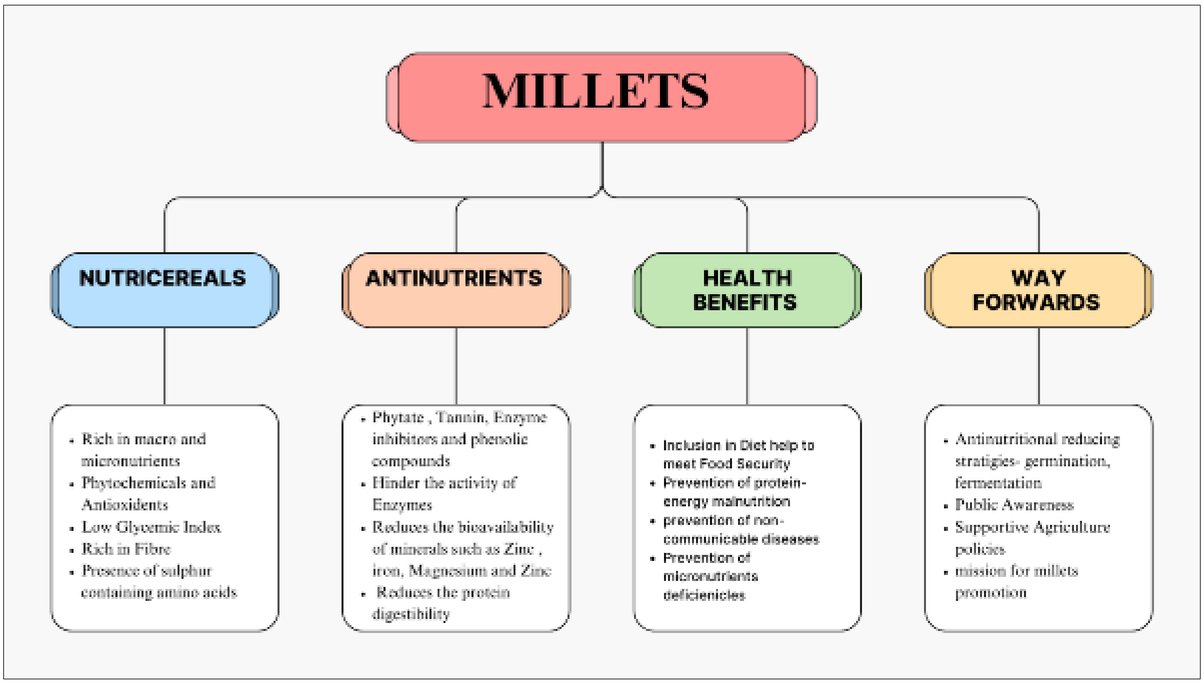


Figure 1 Characteristics of millet crops

1.1. Classification of Millets

There are many environmental conditions under which millet crops can be cultivated as these crops possess special characteristics such as drought tolerant, short duration, good growth on light soils and semi-arid growing condition. Table 1 shows the Classification and agronomical characteristics of important millets. Millets are mainly classified into three groups based on their utilization, grain size and family [8].

Major millets: The grains are grown on a large scale. The Poaceae family which commonly referred to as the grass family, includes these millets. The major millets include sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum Glaucum*) and finger millet (*Eleusine coracana*).

Minor millets: The grains are grown on a small scale. These millets are also members of *Poaceae* family. The minor millets consist of foxtail (*Setaria italic*), Kodo (*Paspalum scobiculatum*), barnyard (*Echinochloa esculenta*), little millet (*Panicum sumatrense*), proso millet (*Panicum milliaceum*), brown top millet (*Brachiaria ramose*), Black Fonio (*Digitaria iburua*), White Fonio (*Digitaria exilis*) and Job's tears (*Coix Lacryma*).

Pseudo millets: These millets do not belong to *Poaceae* family but their characteristics are similar to millets. It includes amaranth (*Amaranthus hybridus*) and buckwheat (*Fagopyrum esculentum*).

Table 1 Classification and agronomical characteristics of important millets**.**

Type of millet	Name	Botanical Name	Origin	Regional Name in India	Crop Duration	Rainfall required	Temp	Special characteristic	References
Major	Sorghum	*Sorghum bicolor*	Eastern Sudanese Savannah	Jowar, Jowari, Juar,	90-120 days	40-100 cm	7-30°C	Resist moisture stress and high temperature conditions	[9,10]
	Pearl millet	*Pennisetum Glaucum*	West Africa	Bajra, Bajri, Sajje,	60-70	20-60 cm	25-30°C	Adaptable to heat, drought	[8,10,11]
	Finger millet	*Eleusine coracana*	Sudan	Ragi, Marwa, Nagli,	90-120 days	50-60 cm	26-29°C	Broad adaptability, Rich source of calcium	[8,10,12,13]
Minor	Foxtail millet	*Setaria italic*	Northern China	Kakum, kaon, kang,	75-90 days	30-70cm	5-35°C	Short duration, tolerant to heat and drought	[8,10,14]
	Kodo millets	*Paspalum scobiculatum*	India	Kodo, Kodra, Kodon, Harka,	100-140 days	800-1200 mm	25-27°C	Long duration, grown well in shallow and deep soil	[8,10,15,16]
	Barnyard millet	*Echinochloa esculenta*	Tropical Asia	Sanwa, Shyama, Banti,	45-70 days	-	15-33°C	Fastest growing, voluminous fodder	[8,10,17,18]
	Little millet	*Panicum sumatrense*	Indian Paninsular	Kutki, Shavan, Sama, Gajro,	80-85 days	40-50cm	-	Short duration, withstand both drought and waterlogging	[8,10,16,19]
	Proso millet	*Panicum milliaceum*	Northern China	Chenna/Barri, Cheno, Baragu	60-90 days	20-50 cm	20-30°C	Short duration, tolerant to heat and drought	[1,8,10]
	Brown top Millet	*Brachiaria ramosa*	Southest Asia	Korale in Kannada	75-90 days	800 mm	20-30°C	Rapidly maturing, best suited for catch crop	[20]

	Black Fonio	*Digitaria iburua*	West Africa	-	-	600-1200 mm	25-30 °C	Survive in drought and heavy rainfall conditions	[10,21]
	White Fonio	*Digitaria exilis*	West Africa	Acha or hungary rice, fonio	-	600-1200 mm	25-30 °C	fast growing and high nutritious	[10,21]
	Job's tears	*Coix Lacryma*	Indo-Myanmar	Adlag, adlay millet	-	-	-	Grown in higher areas, used in folk medicine	[10]
Pseudo	Amaranth	*Amaranthus hybridus*	South America	Ramdana, Rajgaro, Danthu Beeja,	-	500 mm	18-35°C	Adaptable to biotic and abiotic stress	[8,22]
	Buck-wheat	*Fagopyrum esculentum*	No authenticate evidence	Buckwheat, kuttu, Huruli, Bukvit,	60-90 days	-	>30°C	Demand less water and nutrients, superior water use efficiency.	[8,23]

2. Nutritional composition of millets

2.1. Macronutrients

Since millets have high nutritional content, they are referred to as "nutri- cereals" and are advised to be included in a diet. Millets provides average 350 kcal energy, 9.5g protein, 68 gm of carbohydrates, 3.35 gm of fat and 6.5 gm of dietary fiber per 100gm [24]. Finger millet is also recommended for inclusion in the diet due to high nutritional value as it consists of 65-75% carbohydrates, 5-8% protein, 2-5-3.5% minerals and 17-18.90% dietary fiber which is higher than cereals such as wheat and rice [25]. The major carbohydrates present in millets are starch, non-starchy polysaccharides and free sugars. Sorghum consists of 60-75 % starch and finger millet consist of 65% starch and 6.2-7.2% pentosans [25]. Finger millet contains 30-32.4% amylose content. Barnyard millet consists of high amylose content (18-31%), kodo millet contains 18-19.6% amylose, and pearl millet contains 13.6- 18.1% amylose content [25,26]. Finger millet consists of 44.7% essential amino acids and rich in lysine and methionine amino acids [27]. The protein content of millets range 8.3- 15gm/100gm. All millets are rich in essential amino acids such as methionine and cystine. Slow digestive starch is present in finger and barnyard millets. The major portion of protein is present in endosperm (80%) and the remaining portion is present in germ (16%) and pericarp (3%). The bran and germ portions of the grains contain the majority of the essential amino acids but lack in tryptophan and lysine.

Finger millet, barnyard millets, foxtail and proso millets are rich in essential amino acids and inclusion of these millets in diet may help in management of non- communicable diseases. Millets mainly consist of unsaturated fatty acids. However, decortication process reduces the lipid content of the grains. The unsaturated fatty acids help in management of cardiovascular diseases. The fibers contribute bulk to the diet and have beneficial effects on the human body. The transit time of food in the gut increases which leads to slow release of glucose. The binding properties of dietary fiber with bile acids, steroids and toxins help in management of diabetes, obesity, CVDs and cancer. Dietary fibers are essential for digestive health by preventing constipation, promoting a healthy gut microbiome, and reducing the risk of chronic diseases such as colorectal cancer. The biggest health advantage of millets lies in their fibers. The fiber content of millets, including sorghum, bajra, and ragi, is more than oats or whole wheat flour. Bran of the millets is rich source of soluble and insoluble dietary fiber. Kodo millet plays role in positive health due to rich in soluble fibers and non-starchy polysaccharides which increased fecal bulk, and lower the blood lipids levels. A number of non-communicable diseases can be managed owing to high fiber content of millets. The fiber content of different millets is presented in

Table 2. Millets can be combined with cereals to reduces the protein- energy malnutrition [28]. Obesity and diabetes are becoming more common these days, demands for fiber rich and phytochemicals rich food is increasing. Millets are rich in dietary fiber range form 6.3-14 gm/100gm. They have low glycemic index [25,26]. Patients with Type 2 diabetes and cardiovascular disease may benefit from increased consumption of foxtail and proso millets [29,30]. Due to their non- glutinous and non- starchy carbohydrates content, millets are superior over wholegrain cereal [31]. Intake of Foxtail millets help in prevention of cancer, diabetes and cardiovascular diseases [32]. Consumption of little millet decrease the blood glucose level in diabetic patients [33]. Finger millet consists of antioxidant activity that stabilize the free radicals. Foxtail and Proso millet have anti-inflammatory properties that protects against intestinal inflammation and lipase inhibition [34,35]. Amaranth and Quinoa millet also have antioxidant and anti-cancer properties [36,37]. The soluble dietary fiber present in millets helps to reduces blood glucose and cholesterol level [38]. Millets have a macronutrients profile similar to that of major staple grains like rice, wheat and maize. The barnyard millet is rich in energy (300-398kcal/100gm) and carbohydrates(51-69g/100gm). Foxtail millets (8.3-12.3mg/100gm) and Job's tears (11.8-15.8mg/100gm) is good source of protein. Pearl millet(5-7.2mg/100gm) and little millet (3.9-5.2mg/100gm) are good source of fat. Barnyard millet(13.6gm/100gm), pearl millet (11.5g/100gm), sorghum(14gm/100gm) and finger millet(11.2gm/100gm) is rich in dietary fiber (Table 2).

Table 2 Nutrient profile of millets on 100gm edible portion

Millet	**Energy (kcal/ 100gm)**	**Available carbohydrates (g)**	**Protein (g)**	**Fat (g)**	**Dietary fibre(g)**	**Ash (g)**	**Calcium(mg)**	**Iron (mg)**	**Thiamine (mg)**	**Ribo flavin (mg)**	**Niacin (mg)**
Sorghum	345-349	63-72.6	8.6-11.5	1.7-4.7	6.3-14	1.3-2	20-25	5.1 - 5.4	0.30-0.38	0.13-0.15	3.6-4.3
Kodo millet	309-353	65.9-66.8	8.3-9.8	1.4-3.6	6.4-9	1.7-3.3	15-35	1.7-2.3	0.15-0.29	0.2-0.09	1.2-2.0
Little millet	329-353	60.9-66.2	9.4-9.7	3.9-5.2	7.6-7.7	1.3-5.4	16-17	9.3	0.26-0.30	0.05-0.09	1.3-3.2
Finger millet	328-336	67.3-72.6	6.7-7.7	1.3-1.9	3.6-11.2	2-2.6	350-364	3.9-4.6	0.2-0.48	0.12-0.19	1-1.30
Foxtail millet	331-356	55-69	8.3-12.3	4-4.4	1.6-8.5	1.2-3.3	29-31	2.8-4.2	0.49-0.59	0.09-0.11	2.5-3.2
Pearl millet	361-366	63-67.5	9.3-11.8	5-7.2	2.3-11.5	1.2-2.7	26-42	9.3-11	0.28-0.38	0.19-0.21	1.6-2.8
Barnyard millet	300-398	51.5-69.4	6.2-11	2.2-3.9	4.3-13.6	1.3-4.5	17.1-32.7	15.6-18.6	0.33	0.10	4.2
Proso millet	350	65.6	10.4-10.59	1.47-3.8	6.2-11.23	2.9	10-33	2.2-3.4	0.41	0.21-0.28	3.2-.54
Teff	351	66	12.4	2.4	8	2.4	180	7.6	0.39	0.27	3.4
Job's tears	357	67.7	11.8-15.8	1.3-4.7	0.6-5.5	0.2-3.5	46	5.5	0.22	0.1	1.3
White fonio	356	76.9	7.1	1.7	2.2	1.2	24	2.1	0.16	0.18	
Maize yellow	363	67	9.4	4.7	7.3	1.2	26	2.7	0.38	0.20	3.6
Common wheat	340	63.7	11.3	1.7	12.2	1.5	30	3.5	0.39-0.41	0.04-011	4.3-4.4
Rice, white, long	352	78.7	7.1	0.7	1.3	0.64	33	1.8	0.41	0.04	4.3

References- [24,28,39,40]

2.2. Micronutrients

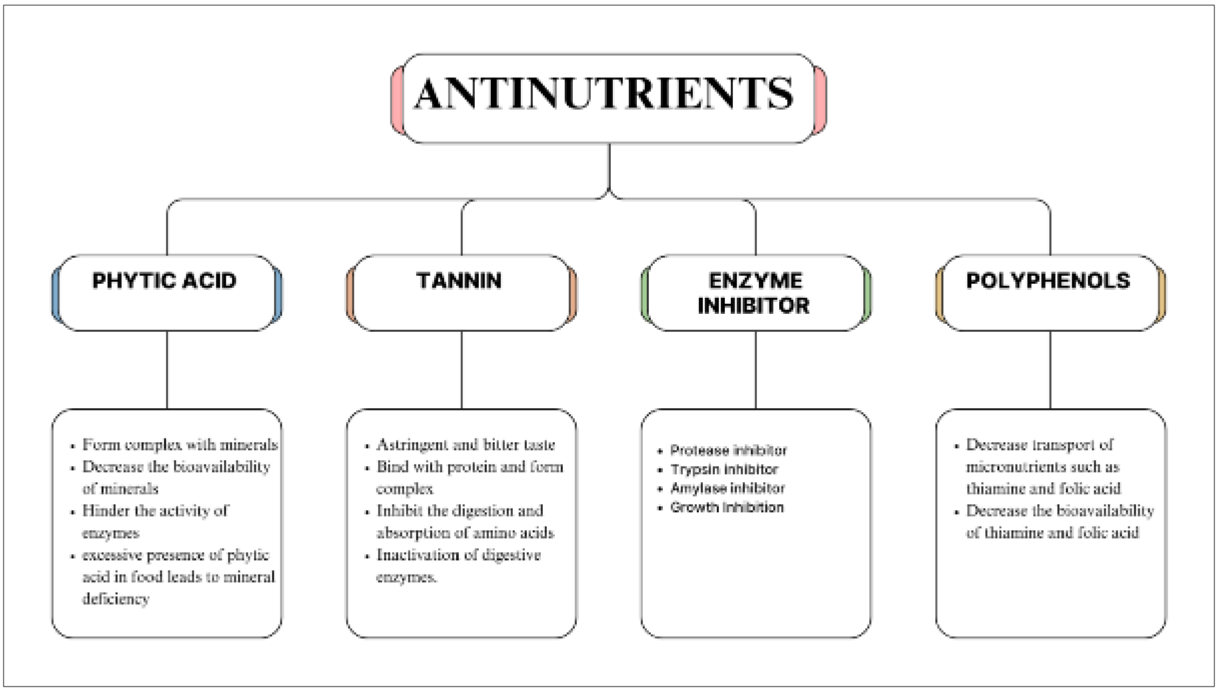
Minerals have a role in the structural development of tissues as well as the regulation of bodily processes. Based on the quantity required by the body each day, minerals are divided into two categories major minerals (calcium, sodium, potassium, chloride, phosphorus, magnesium, and sulfur) and trace minerals (iron, zinc, copper, selenium, iodine, fluoride, molybdenum, and manganese). The calcium content of finger millets is around thirty times higher than of rice grains [32]. Important minerals such as iron(9.3mg/100gm) and phosphorous (373mg/g) are abundant in pearl millet. Sorghum millet consists of 161 mg of magnesium and 315mg of phosphorous [24]. Another crucial micro-nutrient necessary for the cellular metabolism of vital proteins, lipids, and nucleic acids is zinc which is required for maintaining reproductive functions, enhance immunity and cell signaling. Pearl millet (3.29mg/100gm). finger millet (3.13mg/100g), foxtail millet (2.29mg/100g) and proso millet (2.22mg/100gm) have the highest zinc content among millets [41]. Finger millet contains magnesium that has a prominent role in preventing heart attacks [42]. Millets are rich in micro-nutrients in comparison to maize, wheat and rice (Table 2). Vitamins act as coenzyme in various body processes and reactions. Millets' nutritional profile is enhanced due to presence of B-complex vitamins like riboflavin, thiamine and niacin. These vitamins play key roles in energy metabolism, supporting overall health and well-being. Millets consists of 0.15-0.59 mg/100g of thiamine, highest being present in foxtail, riboflavin range from 0.09-0.27 mg/100gm and 1- 4.3 mg/100gm of niacin content (Table 2). Certain millets are good source of folic acid such as proso millet (49µg/100gm), sorghum (46µg/100gm), and kodo millet (39µg/100gm) and are readily assimilated into diets [24]. Finger, little, foxtail and proso millets are rich in Carotenoids which act as antioxidants [43]. Intake of finger, little, foxtail and proso millet inhibit the lipid peroxidation due to presence of vitamin E which act as antioxidant [44]. Various bioactive compounds such as catechin, naringin, p-coumaric acid, taxifolin, ferulic acid, sinapic acid, are present in kodo millet which acts as anti-inflammatory, anticarcinogenic and antidiabetic properties [45]. Intake of little millet protect us from various diseases as bioactive compounds such as luteolin and apigenin are present in little millet which contains antioxidant and anti- inflammatory properties [46]. However, minor millet contains antioxidants compounds such as phenolic acids, flavonoids, phytochemicals, tannins, Xylo-oligosaccharides, insoluble fibers, protein and peptides, carotenoids and vitamin mainly present in bran section of grain [47]. Antioxidants are mainly present in the bran portion of the grains which is removed by milling process.

2.3. Anti-nutritional components present in millets

Anti-nutritional components are naturally present in the grains. These components influence the nutritional value of the individual grains, and their excessive consumption leads to various health consequences. Table 3 represents the phytic acid and tannin content of millets. Anti-nutrients such as phytate, tannin, enzyme inhibitors, polyphenols, and goitrogens make micro-nutrients unavailable for human absorption because of their ability to chelate divalent cationic resulting in mineral malnutrition (Fig 2). High content of anti-nutrients results in lowering the bioavailability of nutrients. Phytic acid reduces the bioavailability of minerals. Enzyme inhibitors impact the digestion of protein and carbohydrates. Some phenolic compounds negatively impact the protein digestion and bioavailability of minerals. These anti-nutrient components decrease the wide acceptability of millets as a food. Table 3 represents the phytic acid and tannin content of different millets. Phytates, phenols, tannins, trypsin inhibitory factors, and dietary fiber, are anti-nutrients found in millet that chelate metals. and impede enzymes [48]. Foxtail, finger and Proso millets contain anti-nutrient compounds such as phytate, polyphenols and tannin which may act as barrier in efficiency and utilization, absorption, or digestion of nutrients [28].

Table 3 Anti-nutritional compound present in millets

Millet	Phytic acid, mg/g	Tannin, mg/g	References
Kodo millet	1.2-1.4	1-1.2	[76]
Little millet	8.4	0.157	[76,77]
Finger millet	8.51-14.19	0.17	[78,79]
Foxtail millet	5.4-11.7	0.287	[39,77]
Pearl millet	8.33	0.88	[80]
Barnyard millet	3.30-3.70	0.59	[79]
Proso millet	9.2	0.218	[76,77]



References- [39,49,50]

Figure 2 Anti-nutritional factors of millets

2.4. Phytates

Phytates are naturally present in the salt form of phytic acid in plants and storage form of phosphorous. Phytates are generally present in the bran fraction of grains, legumes, oilseeds and nuts. Phytate are considered as anti-nutrient as it may inhibits the absorption of essential minerals such as Ca^{2+}, Zn^{2+}, Mg^{2+}, Cu^{2+}, Fe^{2+}, and Mn^{2+} [51]. Phytic acid is mostly found in plant diet as compare to non-vegetarian diet. The excessive presence of phytate in diet leads to mineral deficiencies. Phytic acid is a negative charged ion structure and chelates positively charged minerals such as zinc, iron, manganese and copper and make them unavailable for absorption [52]. Phytic acid form the strongest complex with zinc and hinder its bio-availability [53]. It also hinders the activity of enzymes and form complex with amino acids such as arginine, histidine and lysine and reduces protein solubility [54]. Phytic acid is consider as most effective anti-nutrient which leads to mineral deficiencies due to its property of forming chelating complex with micro-nutrients [50]. Millets such as finger millet, proso millet, foxtail millet and pearl millet contains phytic acids, oxalates, polyphenols and tannin anti-nutrients [55]. Finger millet consists of 0.48 gm and foxtail consists of 0.66 gm of phytic acid per 100gm [56]. Other millets such as little millet, kodo millet, pearl millet, barnyard millet and proso millet contains 8.4, 1.2-1.4, 8.33, 3.30-3.70 and 9.2 mg/g of phytic content respectively (Table 3). Excessive intake of phytic rich diet leads to deficiencies of calcium, iron, zinc and magnesium by reducing their absorption [57,58]. However, phytate intake has anti-cancer, anti -diabetes, anti- atherosclerosis and cardiovascular disease [59]. Various clinical studies support the anti- cancer effect of phytate present in millets such as finger millet and foxtail millets and their implications in prevention of breast cancer [22]. Barnyard millet contains lower amount of phytic and higher quantity of polyphenols, tannins and ortho-dihydroxy phenol secondary compounds as compare to finger millet [60].

2.5. Phenolic compounds

Plant phenols are mainly present in the pericarp, hull, aleurone layer and endosperm of the grain [61]. They are divided into different categories bases on their carbon structure such as phenolic acid, flavonoids, and stilbenes and lignins. Polyphenols are secondary metabolites that protect the plant from various types of stress. Polyphenol present in plants have antinutritional and health promoting properties. They are mainly present in whole grains, pulses, lentils, red kidney and black beans. Phenolic compounds affect the bioavailability of proteins and vitamins such as thiamine. The gossypol phenol is mainly present in cottonseed, affect the absorption of minerals and protein. The presence of bound gossypol in the diet result in hinder absorption of iron and lysine which may also leads to iron and lysine deficiency [52]. Some polyphenols act as antioxidants such as ferulic acid, vanillic and caffeic acid which scavenge the free radicals. The ferulic acid is present in aleurone layer of the grains and helps to reduce low density lipoprotein by acting as antioxidant [62]. The phenolic compounds present in millets have antioxidant, anti-aging and anti-inflammatory properties. So, some phenolic compounds such as polyphenols, phytates and tannins act as antioxidant and plays role in prevention of aging. The seedcoat of finger millet contains phytochemicals which also have antioxidant, antimicrobial and anticancer properties. Kodo, foxtail, finger, little and pearl millets are rich in phenolic compounds and phytochemicals. Sorghum consists of polyphenols which act as anti-oxidants and help in prevention of various diseases [63]. Foxtail millets also contain antioxidant property due to presence of phenolic acid and carotenoids [34]. The bran fraction of brown finger millet contains good amount of polyphenol. Polyphenols present in the bran section of millets showed strong inhibition towards alpha glucosidase and pancreatic amylase which plays an important role in management of postprandial hyperglycemia [64]. Catechin and epicatechin are major flavonoids and ferulic acid is a major phenolic compound present in finger millet. The total phenolic, flavonoids and condensed tannin present in finger millet range from 114.43-179 mg ferulic acid (FAE/100g, 90.24 to 202.94 mg catechin equivalent (CE)/100 mg and 31.76 to 83.59 mg CE /100gm, respectively [65]. Germination of millets increases their phenolic content and antioxidant properties. Vanillic acid, ferulic acid and kaempferol are major phenolic compounds present in raw millets. Phenolic compounds present in millets are also natural inhibitors of alpha- amylase and alpha glucosidase [66]. The phytochemicals present in millets have antioxidant and antidiabetic properties. The total phenolic content of minor millets ranged from 53.28 to 110 mg GAE/g and flavonoids content was 23.80-65.1 mg QE/g of dried extract [67]. It was observed in various studies that phenolic compounds present in millets have inhibitory effects of alpha-amylase and alpha glycosidase along with antioxidant properties [64,66]. A study on foxtail and little millet found that quercetin is most abundant flavonoid and caffeic, ferulic and Sinopic acids were mainly present in soluble fractions. Moreover, addition of millets in functional foods may help in management of diabetes due to their inhibiting property towards alpha glucosidase and alpha amylase [68]

2.6. Enzyme Inhibitors

Enzyme inhibitors are naturally present in the plants. Protease and trypsin inhibitors inhibit the digestion of proteins and minerals by acting as barrier in the activity of enzymes like trypsin, chymotrypsin and other enzymes by blocking the active site of the enzymes. The lipoxygenase inhibits the absorption of vitamin A and tocopherol oxidase affect absorption of vitamin E present mainly in raw soybeans and other plants [62]. Trypsin inhibitors inhibit protein digestion and amylase inhibitors digestion of carbohydrates. Soybeans are rich source of trypsin inhibitors. Protease inhibitors inhibit the activity of protease enzymes in the gastrointestinal tract of the body. Excessive presence of protease inhibitor is related to growth inhibition and pancreatic hypertrophy [69]. Protease enzymes form complex in intestinal chyme and hinder digestion. The bifunctional inhibitors present in ragi form a complex with trypsin and amylase leading to hindrance in protein and starch degradation [70]. The enzyme inhibitors such as protease inhibitors, amylase inhibitors, are mainly present in legumes than cereals and result in decreased bioavailability of minerals as well as digestion and absorption of nutrients [71,72].

2.7. Oxalate

Calcium oxalate is a salt form of oxalic acid, forms a strong bond with minerals such as calcium, magnesium, potassium and sodium. Oxalate forms insoluble complex with calcium. However, oxalate salt formed with sodium and potassium are soluble. The complex formed with calcium may solidify in the kidney or in urinary tract leads to formation of calcium oxalate crystals. The presence of excessive quantity of oxalate in the food may leads to nutrients deficiency [69]. Finger millet contains 29mg/100gm and foxtail millet contains 27 gm/100gm of oxalates [56]. Vegetarian diet contains higher oxalate content which may negative impact the availability of calcium. Soaking and cooking reduces the oxalate content of food by leaching.

2.8. Tannin

Tannin is a polyphenolic compound which is astringent and bitter in taste. The molecular weight of tannin ranges from 500 to 3000. Tannin binds with the proteins by forming a complex with its carbonyl group and decrease the absorption of essential amino acids [73]. Tannin also binds with digestive enzyme, results in hindering their action. They also affect the absorption of vitamin $B_{12,}$ and glucose. They inhibit the intestinal absorption of glucose and methionine [62]. They also inhibit the activities of trypsin, amylase and lipase and interfere with absorption of iron [69]. They are present in beverages, berry fruits, cocoa beans, sorghum and barley [74,75]. Kodo millet consists of 1-1.2 mg/g and pearl millet contains 0.88 mg/g of tannin (Table 3). The excessive tannin in the body leads to reduction in growth and decrease in protein absorption. Lectins are another antinutrient compounds present in cereals in glycoprotein form and cause nutrients malabsorption. Consumption of higher amount of these antinutrients result in impairs digestion of amino acids and micronutrients and then micronutrients deficiencies. However, minor millet contains antioxidants compounds such as phenolic acids, flavonoids, phytochemicals, tannins, Xylo-oligosaccharides, insoluble fibers, protein and peptides, carotenoids and vitamin mainly present in bran section of grain. Germination, fermentation and malting also increase these compounds in millets [47].

2.9. Reducing strategies

The anti-nutritional factors which hinder the acceptability of millet at consumer level can be reduced by using various processing methods such as milling, decortication, heating, soaking, popping, cooking, germination and fermentation. The enzymatic inhibitors can be inactivated by germination which also enhance the nutritional composition and antioxidant properties of millets. Various studies support the positive impact of these antinutritional reducing strategies on nutritional components [81].

2.10. Germination

Germination is the process that begins with the uptake of water by a quiescent dry seed (imbibition) and ends with the emergence of the radicle (embryonic root) through the seed coat. It includes the imbibition, activation of metabolism and radicle emergence stages. Germination is a natural method to increase the bioavailability of nutrients, enhanced vitamin and mineral absorption and increased antioxidant activity. It reduces the phytates, tannins, oxalates and reduces the activity of trypsin inhibitors. Germination of finger millet and pearl millet increased the bio accessibility of mineral and reduces the antinutrients components such as phytic acid and tannins [82,83]. foxtail millet was germinated at 24°C for 4 days and results showed the reduction in total phytic, tannin and saponin content from 6.4 to 2.6mg/g and 0.33 to 0.02 and 0.39 to 0.07 respectively and increase in flavonoids and phenolic acids was observed [84]. Germination leads to phytate degradation and results in decrease in phytate content. Germination reduces the 40% of phytic acid content of millet grain due to activity of phytase enzyme [85]. The germination of pearl millet for 24 hours at 30°C temperature result in reduction of phytate content by 50% due to activity of phytase enzyme which hydrolyzes the phytic acid [86,87]. So, germination of seeds leads to significant reduction in antinutritional components and polyphenols by causing biochemicals changes in grains and enhances the protein digestibility and micronutrients absorption. Germination of foxtail millet at 25°C Temperature with 15.84 min soaking time increased the nutritional profile of millet such as high protein (14.32g/100gm), dietary fiber (27.42 g/100gm) and micronutrients compared to ungerminated foxtail millet flour [88]. Germination of foxtail millet also enhanced the polyphenol profile and total antioxidants activity due to increase in phenolic, flavonoids and GABA content [89]. Germination for 60 hours significantly increased the protein content in proso millet from 12.10-12.80 g/100g and 9.45-9.90 g/100gm in barnyard millet and reduced the 65% oxalic acid, 55% phytic acid and 65% tannins content. It also increases the antioxidant activity from 80.5% to 98.1 % and 79% to 97.2% in barnyard and proso millet respectively [91].

2.11. Fermentation

Fermentation is traditional preservation technique which significantly reduces the antinutrients compounds and enhances the antioxidants activity of millets. Significant reduction in phytate and tannin content was observed as impact of fermentation in case of pearl millet [42,92]. The combination of germination and lactic fermentation of sorghum result in complete degradation of phytate [93]. lactic acid fermentation is cheap method which result in significant reduction in antinutrients compounds. Fermentation for 0 to 48 hour of foxtail millet using lactic acid bacteria (LAB) reduces phytic acid content from 5.33 to 1.78 mg/g, tannins from 2.7 to 0.85 mg/g and increase in total phenolic content from 7.4 to 9.06 mg GAE /g and antioxidants activity from 42.5 to 77.3 % as increase in fermentation time [94]. Fermentation of finger millet flour at an interval of 12,24, and 36 hours significantly reduces the phytic and tannin content and enhanced the nutritional and antioxidant capacity of flour [95]. It was combined treatment of malting for 3 days and fermentation for 2 days significantly reduces the antinutritional compounds present in sorghum and millet and enhances the protein digestibility [96]. Fermentation by *Lactobacillus paracasei Fn032* enhanced the protein digestibility antimicrobial and antioxidants activity of foxtail millet flour [97]. During 24 hours fermentation of pearl millet significantly decrease in phytic acid trypsin and amylase inhibitor was observed but tannin content was increased [98]. Fermentation of pearl millet with *lactobacilli acidophilus* (LP) and *Rhodotorula*(R) at 30°C for 48 hours eliminated the phytic acid and amylase inhibitors and significantly increased the polyphenols content [99].

2.12. Soaking

Soaking is another technique by which antinutritional compounds can be reduced by degradation and leaching of phytates. The complete degradation of phytate is observed when malted cereals are soaked under optical conditions as phytate is water soluble compound. The degradation of phytate will depends on the PH and temperature condition. However, soaking also result losses in proteins, vitamins and minerals and ideal PH is 5.0- 6.0 and 45-65°C temperature for naturally present plant phytases during soaking [100]. Soaking result in reduction of phytate content by 4% in sorghum and 21% in maize by activation of polyphenol oxidase [101]. The soaking of finger millet seeds in water at 30, 40 and 50°C temperature and different time intervals (0, 6, 12,18 and 24 h) showed the increase in flavonoids and antioxidants activity and reduces the antinutrients content [102]. Soaking, germination and fermentation of raw proso millet flour for 12 h, 48 h and 20 h respectively result in reduction of tannin content from 73.4 to 26.5 mg TA/100gm, phytic acid 8.77 to 2.4 mg/g and saponins 167 to 29.1 mg/100g after all three treatment as soaking result in leaches of phytate, germination activates the phytate enzyme and enhanced polyphenol oxidase which reduces the tannin content [103].

2.13. Other methods

Decortication is removal of outer layer of the grains. As most of the antinutritional compounds are present in the pericarp section of the grains. So, dehulling significantly remove the antinutritional compounds present in the bran portion of grains and increase nutrients digestibility. However, dehulling and polishing also result in reduction of micronutrients present in bran section of grains which can be reduced by using various processing treatment such as microwave, Hydrothermal and high- pressure processing [104]. Decortication of pearl millet using stone dehuller(800-1200rpm) or abrasive dehuller reduces the tannin and phytic acid content in millets [105]. Dehulling of foxtail millet result in loss of dietary fiber and antinutritional compounds as they are mainly present in the husk and bran section of grain [39]. Popping is a High -Temperature Short Time (HTST) which result increase in size or volume of grains due to starch gelatinization and puffing is traditional cooking method used to prepare breakfast cereals. Popping of white finger millet at 170-200°C reduce the phytate content by 17.1% by inactivating the antinutrients and enhances the nutrients digestibility [106]. Roasting, frying, microwave heating, extrusion and high- temperature pressure treatment comes under thermal processing Technique [107]. Roasting is rapid thermal dry heat treatment for short time process enhances the antioxidant and phenolic content of millets and puffing and popping also reduces the antinutritional components present in millet. Similarly, flaking of barnyard millet reduces the antinutritional compounds present in it and increases the digestibility of carbohydrates and proteins and bioavailability of micronutrients [108].

However, traditional method such as germination, fermentation and soaking is time consuming process. The modern advance technique such as microwave, Ohmic Heating (OH), pulse light, infrared heating, and extrusion methods can be used to reduces the antinutritional compounds present in millets [109]. In addition, the appropriate use of processing technique will maximize the nutritional use of millets as combination of phytochemicals anti-antinutrients compounds and minimize the negative impact of millets consumption [81]. Reduction of phytic phosphorous content was observed in little millet, barnyard millet and kodo millet by 39%, 23% and 25% respectively after dehulling [110].

3. Conclusion

Millets are good alterative crop to major cereal due to its wide adaptability to harsh climate conditions. Millets are classified into major, minor and pseudo millets. In addition, millets are rich source of macro and micronutrients, phytochemicals and antioxidants. Because millets include a decent quantity of amino acids, dietary fiber, vitamins, minerals and antioxidants that help in prevention of malnutrition, diabetes, cardiovascular diseases and cancer. However, presence of antinutrients such as phytate, tannin, enzyme inhibitors and polyphenols hinder the acceptability and marketing of millets. If the antinutrients are present in excess amount in millets result in micronutrients deficiencies by forming complex with protein and minerals and reduces their bioavailability in the body. So, various methods such as germination and fermentation enhance the nutritional profile of millets and reduces the antinutritional components in the millets which will results in more consumer acceptability of millets.

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