Nutritional Properties of Millets: Nutricereals with Health Benefits to Reduce Lifestyle Diseases and Malnutrition

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Abstract

Millets are nutricereals embedded with lot of nutrients, minerals, and antioxidants grown the semiarid tropics of the world used for both human food, feed, fuel, and fodder. Nutricereals include sorghum (*Sorghum bicolor* [L.] Moench), pearl millet (*Pennisetum glaucum* [L.] R. Br), finger millet (*Eleusine coracana* [L.] Gaertn.), foxtail millet (*Setaria italica* [L.] Beauv.), kodo millet (*Paspalum scrobiculatum* L.), little millet (*Panicum sumatrense*), proso millet (*Panicum miliaceum* L.), and barnyard millet (*Echinochloa colona* [L.] Link and *Echinochloa crus-galli* [L.] P.B.). Database on nutritional and phytochemical constituents of nutricereals is not adequate, and research studies are required to create awareness among urban population. Millet grains were found promising for nutritive value and potential health benefits compared to major cereals such as wheat, rice, and maize. To increase consumption of millets, awareness about the availability of millet-processed food needs to be strengthened. Awareness about processing technologies which will improve nutrition as well as consumer acceptability is crucial to popularize millets. Food products like breakfast cereals, pasta, vermicelli, and bakery products such as cakes and cookies, which are consumer friendly, are ideal foods to popularize in urban areas. To convince the consumer, nutrient information of millets is also important for popularization of novel food products.

Keywords

Minerals · Antioxidants · Fermentation · Soaking · Malting · Fortification

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7.1 Nutritional Importance of Millets

To maintain human health, nutritious food is important. Food should have functional uses and health benefits to support disease-free life. Quality components of food in terms of nutrition play a major role in the maintenance of human health and fitness, thereby reducing malnutrition. Diversified millet food production is an important priority to increase consumption of millets and thereby millet yields to achieve nutritional security. Coarse cereal commodities like millets are not being used as human staple food due to lack of awareness among urban population. Presently, millets are often used for feeding livestock and birds. Nutritional and health-based functional qualities were reported in millets. These crops are less utilized because of the reasons like availability of grains in public distribution system, lower digestibility, taste, etc. Millets are improved with new recipes and awareness created for their increased nutrition to make them feasible in public distribution system and as a source of livelihood for resource-poor farmers.

Millets are important nutricereal crops being drought resistant, climate resilient, and pest and disease resistant grown in 4 months unlike rice and wheat, which are grown for 6 months. Due to these merit characters, millet grains are grown abundantly in countries like India, China, and some African countries to use as human food. In some countries, millets are also used for non-food uses like bioethanol and biofilms. Millets are enriched with major and minor nutrients. Millets are considered as high-energy nutritious cereals to combat malnutrition, feeding the rural population. Millet consumption can prevent and cure the diseases like obesity, diabetes, CVD, etc. Nutricereals are good alternative to celiac patients as a gluten-free food (Saleh et al. 2013).

7.2 Nuticereal Production

Nutricereals are major crops grown in Asian and African countries like India, Nigeria, and Niger, with 97% of the world's production. Millets are considered as important food staples in the human history. Nutricereals are cultivated since 10,000 years ago in East Asia. The world's largest production of nutricereals is from India. Though the annual production of millets increased in India, the consumption of nutricereals has fallen down from 50 to 75%. In India during 2005, a major portion of nutricereals produced are utilized as raw material for ethanol production and livestock feed. However, efforts are made by the Indian organizations to increase millet utilization toward human food and also increase consumer acceptability to achieve higher production.

7.3 Millet Utilization in India

Utilization of millets was higher for pearl millet and maize in Gujarat, finger millet in Karnataka, and jowar in Maharashtra and very low in Kerala, Orissa, West Bengal, and Tamil Nadu. Reports by the National Nutrition Monitoring Bureau (NNMB) showed that rice is the major cereal consumed. Major cereals are being consumed as staple by majority of the population, which comprises of 70–80% of the calories. The study on dietary profile of urban Indians (from the Chennai Urban Rural Epidemiology Study [CURES]) by the NNMB showed that millets contributed only 2% of the total calories (6.7 g/day).

7.4 Types of Millet

Nutricereals are different from each other physically and chemically. They also differ in plant, grain type, maturity, morphological features, etc. Millets are grouped as major millets and minor millets. Major millets are sorghum (*Sorghum bicolor* L. Moench), pearl millet (*Pennisetum glaucum*), and finger millet (*Eleusine coracana*), which are most widely used for human consumption. Minor millets include foxtail millet (*Setaria italica*), proso millet or white millet (*Panicum miliaceum*), barnyard millet (*Echinochloa* spp.), kodo millet (*Paspalum scrobiculatum*), little millet (*Panicum sumatrense*), guinea millet (*Brachiaria deflexa*), browntop millet *(Urochloa ramose*), teff (*Eragrostis tef*), fonio *(Digitaria exilis*), and Job's tears (*Coix lacryma-jobi*).

7.4.1 Sorghum

Sorghum (*Sorghum bicolor* [L.] Moench) is usually referred as jowar (great millet) and has the potential to grow in three seasons, kharif, rabi, and summer seasons. The crop is cold temperature sensitive but able to resist pests and pathogens. It is grown as a staple food crop in West Africa, Asia, and parts of Middle East. Sorghum is also produced in North and Central America, South America, and Oceania, which is used for livestock as per FAO (1995) reports (Fig. 7.1).

In 1981, the sorghum growing area in India earlier is approximately above 16 Mha but slowly reduced to 7.8 Mha in 2007–2008 (equal to 20% of the world's sorghum acreage). Of this, 3.5 million ha was grown in *kharif* season and 4.3 Mha in *rabi* season. Jowar production increased from 9 MT in the early 1970s to 12 MT in the early 1980s, and this for over a period of 10 years until the early 1990s declines to 7.3 MT. At present, average sorghum grain yields in India is 1170 kg/ha in the kharif season and 880 kg/ha in the rabi season.

7.4.1.1 Nutritional Composition

Whole sorghum's nutritional and biochemical quality is superior to rice, corn, and wheat. Sorghum grains have an energy value ranging 296.1 to 356.0 kcal. The

Fig. 7.1 Sorghum panicles and its grain

important biochemical components of sorghum are starch and non-starch carbohydrates apart from total proteins and fats.

7.4.1.1.1 Sorghum Starch

Starch, the major carbohydrate of sorghum, content and composition are affected by the genetic variability and growing environment of the grain. The variability for starch ranges from 32.1 to 72.5%. Starch is composed of amylose (3.5–19.0%) and amylopectin (81.0–96.5%).The amylose and amylopectin in sorghum influence the gelatinization, retrogradation, gelling, and digestibility.

As the association of starch with proteins and tannins is strong in sorghum, sorghum has the lowest starch digestibility among cereals. Sorghum starch can be classified into slowly digestible, which accounts for 30.0–66.2%; rapidly digestible, which accounts for 15.3–26.6%; and non-digestible, which accounts for 16.7–43.2%. Non-starch polysaccharides (6.0 to 15.0 g/100 g) comprise arabinoxylans, which include both soluble (10.0–25.0%) and insoluble fiber (75.0–90.0%).

7.4.1.1.2 Sorghum Proteins

Proteins in sorghum are two types. Major proteins are prolamins, which are contributing to 79% with a range of 77–82% out of the total proteins (7 to 15 g/ 100 g). The other proteins present include albumins, globulins, and glutelins. Prolamins are more popular as kafirins stored in the endoplasmic reticulum as spherical protein bodies, which include α-kafirins with a range of 66–84%, β-Kafirins with a range of 8–13%, and γ-kafirins with a range of 9–21%. The β- and γ-kafirins are present in the peripheral region of protein bodies, while α- and δ-kafirins are located inside. This structure determines the digestibility of sorghum proteins.

The amino acids present in the sorghum proteins include glutamic acid (highest) followed by proline, leucine, and alanine. Usually, kafirins contains less lysine, and it is the main limiting amino acid. The other 5 amino acids such as methionine, cysteine, isoleucine, valine, and threonine are also essential and are limiting in kafirins. With higher content of proteins other than kafirins, amino acid lysine also will increase in the grain endosperm.

Sorghum proteins express low protein digestibility after cooking compared to wheat and maize. Kafirins become resistant to peptidase because of intramolecular disulfide bonds formed, which makes them low digestible. Varieties rich in tannins express reduced protein digestibility up to 50%. Interaction of proteins with starch, non-starch polysaccharides, phytic acid, and lipids and arrangement of proteins inside the grain also cause low digestibility.

7.4.1.1.3 Lipids

As a coarse cereal, sorghum has low lipid content ranging from 1.24 to 3.07%. A major portion of lipids are unsaturated fatty acids (83–88%), while polyunsaturated fatty acids (PUFA) are higher than monounsaturated fatty acids (MUFA) in sorghum. Four major fatty acids are present in many genotypes, the highest content being linoleic (45.6–51.1%), followed with oleic (32.2–42.0%), and palmitic (12.4–16.0%) acid and the lowest fatty acid present being linolenic acid (1.4–2.8%).

7.4.1.1.4 Micronutrients

The micronutrients play a very important role in human nutrition. Micronutrients include minerals and vitamins. Phosphorus, potassium, and zinc are the major minerals present in sorghum. Little variability exists in mineral content as per place of cultivation. The available zinc ranges from 9.7 to 17.1%, while available iron content ranges from 6.6 to 15.7%. Saleh et al. (2013) reported that sorghum is a rich source of some B-complex vitamins (thiamine, riboflavin, and pyridoxine) and fat-soluble vitamins (D, E, and K).

7.4.1.1.5 Phenolic Group of Compounds and Their Bioavailability

The main phytochemical compounds are phenolic compounds, which are biologically active and present in all genotypes. All types of phenolic compounds are present in sorghum, the major being phenolic acids, tannins, and flavonoids (Aruna et al. 2020).

Phenolic Acids

In sorghum, mostly phenolic acids exist as hydroxybenzoic and hydroxycinnamic acid derivatives, which express high scavenging activity and are beneficial to promote health. In sorghum genotypes, which expressed high antioxidant activity, total phenolic acids range from 135.5 to 479.40 μg/g. Among them, protocatechuic acid ranged from 150.3 to 178.2 μg/g and ferulic acid ranged from 120.5 to 173.5 μg/g. Low amounts of the other phenolic acids are included like p-coumaric (41.9 to

71.9 μg/g), followed by syringic (15.7 to 17.5 μg/g), vanillic (15.4 to 23.4 μg/g), gallic (14.8 to 21.5 μg/g), caffeic (13.6 to 20.8 μg/g), cinnamic (9.8 to 15.0 μg/g), and *p*-hydroxybenzoic (6.1 to 16.4 μg/g) acids. They also may contribute to the health benefits of sorghum (Ranga et al. 2020).

Proanthocyanidins (Tannins)

In sorghum genotypes with pigmented testa, like any other plant species, tannins are present as secondary metabolites, which are being produced in abundance against pests and diseases. Tannins are present in sorghum, while they are absent in other cereals such as rice, wheat, and maize. Tannins usually are either extracted with methanol or acidic methanol. Sorghum tannins are mostly in condensed form and usually formed by polymerization of catechins or flavan-3-ols and/or flavan-3,4-diols with a higher molecular weight and polymerization (Awika and Rooney 2004).

Flavonoids

A larger part of flavonoids in sorghum are located in the grain pericarp. Depending on the amount of flavonoids present, pericarp color varies. The three categories of flavonoids are anthocyanins, flavones, and flavanones, which are present abundantly in sorghum. In sorghum, 79% of the flavonoids are 3-deoxyanthocyanidins, which are more stable. The other major flavonoids present in higher quantity in yellow pericarp sorghums are aglycone forms of eriodictyol, luteolin, apigenin, and naringenin ranging from 474 to 1780 μg/g. White sorghums contain the lowest amount of flavanones ranging from 0 to 386 μg/g.

Other Phenolic Compounds

Other phenolic compounds are stilbenes having beneficial effects on plant defense and human health, which are produced from the phenol metabolic pathway. In red sorghum, stilbenes are present in the form of trans-resveratrol and in white genotypes in the form of trans-piceid (0.1 mg/kg) in smaller quantity.

Policosanols and Phytosterols

Sorghum lipid fractions largely comprised of policosanols and phytosterols, which contribute to 33.4–44%. Policosanols that have physiological benefits are long-chained lipids extracted from the sorghum grain. Total policosanol content located in the pericarp of the grain in unpolished sorghum grain was 74.5 mg/100 g, while the content in the polished grain was reduced to 9.8 mg/100 g.

Compared to fruits, vegetables, and other cereal grains, sorghum grains are rich source of phytosterols ranging from 4.13 to 24.45 μg/g, and these are also influenced by growing conditions. Three sterols, namely, sitosterol (44.8 to 48.2%), campesterol (26.1 to 38.0%), and stigmasterol (17.3% to 25.6%), are found in vegetables present in sorghum.

Phytochemicals with Antinutritional Activity

The phytochemicals that have antinutritional activity identified in sorghum largely are phytates, protease inhibitors (trypsin, chymotrypsin, and amylase), and lectins.

The digestibility of proteins and carbohydrates and mineral bioavailability also are decreased with these phytochemicals.

7.4.1.2 Health Benefits

7.4.1.2.1 Oxidative Stress

Chronic and excessive production of free radicals and further development of noncommunicable diseases is prevented by sorghum isolates extracted. Usually phenolic compounds rich in the extracts from black or red sorghum express the functional benefits.

Sorghum phenolic compounds modulate the defense system against oxidative stress through regulation of phase II enzymes and convert them into non-toxic and excretable metabolites. Phase II enzymes are mostly sorghum 3-deoxyanthocyanidins and their profile.

7.4.1.2.2 Cancer

Sorghum phenolics like 3-deoxyanthocyanidins react with carcinogenic cells and increase the apoptosis and inhibit growth and metastasis of affected cancer cells. Sorghum 3-deoxyanthocyanidins exhibit increased cytotoxicity to cancer cells than the respective analogous anthocyanidins such as cyanidin and pelargonidin present in other foods. Sorghum flavones exhibit the estrogenic activity showing apoptosis of the colon cancer cells. Generally, cancers occur due to DNA damage through carcinogens that form reactive intermediates, reactive oxygen species (ROS), and reactive nitrogen species (RNS). The enzyme activity of the phase I (cytochrome P-450) and II removes carcinogens that are endogenous and environmental, thus showing prevention of cancer.

Studies have confirmed that tannins extracted from other foods affect regulatory enzymes, inducing apoptosis. Sorghum tannins also have anticancer activity, and they are known for cancer treatment. Bran extract rich in tannins isolated from sumac sorghum inhibited human aromatase (CYP19) activity in vitro. The inhibition is stronger than black sorghum bran extract rich in 3-deoxyanthocyanidins. This confirmed that the tannins observed in sumac sorghum are having higher inhibitory potential than the 3-deoxyanthocyanidins of black sorghum. Tannins showed inhibition and precipitation of aromatase, which is a key enzyme to the synthesis of estrogen. It is an important target for chemotherapy of breast cancer dependent on this hormone.

7.4.1.2.3 Obesity and Inflammation

Obesity is a lifestyle disorder that leads to many problems. Studies on sorghum rich in tannins showed reduction in weight gain in animals (rats, pigs, rabbits, and poultry). Studies showed that tannins from sorghum can naturally modify starch by interacting strongly with amylose, and a more resistant starch is produced, which is hard to be digested by the small intestine and thus reaches the large intestine, thus showing the functional food benefits of dietary fiber.

Sorghum tannins bind proteins having high proline compared to other proteins. Protein containing more proline units will attract more tannin than the one with lesser units of proline. The increased consumption of sorghum having high tannin may reduce the bioavailability of iron and zinc. Obesity is considered as a chronic low-grade inflammation. The role of fat leading to the development of obesity and its effects was assumed to be a passive one, and adipocytes were assumed to be little more than storage cells for fat. But the new concept derived is that adipocytes and obesity play an important role on inflammatory mediators that initiate this process.

7.4.1.2.4 Dyslipidemia

Dyslipidemia may lead to the risk of cardiovascular disease, and earlier studies (in vitro) observed that sorghum lipid and phenolic fractions influence to reduce parameters related to dyslipidemia. The presence of phytosterols, policosanols, and phenolic compounds and their action may modulate absorption, excretion, and synthesis of cholesterol.

Studies have shown that diet added with sorghum lipids reduced the hepatic and plasma cholesterol of normolipidemic hamsters. The phytosterols of sorghum lipids have the potential to inhibit the cholesterol absorption. It is also shown that phytosterols from other foods inhibited cholesterol absorption in humans, showing increased fecal excretion and reduction of plasma low-density lipoprotein (LDL) concentration. Sorghum lipids having bioactive compounds also reduce the amount of cholesterol present in the gut enterocytes leading to inhibition of its incorporation into micelles, thereby reducing cholesterol absorption.

7.4.1.2.5 Diabetes

Recent studies showed that extracts from sorghum regulate the glucose levels in animals due to the presence of the phenolic compounds. It is known from a clinical study conducted by IIMR in collaboration with the National Institute of Nutrition, Hyderabad, with diabetic patients for 90 days that sorghum consumption in the form of roti supplemented in lunch has decreased the glycosylated hemoglobin HbA_1c and also affected the glucose metabolism positively. Research experiments with mice also, with the intake of extracts of sorghum phenolic compounds, showed hypoglycemic effect and effect on plasma glucose and insulin. Animal studies have shown that sorghum phenolic extracts expressed a hypoglycemic effect similar to glibenclamida, an antidiabetic medication used in the control group.

Sorghum phenolic compounds affect metabolic pathways before and after absorption of carbohydrates and help in the prevention and treatment of glycemic disorders in humans. It was also indicated that phenolic extracts of sorghum express inhibition to the in vitro activity of the enzymes *Bacillus stearothermophilus* α-glucosidase and human pancreatic and salivary α-amylase. The first action mechanism of sorghum on human metabolism is through a decrease in the rate of glucose digestion through inhibition of enzymes.

7.4.1.2.6 Hypertension

In the literature, it is reported that sorghum can reduce blood pressure with the protein isolates of α-kafirins, which inhibit the activity of angiotensin I–converting enzyme.

7.4.1.2.7 Gut Microbiota

The human gut is populated by an array of bacterial species, which perform important metabolic and immune functions, with influence on the nutritional and health status of the host. The uses of sorghum phenolic compounds on human health may result in the action of the absorbed bioactive compounds and their metabolites that affect the microbiota environment.

A lot of investigations reported on health-promoting activities of dietary phenolic compounds; research efforts should be continued in relation to their effect on modulation of gut microbiota. Earlier research studies showed positive effects of phenolic compounds (tannins and anthocyanins) present in foods on gut microbiota increasing the probiotic species such as *Bifidobacterium* spp. and *Lactobacillus* spp. and lowering the harmful microbiota such as *Bacteroides* spp., *Clostridium* spp., *Propionibacterium* spp., *Salmonella typhimurium*, *Streptococcus mutans*, and *Escherichia coli*.

7.4.2 Bajra (Pearl Millet)

Bajra (pearl millet [*Pennisetum glaucum* (L.) R. Br.]) (Fig. 7.2) initially grown in the tropics of Asia, Africa, Central Africa, and India. It is known as bajra in Hindi and sajjalu in Telugu. For a long time, pearl millet has been an important cereal food grain and also as a fodder for livestock and stover crop in the arid and semiarid regions of many countries.

Fig. 7.2 Pearl millet panicles and its grain

7.4.2.1 Nutritive Value of Pearl Millet

In most Asian and African countries, pearl millet is recognized as an important cereal food crop and often supports with shortages of cereal food grains and the nutritional needs of consumers in rural and urban areas. It is a principal source of energy through carbohydrates and other nutrients in the everyday food of a major portion of low-income group consumers.

Bajra contains a fairly good amount of resistant starch, total dietary fiber including soluble and insoluble dietary fiber, minerals, and antioxidants. The chemical composition includes dry matter (92.5%), insoluble ash (2.1%), crude fiber (2.8%), fat (7.8%), protein (13.6%), and total carbohydrates (63.2%) (Patni and Agrawal 2017).

7.4.2.1.1 Calories

Bajra contains a fair amount of calories (361 Kcal/100 g) and is also equal to other staple commodities (wheat, rice, maize). Pearl millet starches have amylose content ranging 20–21.5% and have a higher swelling power and solubility than other millet starches. In this cereal varieties, the percent starch varies from 62.8 to 70.5%, and free soluble sugars such as glucose, fructose, sucrose and raffinose range from 1.2 to 2.6%.

7.4.2.1.2 Proteins

Like other millets, pearl millet grain is gluten free. Protein usually ranges from 9 to 13%. The essential amino acid profile in pearl millet protein is more than sorghum and maize. It contains more lysine (1.9–3.9 g/100 g), threonine, methionine, tryptophan, and cystine. This fair balance of amino acids includes essential amino acids. It has good protein digestibility showing that bajra is a superior cereal as human food. In bajra, essential amino acids (arginine, threonine, valine, isoleucine, and lysine) also had higher digestibility, and bajra is superior to other millet grains.

7.4.2.1.3 Lipids

The average total fat content in bajra grain varied from 1.5 to 6.8%, and it is the highest of all millets. About 75% of the fatty acids in bajra are unsaturated, and the fatty acids present in pearl millet are palmitic, stearic, linoleic, oleic, and linolenic acids, while the first three acids are in higher content and the latter two acids are in lower content. Due to the higher fat content, energy density of pearl millet grain is relatively high and linoleic acid is particularly high (46.3%).

7.4.2.2 Micronutrients

7.4.2.2.1 Minerals

The mineral content of pearl millet grain is determined by the environmental factors like composition and nature of soil. Like other millets, bajra is a rich source of minerals, containing fair amounts of calcium, phosphorus, magnesium, and iron, which are found in the pericarp, aleurone layer, and germ. Polishing grain lowers the important nutrients that are located in the pericarp.

7.4.2.2.2 Other Bioactive Compounds

Pearl millet has antinutrient components such as polyphenols, tannin, phytic acid and phytate, goitrogens, and oxalic acid. Polyphenols and tannin compounds are concentrated in the pericarp. Tannin levels and in vitro protein digestibility are negatively correlated. Polishing and removal of the pericarp decrease the amount of tannins in the grain with a corresponding increase in protein digestibility. Pearl millet contains phenolic compounds (glucosylvitexin, glucosyl, orientin, vitexin) because of which color changes from grey to yellow green at alkaline pH and grey to creamy white under acidic conditions.

7.4.3 Potential Health Benefits in Pearl Millet

Pearl millet is rich in nutritional composition and, hence, has several health-promoting abilities.

7.4.3.1 Malnutrition

Bajra has a high amount of iron approximately 8 mg/100 g and zinc 3.1 mg/100 g, which will contribute to increase the Hb levels. The presence of phytates and polyphenols may affect the iron availability. The use of domestic processes such as popping, germination, and fermentation may decrease phytates and polyphenols, and thus, the availability of iron and zinc may enhance.

7.4.3.2 Constipation

The high fiber content (12 g/100 g) of pearl millet is helpful in obesity and dealing with problem of constipation and can be extensively used to prepare healthy foods with high fiber diet for people.

7.4.3.3 Cancer

Pearl millet contains a higher content of phenolic compounds, which exhibit antioxidant activity, which has anticancer property. Pearl millet has phenols in the grain of 608.1 mg/100 g, while flour contains 761 mg/ 100 g. Phenolic compounds particularly flavonoids have been reported to inhibit tumor development. Phenols are concentrated in the pericarp and testa, and hence, products prepared from whole grain would provide the beneficial effects of the flavonoids and phenols.

7.4.3.4 Diabetes

Diet is considered as an important keypoint in the management of diabetes and other lifestyle disorders, more so in the case of type II diabetes in which the major reason is of glucose absorption, with additional complications of lipid and protein absorptions. Bajra has a very high amylase activity, tenfold higher to wheat. Maltose and D-ribose are being the predominant sugars in whole grain, while fructose and glucose levels are low. Bajra has the lowest glycemic index (GI) (55) as compared to varagu alone, diabetic medicine, and combined with whole and dehulled green gram, owar and ragi. Dietary management of diabetes involves the decrease of post-lunch blood sugar levels and good glycemic control by taking low glycemic foods. The glycemic index (GI) emerged as a dietary basis for designating starchy foods according to the blood glucose response they produce on ingestion. Foods with a low glycemic index are useful to maturity-onset diabetes, by improving metabolic control of blood pressure and plasma low-density lipoprotein cholesterol levels due to less pronounced insulin response.

7.4.3.5 Other Noncommunicable Diseases

Bajra has omega-3 fatty acids showing its potential in prevention and treatment of cardiovascular diseases, diabetes, arthritis, and certain types of cancer. Studies showed that certain omega-3 and omega-6 fatty acids are also converted into eicosanoids, which exhibit anti-inflammatory properties; however eicosanoids made from $n - 6$ fats are more anti-inflammatory. These are known to lower triglycerides in the blood and improve immune response and brain and eye function. They also help in infant development. Omega-3 fatty acids are not synthesized in mammals but have a limited ability to form the long-chain EPA (20-carbon atoms) and DHA (22-carbon atoms) with short-chain 18-carbon $n - 3$ fatty acid ALA. Pennisetins, the class of prolamins in pearl millet, differ from prolamin, zeins of maize and sorghum, respectively.

Chandrasekhara and Shahidi (2011) reported arika (kodo millet) phenolics had higher inhibition activities against oxidation of LDL cholesterol and liposome than that of bajra. They also reported that dehulled grains and hulls inhibited DNA scission, LDL cholesterol, liposome oxidation, and proliferation of HT-29 adenocarcinoma cells. Bound phenolic extracts showed bioactivity and release of these compounds in the colon upon microbial fermentation showed health benefits locally.

7.4.3.6 Allergies

Bajra is gluten free like other millets, and it is the only grain that retains its alkaline properties after being cooked. This is ideal for people with wheat allergies. Gluten-intolerant persons (celiac) are allergic to gliadin, a prolamin specific to wheat and some other common grains.

7.4.4 Finger Millet

Finger millet (*Eleusine coracana* [L.] Gaertn) also called as ragi is known as a calcium capsule. This is a small brown-colored grain looking similar to rai seeds. It is a major food crop in parts of Africa and Asia and Indian subcontinent. Ragi is like any other millets, a robust, tufted, tillering annual grass, nearly 170 cm high. Finger millets are like earhead with approximately 20 nos that resembles a fist when mature and, hence, are called as finger millet. It is known by a variety of names such as mandua in Hindi and ragulu in Telugu (Fig. 7.3).

Finger millet contains a good amount of protein (5–10.6%), starch (65–75%), dietary fiber (15–20%), and minerals (2.5–3.5%). It is rich in calcium among all cereals (344 mg/100 g). However, ragi also contains phytic acid (0.48%), phenolics

Fig. 7.3 Finger millet panicles and its grain

(0.07–0.15), tannins (0.61%), which are protease inhibitors, earlier considered as "antinutrients" because of metal binding and protease inhibition properties, but with the latest research studies and in view of health benefits with these nutrients, they are termed as neutraceuticals. The studies at IIMR reported that antioxidant activity or free radical scavenging capacity is 3.7–14.7%, while IC_{50} is in the range 83–97%. Finger millet genotypes are significantly rich in calcium (0.91 mg/g), phosphorous (5.46 mg/g), sodium (0.62 mg/g), potassium (9.82 mg/g), and magnesium (3.14 mg/g). Trace elements include Fe (547 mg/g), copper (12 mg/g), zinc (63 μg/g), manganese (μg/g), chromium (18 μg/g), molybdenum (10 μg/g), and selenium (1.5 μg/g) (Pasha et al. 2018).

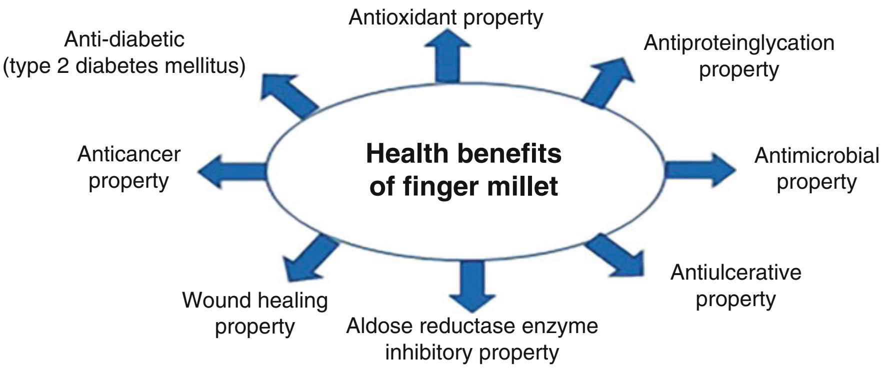
7.4.4.1 Phenolic Compounds

Finger millet is rich in bound and free phenolics. The major bound phenolic acids include ferulic acid and p-coumaric acid, accounting for 64–96% ferulic and 50–99% *p*-coumaric of millet grains, respectively. High-performance liquid chromatography (HPLC) fractionation studies of the polyphenols showed that they were derivatives of benzoic acid (gallic acid, protocatechuic acid, and *p*-hydroxybenzoic acid), cinnamic acid (*p*-coumaric acid, syringic acid, ferulic acid, and trans-cinnamic acid), and a flavonoid compound (quercetin). Benzoic acid derivatives accounted for about 85% of the total phenolic compounds. In addition to these phenolic compounds, direct infusion electrospray ionization mass spectrometry of the seed coat extract showed the presence of naringenin, kaempferol, luteolin glycoside, phloroglucinol, apigenin, (+)catechin/(−)-epicatechin, trans-feruloyl-malic acid, dimer of prodelphinidin (epigallocatechins, 2GC), daidzein, catechin gallates, and trimers and tetramers of catechin (Shobana et al. 2009).

Finger millet genotypes are also known to have proanthocyanidins, i.e., condensed tannins. Procyanidins are high-molecular-weight polyphenols that consist of polymerized flavan-3-ol and/or flavan-3,4-diol units. They are biologically active and, when present in sufficient quantities, may lower the nutritional value and biological availability of proteins and minerals. Among the millet varieties studied, finger (local) millet had the highest content (311.28 ± 3.0 μmol of catechin equivalent/g of defatted meal) followed by finger (ravi), foxtail, little, pearl, and proso millets.

7.4.4.2 Health Benefits

Polyphenols offer several health beneficial and antifungal activities, and the beneficial properties of phenols present in finger millets are outlined below (Devi et al. 2014):



7.4.4.2.1 Losing Weight

Tryptophan, an amino acid present in ragi, reduces appetite and helps to check obesity. *Ragi* also has slow digestibility and has a check on intake of calorie load. The total dietary fiber present in *ragi* gives a high satiety feeling, thus controlling excessive food consumption.

7.4.4.2.2 Bone Health

Calcium-rich *ragi* helps for the bone's strengthening as it is the natural source having the highest calcium for pregnant mothers, children, and geriatric population. Its intake supports for healthy growth of bones in pregnant mothers, children, and geriatric population. It reduces the problems related to the bones preventing fractures.

7.4.4.2.3 Antimicrobial Properties

Plant phenolics specially originated from millets are known to minimize the severity of many lifestyle disorders and prevent the spread of a wide spectrum of fungal pathogens. Grain phenolic compounds, tannins, of finger millet exhibit defense against fungal organisms. Polyphenols and tannins located in the pericarp offer resistance and create an obstacle to the fungal infection. The methanol (acidified) extracts prepared with grain pericarp exhibited high resistance to bacterial and fungal infections in comparison to the extract made from whole grain as the pericarp is rich in high polyphenols.

The major biochemical benefits of polyphenols include prevention of oxidation and cell components by the free radicals formed and irreversible complexation with nucleophilic amino acids, leading to inactivation of enzymes. Some of the mechanisms involved in the inhibitory effect of phenolic compounds include loss of their functionality and the interaction of phenolic compounds and formation of complexes with metals especially tannins with proteins and polysaccharides. During the entire process, they were made unavailable to microorganisms.

7.4.4.2.4 Glycemic Response

Diabetes is a lifestyle metabolic disease shown with hyperglycemia, due to insufficient release of insulin with metabolic changes in starch, protein, and fats. Research studies showed that hyperglycemia leads to glycosylation of proteins (non-enzymatic), resulting in increased problems in diabetes. Hence, regulating the increase in post-lunch blood glucose is critical for treatment of diabetes. The intake of diets with high fiber and complex slow digestible starches lowers acute cardiovascular problems. The finger millet diet is known as an example for this with high sustaining power and is usually recommended for diabetics. The phenolics are associated in partial inhibition of amylase and α-glucosidase during enzymatic hydrolysis of complex carbohydrates, which delay the absorption of glucose, thereby controlling the post-lunch blood glucose levels. Beneficial effect of dietary fiber is usually attributed to either slower gastric emptying or formation of unabsorbable complexes with available carbohydrates in the gut lumen, and these two properties might result in the delayed absorption of carbohydrates and in the reduction of absolute quantity absorbed.

7.4.4.2.5 Inhibition of Collagen Glycation and Crosslinking

Finger millet could have a potent therapeutic role as dietary supplements for the prevention of glycation-induced complications, which occur in diabetes or aging. The non-enzymatic glycosylation, which is referred as a chemical reaction between the aldehyde group of reducing sugars and the amino group of proteins, is a major factor for the complications of diabetes and aging. Increased oxidative stress and hyperglycemia contribute significantly to the accelerated accumulation of advanced glycation end products and the crosslinking of collagen in diabetic patients. Free radicals play a major role in non-enzymatic glycosylation of collagen and crosslinking whereas antioxidative conditions and free radical scavengers inhibit these reactions.

7.4.4.2.6 Wound Healing Process

Antioxidants in terms of phenolics present in all nutricereals prevent tissue damage and initiate healing of the wounds. The injured cells at the wound site show inflammation, which is a reaction to the wound and protective response toward healing process and process of tissue repair is initiated. The wound healing process is disturbed in diseased situations like hyperglycemia and age-related problems due to sudden shooting up of free radicals. This leads to cell damage, and the wound becomes a deeper wound. The antioxidants from millets intervene here and reduce the wound and allow it to heal.

The perfect wound healing process is interrupted in diseased conditions like diabetes and age-associated biochemical phenomenon due to an increased level of free radicals. Eventually, cell damage leads to necrosis and conversion of superficial wound into a deeper wound.

7.4.4.2.7 Earlier Research on Millets for Inhibition of Malt Amylases, Pancreatic Amylase, and Intestinal α-Glucosidase

Phenols and phenolic group of compounds are considered as inhibitors of digestive enzymes (amylase, glucosidase, pepsin, trypsin, and lipases) reported in literature extensively. These compounds inhibit amylase and glucosidase and reduce post-prandial glucose. Also association between phenolics and dietary fiber may lead to amylase inhibition and thereby have the potential to control type II diabetes mellitus. Phenolic acid such as trans-cinnamic acid showed more inhibitory activity up to 79.2%, while syringic acid exhibited lower inhibitory activity up to 56%. The phenolic compounds also modify proteins/enzymes and affect characters like molecular weight, solubility, and in vitro digestibility of biopolymers depending on the structure. The concentration and the number and position of hydroxyl groups of the phenolics affect the decrease in enzyme activity.

7.4.4.2.8 Inhibition of Aldose Reductase (AR)

Cataract occurs through the polyol pathway. Aldose reductase (AR) enzyme is very important in genesis of cataract. Cataract caused by diabetes is indicated by sorbitol accumulation with the action of aldose reductase (AR). AR-mediated sugar-induced cataract during diabetes is caused by the glycation (non-enzymatic), i.e., binding of glucose to protein molecule (Chethan et al. 2008).

The biochemical action of polyphenol inhibition on aldose reductase is assumed to be by replenishing the depletion of NADPH levels, inhibiting conversion of glyceraldehyde to glycerol and glucose to sorbitol in enzymatic mode. Specific phytochemicals such as phenolic acids in finger millet (gallic, protocatechuic, *p*-hydroxybenzoic, *p*-coumaric, vanillic, syringic, ferulic, and trans-cinnamic acids and the quercetin) were found to reduce cataract substantially.

7.4.5 Foxtail Millet

Foxtail millet (*Setaria italica* L.) is one of the world's oldest grown cereal, which is mostly grown in China, Japan, and India (Fig. 7.4). Foxtail millet is also popular as Italian or German or Siberian or Hungarian millet. It is known as kangni in Hindi and korralu in Telugu. This cereal stands the second producing 6 MT among the overall

Fig. 7.4 Foxtail millet panicle and its grain

world's total millet production feeding millions of people, grown on poor or marginal soils in continents of southern Europe and temperate, subtropical, and tropical Asia.

7.4.5.1 Nutritional Composition

The major nutritional constituents of this cereal are total carbohydrates, which include starch, total protein, total dietary fiber, fat, vitamins, and minerals. The biochemical composition of korralu (foxtail millet) imparts to its nutritional and sensory qualities like aroma and flavor.

The mean protein content varied from 113 to 129 mg/g, starch is in the range of 466–521 mg/g, amylose is 111–165 mg/g, and fat range is 36–39 mg/g. The total dietary fiber content is in the range of 173–208 mg/g, total phenols are 0.74–0.88 mg/g, and free radical scavenging activity is 13.3–20.6%. Mineral profile includes calcium (0.19–0.23 mg/g), phosphorous (4.1–7.15 mg/g), sodium (0.54–0.61 mg/g), potassium (5.43–9.2 mg/g), and magnesium (2–3.5 mg/g). Trace elements include iron (208–386 mg/g), copper (11–21 mg/g), zinc (70–80 mg/g), manganese (24–39 mg/g), chromium (12–18 mg/g), molybdenum (1–2.9 mg/g), and selenium (0.9–1.0 mg/g) (Longvah et al. 2017).

7.4.6 Kodo Millet

Kodo millet (*Paspalum scrobiculatum* L.) is also a traditionally cultivated millet mostly grown in Tamil Nadu, state in India. It is largely cultivated in damp habitats of tropical and subtropical places of the world (Fig. 7.5). This cereal is also known as kodon in Hindi and arikelu in Telugu. It is grown today in Uttar Pradesh in the North and Kerala and Tamil Nadu in the South in the Indian subcontinent.

Fig. 7.5 Kodo millet panicles and its grain

7.4.6.1 Nutritional Composition

The mean protein content varied from 78 to 103 mg/g, starch is in the range of 476–603 mg/g, amylose is 153–167 mg/g, and fat range is 25–32 mg/g. The total dietary fiber content is in the range of 318–331 mg/g, total phenols are 1.85–2.0 mg/g, and free radical scavenging activity is 6.6–7.4%. Mineral profile includes calcium (0.22–0.25 mg/g), phosphorous (3.45–4.73 mg/g), sodium (0.61–0.65 mg/g), potassium (4.23–6.40 mg/g), and magnesium (2.1–3.01 mg/g). Trace elements include iron (1082–1413 mg/g), copper (17–20 mg/g), zinc (59–76 mg/g), manganese (47–89 mg/g), chromium (20–42 mg/g), molybdenum (0.6–1.2 mg/g), and selenium (1.2 mg/g).

7.4.7 Proso Millet

Proso millet (*Panicum miliaceum* L.), also known as common millet, hog millet, broom corn, Russian corn, and brown corn, is an annual grass, growing from seed each year (Fig. 7.6). It is grown since 2000 BC in the central regions of Europe and also known as barre in Hindi and varigalu in Telugu.

7.4.7.1 Nutritional Value

The mean protein content varied from 106 to 122 mg/g, starch is in the range of 501–527 mg/g, amylose is 100–175 mg/g, and fat range is 33–35 mg/g. The total dietary fiber content is in the range of 219–243 mg/g, total phenols are 0.66–0.77 mg/g, and free radical scavenging activity is 19.9–21.5%. Mineral profile includes calcium (0.15–0.22 mg/g), phosphorous (4.26–5.54 mg/g), sodium (0.57–0.60 mg/g), potassium (4.41–5.32 mg/g), and magnesium (1.97–2.97 mg/g). Trace elements include iron (423–550 mg/ kg $^{-1}$), copper (14–18 mg/g), zinc (74–91 mg/g), manganese (21–45 mg/g), chromium (13–19 mg/g), molybdenum (1–1.4 mg/g), and selenium (1.1–1.2 mg/g).

Fig. 7.6 Proso millet panicles and its grain

Fig. 7.7 Barnyard millet panicles and its grain

7.4.8 Japanese Barnyard Millet

Japanese barnyard millet (*Echinochloa crus-galli* [L.] P. Beauvois) is a crop that can be used for various uses. This millet is also cultivated for human food and livestock fodder (Fig. 7.7). This cereal is also known as barnyard millet in English, jhangon in Hindi and udalu in Telugu. It is a rich source of protein and dietary fiber. The protein is highly digestible and fibre also is good in soluble and insoluble fractions.

7.4.8.1 Nutritional Value

The mean protein content varied from 101 to 126 mg/g, starch is in the range of 482–542 mg/g, amylose is 89–119 mg/g, and fat range is 36–39 mg/g. The total dietary fiber content is in the range of 242–261 mg/g, total phenols are 1–1.16 mg/g, and free radical scavenging activity is 13.2–16.2%. Mineral profile includes calcium (0.20–0.22 mg/g), phosphorous (5.33–6.17 mg/g), sodium (0.68–0.69 mg/g), potassium (7.34–7.92 mg/g), and magnesium (2.40–3.08 mg/g). Trace elements include iron (301–381 mg/g), copper (10–11 mg/g), zinc (76–103 mg/g), manganese

Fig. 7.8 Little millet panicles and its grain

(36–42 mg/g), chromium (19–22 mg/g), molybdenum (0.7–1.3 mg/g), and selenium (1.1–1.2 mg/g).

7.4.9 Little Millet

Little millet (*Panicum sumatrense*) is a traditional millet grown and consumed as rice at a larger scale in India (Fig. 7.8). It is also grown to some extent in altitudes of 2100 m. This cereal is also known as kutki in Hindi and samalu in telugu. The grains are of smaller size than those of other small millets.

7.4.9.1 Nutritional Composition

The mean protein content varied from 102 to 134 mg/g, starch is in the range of 420–521 mg/g, amylose is 119–125 mg/g, and fat range is 37–41 mg/g. The total dietary fiber content is in the range of 210–272 mg/g, total phenols are 0.95–1.18 mg/g, and free radical scavenging activity is 6–14%. Mineral profile includes calcium (0.19–0.24 mg/g), phosphorous (4.82–6.98 mg/g), sodium (0.50–0.72 mg/g), potassium (3.74–5.04 mg/g), and magnesium (2.33–3.44 mg/g). Trace elements include iron (457–515 mg/g), copper (9–12 mg/g), zinc (88–161 mg/g), manganese (26–33 mg/g), chromium (21–28 mg/g), molybdenum (1.3–1.9 mg/g), and selenium (1–1.3 mg/g).

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