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REVIEW ARTICLE

Potential of underutilized millets as Nutri-cereal: an overview

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Abstract In this current scenario with changing food habits, escalating population and unrestricted use of natural resources, there are lacking of resources to provide nutritious food to all. Natural plant resources are fast depleting and need to explore new alternatives. Besides the staple rice and wheat; lots of underutilized crops are being consumed that are having great potential to replace the staple crops. Millets are one of the major underutilized crops with a Nutri-cereal potential. Millets are highly nutritive, non-acid-forming, gluten-free and having dietary properties. Despite the fact that millets are highly nutritious, their consumption is still limited to the conventional and poor population due to lack of awareness towards its nutritional values. There is lack of processing technologies, lack of food subsidies and inconvenience in food preparations which makes millets more obsolete. Millets are Nutri-cereals and rich in carbohydrates, dietary fibres, energy, essential fatty acids, proteins, vitamin-B and minerals such as calcium, iron, magnesium, potassium and zinc, which helps to prevent from post-translational diseases like, diabetes, cancer, cardiovascular and celiac diseases, etc. Millets help in controlling blood pressure, blood sugar level and thyroid but inspite of these functional properties, millets consumption is still declining. Millets utilization in-combination with other staple food crops to develop food alternatives has become an emerging area for food industries. Besides, to strengthen our fight against malnutrition in children and adolescents, consumption of millets can help to foster immunity and health. Here, author's have reviewed the potential of millets for their Nutri-cereal qualities.

Keywords Millets · Nutri-cereals · Underutilized food · Anti-diabetic · Anti-cancerous food

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Introduction

Millets vary from one another by its grain type, appearances, maturity, and morphological features, etc. On the darker side, these are underutilized and neglected crops due to their lower cooking quality and lower preference determined by affluence, longer time and efforts involved in processing of the millets. If these problems could be resolved, their high nutritive value can make them even more valuable as food for farmers and a possible income source (Girish et al. 2014). Developments in productivity enhancement and processing of rice, wheat, maize, and some other dominant crops have led to the narrowing food habits which has made many other crops underutilized (Gupta et al. 2013). Underutilized millets are small-seeded,

widely grown, highly nutritive crops that can withstand in drought situations and require very little irrigation for production. Their growing season is short and typically thermo-tolerant, pest-free,and requires no extra fertilizer for growth. Biodiversity International (BI USA), National Academy of Sciences (NAS USA), and International Centre for Underutilized Crops (ICUC) have identified around 200 underutilized crop species for different socio-geographic and economic zones of the world out of which 29 are millet species (Gupta et al. 2013).

Millets are the indigenous crop that used as a staple food in many parts of the world and especially in India, China, and some parts of Africa. In India, there is an old Kannada proverb that means "A rice eater is always weightless like a bird; A jowar eater is strong like a wolf; A Ragi eater always remains disease-free". Both history and dietary patterns reveal that millets are the oldest food crop known to humans and have been cultivated for thousands of years. Possibly millets were the first known cereal to be used as food because, in the middle ages, Pauls and Romans were consuming millets as porridges in place of rice (Ambati and Sucharitha 2019). Millets play a significant role in the traditional diet of many states of India and its different varieties are consumed in many regions of India. In the current milieu, India is confronting both the pre and post progress stages and working in progressive manner and making every possible effort to get a developed country tag. Pre-progress issues are the common fundamental issues as lack of healthy sustenance and distinctive insufficiencies like Fe, Ca, and other nutrients while post progress issues are for example obesity, diabetes, cardiovascular disease etc. (Omram 2001). Several researches, reviews, and reports are demonstrating that India is in transition mode so confronting both the issues. Global hunger index (GHI) has given us extremely low merit while on the other hand, the rate of malnutrition, obesity, cardiovascular diseases are also escalating alarmingly (GH Index 2019).

As per the World Health Organization (WHO), malnutrition refers to deficiencies, over abundance, or irregularity in a person's intake of energy and nourishment (WHO and World Bank 2019). The pace of ailing healthy adolescents, youngsters, pregnant and lactating women is high in India. It influences the newborn kids in several ways including weak immune system, chronic illness, survival, proper organ formation, etc. The latest United Nations Children's Emergency Fund (UNICEF) report-2019 reveals that in India newborn's mortality rate is 8.8% and malnutrition caused 69% of deaths of kids underneath 5 years ago (UNICEF 2019). Besides; India has become a major country contributing to the growth of the diabetic population. Due to the continuous upsurge in diabetes patients, India is known as the diabetic capital of the world. Diabetes has manifold expanded the danger of kicking the bucket from respiratory failure contrasted with non-diabetic. Global Heart Initiative-WHO has indicated that over 80% of cardiovascular disease death occurs in low and middle pay nations (GH Initiative 2019).

Millets are the common small-seeded annual grasses or cereals belongs to the family *Poaceae* native to Ethiopia and successfully adopted by the India, China, Australia, Africa, and some regions of the United States of America (U.S.A.). Millets are resistant to diseases and can grow without any pesticide use (Thakur and Tiwari 2019). Millets do not require fumigants and some millets like; foxtail millets acts as an anti-pest in the similar storage conditions of rice and pulses. Millets are the stress-tolerant grains that can grow in low-quality soil or with less nutritional requirements, tolerant to temperature fluctuations, and having a unique short growth season (Malathi et al. 2016). These can grow in either waterlogged or moist areas to drought regions and can grow in arid and semi-arid regions (Michaelraj and Shanmugam 2013). Major millet crops of India are pearl millet, proso millet, foxtail millet, and finger millet while various other millet varieties as quinoa, kodo millet, barnyard millet, and little millet are also in use. In their cultivating area millets provide most of the energy and protein requirement to the population. Millets contain a very high amount of dietary carbohydrates 60–70%, dietary fibers 10–12%, protein 6–9%, less amount of fat 1.5–5%, and a considerable amount of minerals 2–4% (Annor et al. 2017). In this review, the authors focused on the compounds and nutraceutical properties of millets and also emphasis on some flavonoids, phenols, and other therapeutically important compounds that make them Nutri-cereals.

Millets as Nutri-cereal: scope

Millets are highly nutritive food crops that contain a high amount of protein, dietary fibre, essential fatty acids, some minerals like potassium, zinc, magnesium, calcium, iron, vitamins mainly vitamin-B complex. Millets also help in combating many diseases like diabetes, cardiovascular disease, blood pressure, thyroid, celiac disease by maintaining the blood-pressure and sugar level (Ambati and Sucharitha 2019). Due to its high nutritional qualities, these are considered as Nutri-cereals. Indian Council of Agricultural Research and Indian Institute of Millets Research (ICAR-IIMR) has described Nutri-cereals as highly nutritious grains that contain a comparable amount of nutrients to staple food.

For restraining both of these pre and post progress problems, need to explore more for a quality alternative of staple food. India is wealthy in its food security. Other than

rice and wheat, several other millets and cereals are consumed as a food. India is driving underway of foxtail millet, barnyard millet, quinoa, pearl millet. All these food crops are wealthy in supplements anyway get outdated because of the withdrawal of our propensities towards rice and wheat. Millets allude to the gathering of exceptionally seeded little yearly grass which is profoundly lenient to dry spell and other extraordinary climate conditions. Millets are generally appropriated all through the tropic and subtropic parts of Asia and Africa in particular India, Nigeria, and Mali (Vinoth and Ravindhran 2017). Millets comprise similar measures of protein, nutrients, iron, calcium, fibre, high density lipoprotein (HDL), cancer prevention agents, and are without gluten and so on so otherwise called Nutrigrains (Michaelraj and Shanmugam 2013). So for strengthening efforts against food crisis, pre and post progress problems, for supporting and encouraging the farmers for producing millets and for agri-industries in millets utilization, the Government of India had announced the year 2018 as the national year for millets production and later forwarded a proposal to United Nations (U.N) to declare 2018 as "international year for millets".

The finger millet contains the highest amount of flavonoids. It is because the levels of flavonoids vary significantly between different millet varieties, particularly finger millet and pearl millet. In the red and brown pigmented millet species flavonoid level is higher due to the presence of anthocyanin flavonoid-type pigments. Literature shows that foxtail millet, pearl millet, and proso millet contain a higher amount of phenolic acids. However, a very high proportion of their phenolic acid content is insoluble as they are cell walls bound and may not be bioavailable. With regards to tannins (proanthocyanidins/procyanidins), it is considered that finger millet is probably the only millet that contains tannins in some of its brown varieties (Taylor et al. 2016). The structures of major millet phenolic compounds are shown in Fig. 1. Millets have some great advantages; Nutri-cereals in nature, wealthy in dietary fibre, likewise wealthy in small and large scale supplements, gluten-free, alkaline, best fortification agent (fortificant), intestinal friendly, wealthy in cell reinforcements, phenolic mixes, contain wellbeing advancing mixes, effectively edible, wealthy in the lecithin in sensory system fortify, helps in bringing down bad cholesterol like low density lipoprotein (LDL), very low density lipoprotein (VLDL), triglycerides, etc. It also reduces numerous malignant growths and cardiovascular disease (Rao et al. 2018).

Nutri-cereal

Pearl millet (*Pennisetum glaucum*)

Pearl millet is a widely grown indigenous millet commonly known as Bajra and cultivated in sandy soil with lesser irrigation requirement (Rao et al. 2018). Due to higher oil content (4–9%) pearl millet can easily be stored at low temperatures and moisture conditions (Jain and Bal 1997). These are rich in both the micro and macronutrients and its flour is consumed in various bakery and traditional food items. Its phytochemical constituents helps in lowering cholesterol levels and maintaining lipid profile. It contains substantial amount of folate, copper, zinc, iron, magnesium, calcium, vitamin B complex, and unsaturated fatty acids (Rao et al. 2018). It contains high folate makes it a biofortificant against the anemic population. The presence of magnesium can foster the treatment of migraines and also can reduce the respiratory problems in asthmatic patients (Ambati and Sucharitha 2019). Pearl millets also contain some phytonutrients such as apigenin, flavonoids, lignin, and myricetin that help in preventing breast cancer, cardiovascular disease and are anti-fungal and anti-ulcerative (Thakur and Tiwari 2019). It is reported that pearl millet also induces the hypoglycaemic effect and improves the lipidemic control in diabetic rats (Sukar et al. 2020).

Foxtail millet (*Setaria italica*)

Foxtail millet is the second highest grown millets in India commonly known as Kangni. These are generally cultivated in semi-arid areas and require less irrigation. Foxtail millets are antipest and contains a good amount of protein, dietary fibre, calcium, vitamins, iron, copper and also helps in increasing disease resistance capacity (Rao et al. 2018). It is non-acid-forming and non-glutinous, so easily digestible. It helps in steadily releasing sugars in the body without hindering body metabolism (Gupta et al. 2013). It contains catechin, quercetin, apigenin, kempherol that helps in combating diabetes, cardiovascular disease, maintaining dyslipidemia. Due to the magnesium content it is known as healthy heart food. It is anti-microbial, anti-tumorigenic and help in body detoxification (Thakur and Tiwari 2019). Lin et al. (2020) has demonstrated that foxtail millets shows the anti-ulcer response along with pervasive antioxidant effect and protect the gastric mucosa.

Barnyard millet (*Echinochloa* spp.)

Barnyard millet is the rapidly grown millet crop generally harvested within 6 weeks commonly known as Swank or Shyama (Singh et al. 2019). It is rich in protein, dietary

fibre and some of its soluble and insoluble fractions and low carbohydrate. It mainly contains 3 fatty acids; linoleic acid, palmitic acid, and oleic acid. Barnyard millet is very effective in reducing the blood sugar level and due to its gluten-free nature; it also prevents from celiac diseases (Rao et al. 2018). It contains anti-oxidative phenolic compounds, flavonoids, and serotonin derivatives, and shows very strong anti-oxidative activity (Watanabe 1999). Luteolin, N-(p-coumaroyl), serotonin, and tricin are its major compounds that are anti-cancerous, anti-rheumatic, and anti-diabetic (Thakur and Tiwari 2019).

Little millet (*Panicum miliar*)

Little millet is commonly known as Gajrao. It contains around 37–38% of dietary fibre and good amount of protein. It can be utilized for snacks, baby foods, processed foods, etc. (Rao et al. 2018). It contains apigenin that helps in combating diabetes, celiac disease, cardiovascular disease, high cholesterol level, and is anti-cancerous (Thakur and Tiwari 2019). These are also good for wheat intolerant people. Little millets are rich in phosphorous and iron and also carry a high amount of vitamin-B. Germinating little millets are the good sources of α-amylase with higher purity and specific yield (Usha et al. 2011). The soluble fraction of little millets contains around 80% of phenolic (caffic, ferulic and sinapic acids) and flavonoid (kaempferol and luteolin) contents (Pradeep and Sreerama 2018).

Finger millet (*Eleusine coracana*)

Finger millet is an annual, dry season crop that is adjusted to fairly reliable precipitation conditions. It contains considerable amount of protein, dietary fibres, essential amino acids, vitamin A, and vitamin-B (Rao et al. 2018). It also contains a high amount of calcium (10 times as compared to rice and wheat) and phosphorous and helps in controlling high blood cholesterol, constipation, and intestinal cancer (Michaelraj and Shanmugam 2013). It is considered as the best food for diabetic people and controls hyperglycemia and blood sugar levels (Rao et al. 2018). It also contains catechin, myricetin, epicatechin, tricin, epigallocatechin, luteolin, taxifolin, kempherol, vitexin, daidzein, gallocatechin, pyrocyanidin B1, apigenin and pyrocyanidin B2, all these are vital in diabetes and cardiovascular disease treatment. Finger millets are anti-microbial and anti-tumorigenic in nature (Thakur and Tiwari 2019). Banerjee et al. (2017) has reported the performance aspects of flavonoids and phenolic compounds against the inhibitory activity of pathogenic bacteria, such as *Bacillus cereus, Escherichia coli, Klebsiella pneumonia, Listeria monocytogenes, Proteus mirabilis, Pseudomonas aeruginosa, Serratia marcescens, Staphylococcus aureus, Streptococcus pyogenes,* and *Yersinia enterocolitica.* Another study has recommended that an instant health beverage powder supplement or an extract of finger millet can use to combat the calcium-deficient diseases. The study also reveals that this drink can compete with any sort of health drink available in the market (Tripathi et al. 2014).

Quinoa (*Chenopodium quinoa*)

Quinoa is considered as pseudo-cereal or pseudo-grain due to its high protein content. It can grow at an altitude of around 3500–4000 above mean sea level (MSL) in cold and high and climatic zones and used in cooking, baking, or as green fodder, animal feed, and pellets (Jacobsen 2003). It has gained huge attention from Asia, Europe, and the United States due to its higher minerals, protein, and vitamin composition. In India, quinoa cultivation is done in the high altitude area of the Indian Himalayan region (Bhargava et al. 2006). It contains flavonoids, polyphenols, and phytosterols with some possible nutraceutical properties. It contains high amount of protein, dietary fibre, minerals, and vitamins that help in combating diabetes, protein-energy malnutrition, celiac disease, maintaining dyslipidemia, cardiovascular disease, and intestinal health (Li et al. 2018). It is rich in iron, magnesium, copper, phosphorus, potassium, and zinc and also contains lysine and methionine amino acids which are lacking in cereals. Besides, quinoa is considered as an oil crop due to the high amount of available oil, omega-6 fatty acid, vitamin-E, and vitamin-B (James 2009).

Sorghum (*Sorghum vulgare*)

Sorghum is a traditional staple food for the dry land population of the world and commonly known as Jowar. Worldwide sorghum is the fifth highest produced crop and fourth in India. Its nutritional qualities are better than rice and it contains β-carotene, folic acid, fibre thiamine, and riboflavin (Rao et al. 2018). Sorghum is rich in condensed tannins, flavonoids, and phenolic acids. Its antioxidant and pigments level are competitive to vegetables and fruits. Sorghum is anti-carcinogenic and lowers oesophageal cancer (Dykes and Rooney 2006). It also contains protein, vitamins like vitamins B1, B2, and B9; some essential minerals like calcium, iron, potassium, phosphorus, sodium, and zinc; dietary fibre, etc. Sorghum is a highly nutritive and prosperous millet contains a high amount of nutritional value than rice or wheat and having nutraceutical properties that help in fighting both pre and post-transition problems such as, arthritis, heart-related cardiovascular diseases, less body weight, and body mass index (BMI), malnutrition, obesity, etc. (Chhikara et al. 2019).

Kodo millet (*Paspalum scrobiculatum*)

Kodo millet is drought resistant, pest resistant, thermophilic xerophytic plant that is native to subtropical and tropical regions of Africa that have become indigenous Indian millet as it has domesticated here around 3000 years ago (Singh et al. 2019). Kodo millet is commonly known as Kodra. Kodo millet has the highest dietary fibres concentration as compared to other millets and an ideal food for diabetic patients. It contains a high amount of protein, low-fat content, a considerable amount of vitamins like folic acid (B_9), niacin (B_3), pyridoxine (B_6), and some minerals like calcium, iron, magnesium, potassium, zinc, etc. Due to lack of gluten, it is used by the gluten or wheat intolerance people. Kodo millets also contain lecithin which is good for strengthening the nervous system. Consumption of kodo millet is good for post-menopausal women that are suffering from high cholesterol problems or dyslipidemia, high blood pressure, and heart-related diseases (Rao et al. 2018). Kodo millet can significantly decrease diabetes in rats caused by alloxan and can be used in rendering general debility, hemorrhages, hepatopathy, and inflammation (Jain et al. 2010). The stem of kodo millet's plant can be used as a poultice if suffering from beri-beri while the concentrate of kodo roots can be used as diuretic and galactagogue (Castillo et al. 2005).

Proso millet (*Panicum miliaceum*)

Proso millet is an ancient important crop of the human diet particularly in Asia, Australia, Europe, and the USA (Mustac et al. 2020). The common name of proso millet is Chena having shorter growing season (Singh et al. 2019). It contains high amount of calcium, dietary fibre, protein and is gluten-free. It is the most inexpensive source of manganese in contrast to other available nuts, spices, and cereals. It helps in lipid profile improvement and cholesterol reduction. Proso millets are good for bones and also help in combating cardiovascular diseases and breast cancer (Rao et al. 2018). Carotenoids extract of proso millet has very high cellular antioxidant activity as compared to fruits and vegetables. Proso millets have higher anti-proliferative activity against the human liver cancer cells but dose dependant. It contains around 65% of phenolic compounds and rich in some bioactive phytochemicals like caffeic acid, chlorogenic acid, ferulic acid, and syringic acid that all are beneficial for human health (Zhang et al. 2014). The protein concentrate of proso millet significantly increases the glycemic response and but decreases the insulin level in mice (Choi et al. 2005). Another similar study on diabetic rats has demonstrated the preventive nature of the protein concentrate of proso millet and stated that it directly affects the D-glucosamine induced liver injuries in rats (Ito et al. 2008).

Nutritional value of millets

Millets are a significant food source in dry and semi-parched parts of the world. They give protein, unsaturated fats, minerals, nutrients, dietary fibre, and polyphenols (Alaunyte et al. 2012) composition is given in Table 1.

Millets as Nutri-cereals: proven aspects

The Millet Network of India (MNI) has considered millets as Nutri-cereals rather than coarse cereals. Millets are rich in protein that helps in combating protein energy malnutrition (PEM), fibre that helps in combating, cardiovascular diseases, and digestion problems, gluten-free that helps in combating celiac disease. Phyto-nutrient compounds present in millets are shown in Fig 1. Millets also contain minerals, vitamins, and antioxidants that help in the detoxification of the human body. Millets require very less irrigation and their growing season is very short. They can withstand a wide range of temperature changes and can grow under hot and dry temperatures without any fertilizer supplementations. Barnyard millet is rich in antioxidants and helps in maintaining body temperature and lipid profile. Both Barnyard, and foxtail millet repairs body cells and prevent gall stones, breast cancer, and cardiovascular diseases (Lee et al. 2010; Xie et al. 2019; Kumar et al. 2020). A previous study by Lee et al. (2010) has confirmed that foxtail millet improved the cardiovascular health of hyperlipidemic rats by decreasing trigycerides level in plasma. Foxtail millet showing the anti-cancerous property also, previous research study concluded that foxtail millet derived phenolic extract strongly impede the MDA-MB-231 breast cancer cells proliferation in dose-dependent manner (Zhang and Liu 2015). High dietary fibre and magnesium also manage the blood sugar level and controls diabetes and dyslipidemia. A high concentration of calcium mineral helps in combating bone and weight loss problems. Like quinoa, non-acid generating foods that are easily digestible. Foxtail millet and quinoa both are rich in protein, fibre, minerals, vitamins, phytochemicals, tannins, polyphenols, and having high lysine and carotenoid content. Besides, both are having great qualities that can play enhancing functional as well as nutritional food security (Singh et al. 2019).

In 2006 a U.S. Patent was granted for the extraction methods of anti-obesity agents that are hydroxyproline or N-acyl derivatives of hydroxyproline from millets. This patent also covers all the aspects of separated

Table 1 Comparative nutritional and health promoting attributes of millets, rice and wheat

S.N	English Name	Scientific Name	Common Names	Phytonutrients	Health benefits	Protein (g/ 100 g)	Total fat (g/ 100 g)	Dietary fibre (g/ 100 g)	Carbohydrates (g/100 g)	States of production
1	Barnyard millet	*Echinochloa* spp.	Banti, Khira, Konidhan, Kutdirvali, Oodalu, Sanwa, Shyama, Swank	Luteolin, N-(p-coumaroyl), tricin, serotonin	Anti-diabetic, Anti-cancerous, Anti-rheumatic	6.20	2.20	-	65.55	Arunanchal Pradesh, Madhya Pradesh, Nagaland, Tamilnadu, Uttrakhand, Uttar Pradesh
2	Finger millet	*Eleusine coracana*	Ragi, Mandua, Keppai, Nagli, Nachni, Mandiya, Marwa	Apigenin, catechin, diadzein, epicatechin, epigallocatechin, gallocatehin, Kempherol, leuteolin, myricetin, pyrocyanidin B1, pyrocyanidin B2, quercetin, tricin, vitexin	Anti-tumerogenic effect, Anti-diabetic, Antioxidants, Antimicrobial	7.16	1.92	11.18	66.82	Andhra Pradesh, Karnataka, Maharashtra, Tamilnadu, Uttarakhand
3	Foxtail millet	*Setarica italic*	Kakon, Kangani, Kang, Kangni, Kangam, Kanghzu, Kaon, Navane, Rala, Tanai, Thena	Apigenin, catechin, kempherol, quercetin	Detoxification of body, Anti-tumerogenic effect, Curing infectious disease	12.30	4.30	-	60.09	Andhra Pradesh, Arunanchal Pradesh, Karnataka, Maharashtra, Rajasthan, Tamilnadu, Uttar Pradesh,
4	Kodo millet	*Paspalum Scrobiculatum*	Anika, Kodon, Kodra, Kodua, Harika, Varahu, Varaku	Apigenin, isovitexin, kempherol, leutolin, quercetin, vitexin	Anti-diabetic, Anti-cancerous, Anti-rheumatic	8.92	2.55	6.39	66.19	Chhatisgarh, Madhya Pradesh, Maharashtra, Tamilnadu, Uttar Pradesh
5	Little millet	*Panicum miliare*	Gajrao, Kuri, Kutki, Sama, Samalu, Sava, Suan, Swank	Apigenin	Anti-diabetic, Anti-cancerous, Anti-rheumatic	8.92	2.55	6.39	65.55	Chhatisgarh, Jharkhand, Karnataka, Madhya Pradesh, Tamilnadu
6	Pearl millet	*Pennisetum glaucum*	Bajra, Bajri, Cumbu, Sajja, Sajje	Apigenin, flavonoids, lignin, myricetin	Anti fungal, Anti-ulcerative, Prevent breast cancer and cardiac arrest	10.96	5.43	11.49	61.78	Gujrat, Haryana, Maharashtra, Rajasthan, Tamilnadu, Uttar Pradesh
7	Proso millet	*Panicum miliaceum*	Bachari, Baragu, Bari, Chena,Panivargu, Vari	Apigenin,myricetin, kempherol	Anti-diabetic, Anti-cancerous, Anti-rheumatic	12.50	1.10	-	70.04	Bihar, Maharashtra, Orrisa, Rajasthan, Tamilnadu

Table 1 continued

S.N	English Name	Scientific Name	Common Names	Phytonutrients	Health benefits	Protein (g/ 100 g)	Total fat (g/ 100 g)	Dietary fibre (g/ 100 g)	Carbohydrates (g/100 g)	States of production
8	Quinoa	*Cheno podium quinoa*	Quinoa	Lutein, zeaxanthin, β- carotene, flavonoids	Anti-cancerous Helps in constipation and celiac disease	13.11	5.50	14.66	53.65	Andhra Pradesh, Uttrakhand
9	Sorghum	*Sorgum bicolor*	Cholam, Jola, Jondhala, Jonna, Jowar, Juara, Rotla	Apigeninidin 5-glucoside,Luteolinidin,5-Methoxyluteolinidin,Luteoforol,Apigenin,Eriodictyol	Anti-diabetic Anti- cancerous Anti-tumor Helps in curing oxidative stress, Coronary heart diseases	9.97	1.73	10.22	67.68	Andhra Pradesh, Madhya Pradesh, Maharastra, Karnataka, Tamilnadu
10	Wheat	*Triticum* spp.	Anaaj, Ghehu	Lutein, zeaxanthin, β- carotene	Reduction in diabetes, Cardiovascular disease and forms of cancer (notably colo-rectal cancer)	11.8	1.5	11.2	71.2	Bihar, Gujrat, Haryana, Madhya Pradesh, Punjab, Rajasthan, Uttar Pradesh
11	Rice	*Oryza* spp.	Chawal	Lutein, zeaxanthin, β- carotene	Helps in curing dysentery, Cardiovascular disease, Alzheimer's	6.4	1	4.43	76.7	Andhra Pradesh, Assam, Bihar, Chattisgarh, Haryana, Orrisa, Tamilnadu, West Bengal

Source: Indian food composition tables, NIN-2017, Nutritive value of Indian Foods, NIN-2007),(Souci et al. 2000), (Thakur and Tiwari 2019), (Rao et al.2017), (Verma 2011),(Shewry and Hey 2015),(Gopalan et al. 1989), and www.farmer.gov.in)

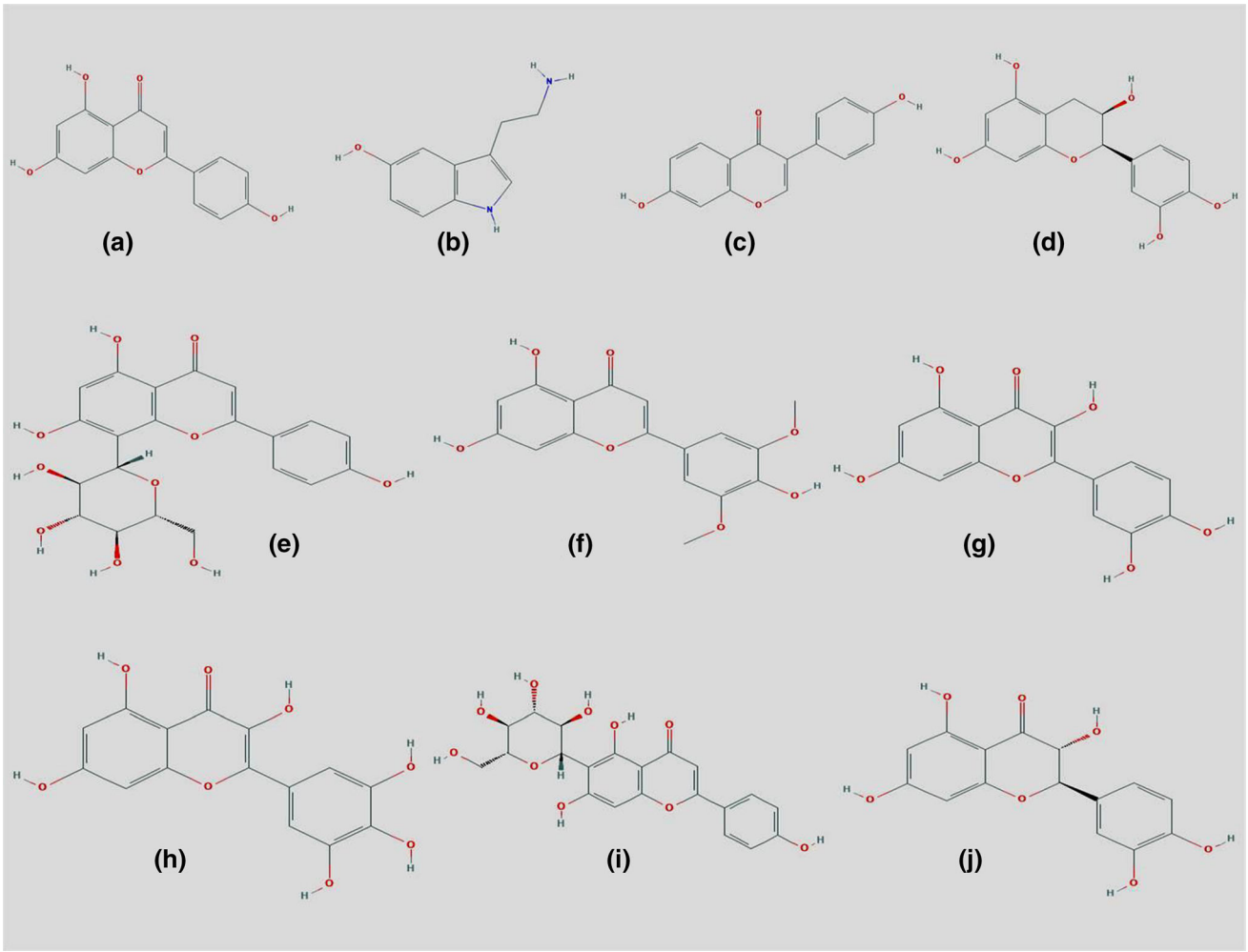

Fig. 1 Phyto-nutrient compounds present in millets; **a** Apigenin, **b** serotonin, **c** daidzein, **d** epicatechin, **e** vitexin, **f** tricin, **g** quercetin, **h** myricatechin, **i** isovitexin, **j** taxifolin. Source- https://pubchem.ncbi.nlm.nih.gov/

hydroxyproline or its N-acyl derivatives as a pharmaceutically active salt thereof or, food and drink additives, food and drinks, feeds, and feed additives for anti-obesity containing the same compound (Kamiya and Shirai 2006).

Ugare et al. (2014) has revealed that consumption of barnyard millets expressed food to draw out high satiation value and no food craving in between millet meals and manifest comfortable bowel movement that cured their problem of constipation. Millets reduce the triglycerides and regulate the blood sugar level better along with the diastolic, lipid, and systolic profiles of millet diet people. So, millet diet especially finger millet, foxtail millet, and sorghum is recommended for diabetic patients (Vedamanickam et al. 2020). Intake of foxtail millet improves the glycemic index, insulin, cholesterol, triglycerides, HDL, VLDL, and LDL. So it can be used by diabetic patients for managing their diabetes as well as dyslipidaemia (Jali et al. 2012). Foxtail millets increases the level of triglycerides for the betterment of atherosclerosis in type 2 diabetic kk-Ay mice (Choiet al. 2005). The β-glucan (βG) isolated from finger millet has better antibiofilm activity against *Enterococcus faecalis, Lysinibacillus fusiformis, Proteus vulgaris,* and *Shigella sonnei* at very less minimum inhibitory concentration (MIC) and βG is also an active inhibitor of α-amylase and α-glucosidase, so a proven antidiabetic agent. The minimum dose for biomedical applications is suggested 100 µg/ml for anti-diabetic, anti-bacterial, and anti-oxidant activities (Divya et al. 2020).

Foxtail and barnyard millet repairs the cells and tissues of the body, prevent gall stones formation, detoxify the immune system and prevent cardiovascular disease and breast cancer in pre-menopause (Gupta et al. 2013). Daily quinoa consumption tends to modify the response of glucose but has minimal effects on other cardiovascular disease risk biomarkers (Li et al. 2018).

Phenolic acid bound arabinoxylans (PA-AXs) from barnyard and foxtail millets dosage causes no toxicity in muramic macrophage cells while an increase in nitric oxide

(NO), reactive oxygen species (ROS), cytokine production, and better immune-stimulation. PA-AXs or purified PA-AX increases the immune-stimulatory action of millets (Srinivasan et al. 2020). Foxtail millet proteins and prolamine peptide (MPP) are also in use as an anti-inflammatory and anti-carcinogenic agent, while bound polyphenol of inner shell (BPIC) isolated from foxtail millet's bran are also a proven anti-tumor agent (Ji et al. 2020). Millets are anti-cancerous as Lunasin (unique 43 amino acid peptide chain) present in millets inhibits the histone acetyltransferases (HAT) which plays an important role in cancer development (Park et al. 2009). Finger millet polyphenols also inhibit the cataract genesis in humans by inhibiting its major cause aldolase reductase (Chethan et al. 2008). Finger millets seed coats are anti-teratogenic, anti-diabetic, hypocholesterolemic, hypoglycaemic, and nephroprotective in nature (Shobana et al. 2010).

Millets are the best agents for bio-fortification and its high iron content helps in combating anaemia. As a functional food-millets are cost-effective and rich in calcium that helps in combating the calcium malnutrition risk in children, pregnant women, and lactating women.

Millet starch hydrolysis

Millets contain about 55–60% of starch and about 20–32% amylase in normal millets whereas in finger, pearl, foxtail, proso millet it is less and ranges about 34–35%. It is reported that the glycemic index and amylase content of millets are inversely proportional to each other (Casey & Lorenz 1977). The architecture of millet starch also plays an important role in its hypoglycaemic effect. Polygonal, a couple of spherical starch granules, and some of the pores are present on millets. The existence of these pores on starch eases the arrival of the starch hydrolysis enzyme. Finger millet lacks the pores and having the least enzymatic activity (Kaur et al. 2007).

Effect of lipid on millet starch hydrolysis

Millets contain various essential fatty acids i.e. linoleic acid, palmitic acid, lauric acid, oleic acid and starch and their complexion describes the effectual reduction in starch hydrolysis rate (Kawai et al. 2012). Millet starch hydrolysis decreases when cooked with lipids (Annor et al. 2017).

Effect of protein on millet starch hydrolysis

The impact of protein on starch hydrolysis rate is related more to their capacity to form physical obstruction between starch and their degrading enzyme. Protein like globulin, albumin, glutenins surrounds starch granules that act as hurdles to amylase. In millets the glycemic index decreases due to the starch and protein cooperation (Hamaker and Bugusu 2003).

In-vitro protein digestibility (IVPD) in millets

Plant protein (cereal, grains, legumes) are less digestible in comparison to the animal proteins, this may due to many factors like inhibition of digestive enzymes by tannins, protease inhibitors, organization of protein, the low solubility of the protein, lower enzyme unavailability due to the cell wall or seed coat (Becker and Yu 2013). However, the significant increase in IVPD occurs when soaking and dehulling is performed before cooking. IVPD of untreated millet is less than the treated millets after dehulling, soaking, and cooking. While soaking also changes the IVPD of millets significantly (Pawar and Machewad 2006).

Anti-cancerous effect of millet

Millets contain antioxidants, β-glucans, phytosterols, and lignins that help in preventing colorectal, breast, prostate, and many other types of cancers. Dietary sitosterol (SIT) in millets might protect against colon cancer that is induced chemically. SIT causes a significant reduction of tumors in rats (Awad et al. 1996). Lignins are anti-cancerous and induce the growth of bifidobacteria by forming short fatty acid chains of propionate, acetate, and butyrate. Butyrate acts on secondary chemoprevention by reducing the growth of cancerous lesion cells and by inhibiting malignant tumor formation (Chen et al. 1993).

Effect of millets on cardiovascular disease

Millets contain antioxidant properties that help in managing dyslipidemia hence lower the risk of coronary heart disease. Presence of fiber mainly dietary fiber, β-glucans, policosanols, phytosterols possess anti-cholesterolemic properties whereas the presence of apigenin, flavonoids possess antioxidants properties (Kaur et al. 2012).

Anti-tumorigenic effect against chronic myeloid leukemia k562 (CML) in finger millet

CML is an uncontrolled growth of myeloid cells in the bone marrow. Finger millet as Nutri-cereal helps in curing many infectious diseases. Finger millet seed extract having anti-proliferative activities on CML k562 due to the presence of a bifunctional complex of alpha-amylase trypsin inhibitor i.e. RBI (ragi bifunctional inhibition), that helps in inhibiting trypsin and alpha-amylase simultaneously (Chandra et al. 2016).

Strategies to increase bioavailability of millet compounds

Germination, hydrolysisenzyme, induces biochemical change, the formation of new components, and modification in structure may increase the nutritive value of grains (Annor et al. 2017). Finger millet germination causes progressive increase in sugar and decrease in starch and some antinutrients like phytate and tannins. Prolonged germination of 96 h increases the protein and IVPD significantly (Mwikya et al. 2000).

Fermentation is also one of the processes that increase the bioavailability of the millets and studies have demonstrated that in vitro protein digestibility (IVPD), nutritive value, and protein availability also increases after fermentation. Fermentation and germination of sorghum millet enhance the nutritional profile and also causes significant changes in anti-nutritional factors and their chemical composition (Chavan et al. 1989). Hassan and his colleagues have demonstrated that germinated millets show an increase in protein and protein digestibility in comparison to the soaked, coarsely grinded, dry heated, debranned millets. The study also implicated that fermentation of the germinated and coarsely grinded millets also greatly increases the protein and its digestibility (Hassan et al. 2006).

Millet based functional foods

The food industry is developing new products and due to consumer's awareness, the demand for cereal-based wholegrain foods is increasing which is causing the incorporation of underutilized crops in food products and giving a healthier alternative of staple food (Alaunyte et al. 2012). Several researches have reported that the use of millets as functional food or a bio-fortificant is increasing the effectiveness and efficacy of the food. With the escalating demand for gluten-free grains, millets are expeditiously gaining popularity. Food technologists and researchers have developed a lot of gluten-free functional food including noodles, pasta, various cookies, extrudate, injera, sourdough bread, non-sourdough bread, and fat replacer, etc. that are in use for gluten intolerant people (Mancebo et al. 2015).

Omoba et al. (2015) has developed biscuits as a ready to eat food supplements for school going children by using sorghum, pearl millet, and soya. This study also reveals that two biscuits per day can contribute to an average 13% of total dietary reference intake of fibre among 4–8 years aged child whereas can contribute around 11, 16, and 8% of Fe, Mg, and Zn respectively. The shelf-life, nutritional and sensory qualities of millet fortified biscuits was also found good (Mancebo et al. 2015; Anju and Sarita. 2010). Multi millet cookies also reduce the blood sugar level in albino rats and also show hypoglycaemic effect (Subbulakshmi et al. 2017).

Noodle is one of the major fast food consumed around the world. Millet blend composite flour made noodles shows a very less glycemic index but it requires longer cooking time as compared to branded noodles (Vijayakumar et al. 2010). Similar researches with improved methods and enhanced sensory, dietary, and nutritious parameters are also reported (Collar, 2016). Gluten-free bread with millets bran can be a key factor in this research because comparatively higher phenolic content (117%) and dietary fibre (76%) have been reported by using a little concentration of proso millet's bran. However, it's sensory and other nutritional aspects aren't tested (Mustac et al. 2020). Use of amaranth, quinoa, buckwheat, teff, and rye as a bread material is also tested and high phenol, dietary fibres, non-glutenious and spongy bread with 70% acceptability has been achieved (Collar and Angioloni 2014).

Pearl millet flour pasta possesses very low cooking loss, ash content and high protein, iron, zinc, texture, and color along with satisfactory acceptance in terms of hardness, chewiness, cohesiveness, gumminess, and springiness (Jalgaonkar and Jha 2016). By utilizing the composite finger and pearl millet flour, fortification of functional foods with underutilized millets can increase the protein, carbohydrate, fat, and other nutritional aspects of food (Gull et al. 2015). Gluten-free tagliatelle (variety of pasta) is also developed by the teff flour and very low glycemic Index (GI) has been achieved for celiac disease patients (Giuberti et al. 2016).

Millets are soothing, easily digestible, and support the health of gut microflora which make it comparable to prebiotics (Banerjee et al. 2017). Many researchers have studied the pro and pre-biotic aspects of millets and successfully suggested that utilization of millets as a prebiotic is acceptable and beneficial (Kunchala et al. 2016).

Similarly, a high quality (calcium and protein-rich around 96.5 and 12.25% respectively) and nutritious beverage powder supplement made for anemic, lactating, pregnant ladies, or people during menopause are using it (Tripathi et al. 2014).

Strategies for enhancing the millet production

1. Introducing millets in ready to cook food for diabetes, gluten intolerance, cardiovascular patients (Jalgaonkar and Jha 2016).
2. Introducing millets along with rice, wheat, pulses in public distribution system (PDS) so that everyone can get benefits from millets.
3. Introducing millets in making nutri-bar, biscuits, and bread rich in protein, calcium, iron, and many micronutrients (Mustac et al. 2020; Anju and Sarita 2010).
4. By increasing the shelf -life of millets and also enhances the post-harvest management (Gupta et al. 2013).
5. Introducing in the probiotics industry as millets are intestinal friendly that also supports healthy microflora of the gut (Thakur and Tiwari 2019; Kunchala et al. 2016).

Conclusion

Underutilized millets are Nutri-cereals and must be implemented in the developing countries like India due to their high nutritional qualities, wealthy dietary fibre concentration and likewise effective in small as well as large scale supplements and best agent for fortification. Millets are nutrients rich and contain iron, calcium, manganese, magnesium, zinc, potassium, and phosphorus. Millets are gluten-free, alkaline in nature, soothing, and intestinal friendly so gluten/wheat intolerants and constipation patients can consume them. Its cells and tissue maintenance actions are effective in inflammations. Millets contain tannins, phenolic mixes, flavonoids, and other important amino and fatty acids. These are effectively edible and rich in β-carotenoids and lecithin so functional food can be prepared as pasta, noodles, biscuits multigrain floor, etc., these help in keeping down the cholesterol like LDL, VLDL, triglycerides, etc., to safeguard us from hypertension. Millets also decrease the chances of getting numerous malignant growths and cardiovascular disease. All the aforementioned nutrients provide energy to body for the growth, maintenance, reproduction, and for performing all the body functions. Millets as high-energy nutritious food if utilized properly can combat malnutrition, obesity, diabetes, cardiovascular disease, protein-energy malnutrition, celiac disease, etc., as free from gluten. Millet is a yield with dry season safe characteristics, simple to process; it contains a high measure of lecithin and is magnificent for reinforcing the sensory system. Millets are plentiful in vitamins; and contains vitamins A, B, D, and E, particularly (B3) niacin, B6, and B9, just as the minerals; calcium, iron, and many other minerals. Proper millet utilization can help us easily to overcome many pre and post-transition diseases and can create a healthy and disease-free environment in our country. However, bio-fortification and development of some functional foods (biscuits, slices of bread, pasta, noodles, beverage powder etc.) can also be a potential alternative.

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Compliance with ethical standards

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