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NUTRITIONAL VALUES AND POTENTIAL HEALTH BENEFITS OF MILLETS- A REVIEW

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ABSTRACT

In the era of 21st century, rapid urbanisation, climate change, increased population, scarcity of water and increased dry land are the factors responsible for the worldwide agricultural and nutritional challenges. As a widely cultivated popular grain in arid and semiarid regions across the globe, Millets can act as a multifaceted solution to the above global challenges because of their rich vitamins, minerals, phytochemicals and anti-oxidant content. In addition to vitamins, Millets are the rich source of flavanoids such as apigenin, catechin, daisein, orientin, isoorientin, lutolin, quercetin, vitexin, isovitexin, myricetin sponarin, violanthin, lucenin-1, and tricin. Further, the presence of essential amino acids enriches the nutritive potential of Millets. The rich anti-oxidant content in Millets reduces oxidative stress in human and animal models by significantly minimizing Reactive Oxygen Species (ROS) generation. Several bioactive principles in Millets are known to decrease cardiovascular risk, diabetes, ageing and even cancer. However, nutritive and therapeutic potentials of bioactive compounds found in Millets are underexplored and a systematic review encompassing available data in literature is grossly missing. The aim of this review is to compile the recent advances that have been carried out covering nutritional properties, processing technologies and their effects in reducing anti-nutritional factors enhancing nutrient bioavailability along with the potential health benefits of millets. Consumption of various traditional and modern millet based food and studies conducted in examining the bioavailability of minerals after consuming millet based food is also discussed in this review.

Contribution/Originality: Millets though are widely cultivated in arid and semiarid regions, its nutritional values and potential health benefits have been poorly investigated. The major and minor millets vary widely in their nutritional contents and other bioactive phytochemicals. The present review is an attempt to compile first hand data related to nutritional composition and its role as a potent phytotherapeutics against numerous diseases.

1. INTRODUCTION

The progression of Millennium Development Goal (MDG) led to the emergence of Sustainable Development Goal (SDG). In 2015, as the second goal of SDG, the United Nations committed to achieve zero hunger and improve nutrition by 2030. This changed the food security measure of total calorie (prevalent during MDG) to nutrient content food for adequate nourishment [1] as the overall physical and mental well-being of human being depends on the consumption of nutritious food [2]. The 2016 global nutrition report explains that around 44%

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population of 129 countries experience the high level of under nutrition due to nutrient imbalanced diet [3]. The problems of nutritional challenges are likely to be compounded as a result of rise in population, reduced production and exposure to climate change [1]. Further, climate change induced erratic alteration in pattern of rain, intensity and distribution of rain over the globe reportedly increasing the dry land mass and significant loss of water table. The possibility of having increased staple cereal production is highly compromised with the gradual increase in dry land and deepening of ground water level [3, 4]. As Millets can grow luxuriantly on dry and less fertile soil, Millets can serve as preferable alternative where major cereals fail to provide sustainable yield [3, 5].

Millets cultivation has several agrarian importances in comparison to the cultivation of major cereals. For example, the yield of rice is known to be low on a soil having salinity higher than 3dS/m. On the contrary, millets (pearl millet and finger millet) can grow and provide better yield up to a soil salinity of 11-12 dS/m. The rainfall requirement of rice (120-140 cm) is several folds higher than the average rainfall requirement of millets (proso millet and pearl millet) of 20 cm. Additionally, millets fall under the C4 group of cereals, having the characteristics of taking more carbon dioxide and converting that into oxygen, high water holding capacity, and require low input. This makes them environment friendly and accessible. Thus, millets can be useful in addressing the issues like climatic uncertainties and reducing atmospheric carbon dioxide [3]. Along with the agricultural advantage, nutrient content in terms of richness in amino acids, minerals, anti-oxidants and with various health benefits [2, 6-9] make millets superior than staple cereals like rice and wheat.

Studies have been carried out describing nutritional and biological roles of millets, processing technologies, consumption of various millet based food and health benefits of millets [2, 3, 10-13]. However, a single study compiling all aspects of millets is scantly available. Thus, to breeze the above conspicuous gap, this review has been carried out. The remainder of the paper is as follows. Section 2 provides information on origin and distribution of millets. Section 3 explains the nutritional values of millets vis-à-vis makes a comparison with rice and wheat. Section 4 portrays the health benefits of millets. Section 5 throws a light on nutritional bioavailability explaining how different processing techniques affect the bioavailability of nutrients in millets. Consumption of various millet based foods and studies conducted in examining the bioavailability of minerals after consuming millet based food is explained in section 6 and section 7 concludes.

2. ORIGIN AND DISTRIBUTION OF MILLETS

Millets are basically grown in arid and semi-arid regions of Africa and Asia [14]. Pearl millet (*Pennisetum glacum*), proso millet (*Panicum miliaceum*), foxtail millet (*Setaria italic L.*), and finger millet (*Eleusine Corocana*) are the four major types of millets. Further, little millet (*Panicum Sumatrense*), kodo millet (*Paspalm Scrobiculatum L.*), and barnyard millet (*Echinochloa Frumentacea*) are regarded as minor millets [11]. Pearl millet is cultivated in more than 30 countries of Asia, Africa, and Australia, constituting 95% of the total millet production at global level [15-17]. Foxtail millet is the second largest crop in millet category cultivated in semi-arid regions of Asia, North America, Australia, and North Africa [18, 19]. Finger millet is grown in the rural population of East and Central Asia and is the sixth largest crop [19]. Alike pearl millet, proso millet is also cultivated in all continents except South America and Antarctica. Among all millets, barnyard millet is the fastest growing crop and can grow under unfavourable condition and cultivated in Egypt [11]. Kodo millet is native to South America and later domesticated in India [20]. It is draught resistance and can grow in poor soils. It is mainly cultivated in arid and semi-arid regions of India and African countries [11]. Little millet plants are shorter and can grow in sandy loam and saline nature of soil, cultivated throughout India [11].

3. NUTRITIONAL VALUES OF MILLETS

Consumption of nutritious food is highly essential to lead a healthy life [21]. Millets are known to have enormous nutritive values in comparison to rice and wheat [2]. In addition, presence of gluten free proteins with

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high fibre and richness in bioactive compounds makes millets a healthy food [3]. The macro and micro nutrient content of millets in comparison to major cereals are presented below.

3.1. Macronutrients

Carbohydrate, protein, lipids, and dietary fibre are known as macronutrients. Carbohydrates are essential part of our diet as it contributes approximately 50% of the daily calorie intake [22]. Carbohydrates contain carbon, hydrogen, and oxygen in the ratio of 1:2:1 [23]. Based on the degree of polymerisation, carbohydrates are categorised as monosaccharaides, disaccharides, oligosaccharides, and polysaccharides [23]. The carbohydrate content in millets ranges from 55.0gm/100gm (barnyard millet) to 72.6gm/100gm (Sorghum). Proteins are the most essential component of tissue in human and animal [24]. The dietary protein can be useful only when it gets hydrolysed by proteases and peptides to amino acids[1] and dipeptides. Thus, the nutritional value of dietary protein depends on the proportions of amino acid. The presence of essential amino acid in different millets in comparison to wheat is presented in Table 2. It is evident that even though the protein content of wheat is comparable with protein contents of foxtail and little millet (Table 1), the presence of essential amino acids like leucine, isoleucine, valine, and phenylalanine make millets superior. Fibre is also essential element for maintenance like digestion, body weight, blood sugar, triglycerides and cholesterol [25]. Complex carbohydrate such as polysaccharides forms the fibre. Millet seed coats are the sources of dietary fibre [26]. Barnyard millet is having the highest crude fibre content of 9.8 g/100 g, which is several times higher than wheat and rice. The macronutrient contents of different millets are compared with rice and wheat in Table 1.

Table 1. Macronutrient contents of millets with major cereals rice and wheat.

Crops	Protein (g/100g)	Carbohydrate (g/100g)	Fats (g/100g)	Crude Fibre (g/100g)	Total energy (Kcal)	Reference
Pearl millet	11.4-11.8	67.0-69.10	4.87-5	1.2-2.3	361-363	[1-4]
Foxtail millet	11.2-15	60.9-67.3	3.3-4.3	6.7-8.23	352-391	
Finger millet	7.3-7.7	71.52-72	1.3-1.5	3.6	328-336	
Proso millet	10.0-13.0	67.09	3.09	8.47	352.5	
Barnyard millet	6.2-13.0	55-65.5	2.2-3.9	9.8-13.6	300-307	
Kodo millet	8.3-10.0	63.82-66.6	3.03-3.6	5.2-8.2	349.5-353	
Little millet	6.2-15.0	60.9-67	4.7-5.2	7.6	329-341	
Rice	4.99-7.9	78.2-82.8	0.5-1.9	0.2-1.63	345-369	
Wheat	11.6-13.78	69.88-73.9	0.9-2.81	0.3-1.77	348-438	
Sorghum	10.4-10.82	70.7-72.9	1.9-3.1	1.6-2.0	329-349	

3.2. Micronutrients

The minerals and vitamins are considered as the micronutrients due to their small requirements for human body. Minerals play important roles in human body starting from bone formation, clotting of blood, normalising heartbeat, enhancing immunity and helping nervous system to work properly [3, 25]. Therefore, deficiencies of the minerals may cause several health issues. Calcium and iron deficiencies are the most common micronutrient deficiencies found both at global and national level [27, 28]. Calcium content of finger millet is the highest (350 gm/100gm) amongst cereal category, which is several folds higher than wheat and rice. The calcium content of finger millet can meet around 50% of the recommended dietary allowance (RDA) prescribed by Indian council of Medical Research (ICMR) for men and women, boys, and girls and can meet around 40% of lactating and pregnant women [25]. Thus, consumption of finger millet can address the calcium deficiency and osteoporosis problem. Barnyard millet, little millet, pearl millet and foxtail millets are the rich sources of iron. The highest iron content

[1]Based on the nitrogen balance, amino acids are classified into two categories- essential amino acids and non-essential amino acids. Among these two, nutritionally essential amino acids are more important as they are not synthesised by human body. Therefore, diet must be provided for that.

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(amongst millet category) is found in little millet of 9.3mg/100gm, which can meet around one-third of the daily iron required for pregnant women (35mg/d, which is the highest iron requirement among all categories of people). Long term exposure to zinc deficiency enhances the possibility of exposure to diarrhoea, low physical growth, and suppressed immune function [29]. The highest zinc content is found in little millet (3.7 mg/100gm) followed by pearl millet (3.1 mg/100gm), barnyard millet (3.0 mg/100gm) and finger millet (2.3 mg/100 gm). Millets are also good source of water soluble vitamins like thiamine, riboflavin, and niacin.

Foxtail millet has the highest thiamine content (0.59 mg/100gm) amongst millet category. The highest riboflavin content is found in pearl millet (0.25 mg/100gm) followed by finger millet (0.19 mg/100gm) and foxtail millet (0.11 mg/100gm), which is several folds higher than staple cereals like rice and wheat. Niacin content is found to be the highest (4.2 mg/100gm) in barnyard millet amongst millet category. The above nutrient contents make millets nutricereals. The micronutrient contents of millet crops are presented in Table 3.

Table 2. Essential amino acid content in millets and wheat.

Amino acids	Wheat flour refined	Foxtail Millet (defatted flour)	Proso Millet (dehulled grain)	Pearl Millet (true prolamine)	Finger Millet (native grain)	Reference
Histidine	1.2	1.3-2.11	2.1	1.4-1.7	1.3-2.3	[4, 5]
Lysine	1.1	1.4-1.59	1.5	0.5-1.9	2.2	
Isoleucine	2.2	4.59-4.8	4.1	2.6-5.1	4.0-4.3	
Threonine	1.5	1.9-3.68	3	2.4-3.3	2.4-4.3	
Methionine	0.9	1.8-3.06	2.2	1-1.5	2.5-2.9	
Valine	2.4	4.3-5.81	5.4	3.3-4.2	4.8-6.3	
Tryptophan	0.6	0.6	0.8	1.1-1.2	1	
Leucine	4	10.4-13.6	12.2	7.5-14.1	6.5-10.8	
Phenylalanine	2.9	4.2-6.27	5.5	2.9-7.6	3.1-6	

3.3. Phenolic Compounds

Phenolic compounds contain phenol function group as a fundamental component. These are secondary metabolites of plants responsible for color, nutritional and anti-oxidant properties [3, 11, 30]. Phenolic acid, flavonoid and tannins are the classifications of phenolic compound [3]. Table 4 presents the data related to total phenolic content (TPC) of free, hydrolysed (etherified and esterified), and bound phenolic compounds of different millet grains. It is apparent from the table that TPC of kodo millet is found to be the highest in free, esterified and insoluble fraction; whereas, the TPC of pearl millet is the highest in etherified fraction.

Benzoic and cinnamic acids are the derivatives of phenolic acids. Hydrobenzoic acid and hydrocinnamic acids are further sub classifications of phenolic acids [31]. The highest amount of hydrooxybenzoic acid and its derivatives (62.2µg/g) are found in the soluble fraction of finger millet; whereas, the highest amount of hydrooxycinnamic acid and derivatives (171µg/g) is found in foxtail millet [7].

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Table 3. Micronutrient contents of millets with major cereals rice and wheat.

Crops	Ca (mg)	Fe (mg)	Na (mg)	K (mg)	Mg (mg)	Zn (mg)	Carotene (µg)	Thiamine (µg)	Riboflavin (µg)	Niacin (µg)	References
Pearl millet	42.0	8-11	10.9	307.0	137.0	3.1	132.0	0.33-0.38	0.21-0.25	2.3-2.8	[2, 4]
Foxtail millet	31.0	2.8	4.6	250.0	81.0	2.4	32.0	0.59	0.11	3.2	
Finger millet	344-350	3.9	11.0	408.0	137.0	2.3	42.0	0.42	0.19	1.1	
Proso millet	-	-	-	-	-	-	-	-	-	-	
Barnyard millet	20-22	5.0-18.6	-	-	82.0	3.0	0	0.33	0.10	4.2	
Kodo millet	35.0	1.7	-	-	-	-	-	0.15	0.09	2.0	
Little millet	17.0	9.3	8.1	129.0	133.0	3.7	0	0.30	0.09	3.2	
Rice	10-33	0.7-1.8	-	-	90.0	1.4	0	0.06-0.41	0.04-0.06	1.9-4.3	
Wheat	23-30	2.7-3.5	20.0	315.0	132.0	2.2	25.0	0.12-0.41	0.07-0.10	2.4-5.1	
Sorghum	25.0	4.1-5.4	7.3	131.0	171.0	1.6	47.0	0.37-0.38	0.13-0.15	3.1-4.3	

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Table 4. Total phenolic content (TPC) in different millet grains.

Millet type	Free	Esterified	Etherified	Insoluble bound	Reference
Pearl millet	1.27±0.2	1.82±0.2	3.94±0.1	9.14±0.2	[6]
Finger millet	9.67±0.4	0.41±0.1	2.15±0.1	3.20±0.2	
Foxtail millet	4.49±0.2	0.37±0.1	0.32±01	11.6±0.2	
Proso millet	0.55±0.2	0.7±0.1	2.05±0.1	2.21±0.1	
Kodo milet	16.2±0.5	2.2±0.1	1.55±0.1	81.6±0.2	
Little millet	5.77±0.7	1.37±0.2	2.48±0.1	9.64±0.2	

Flavonoids are considered as more powerful antioxidants than vitamin E & C [32]. Apigenin, catechin, daisein, orientin, , isoorientin, lutolin, quercetin, vitexin, , isovitexin, myricetin sponarin, violanthin, lucenin-1, and tricin are the commonly found flavonoids in millets [7, 11, 33, 34]. Soluble fraction of finger millet contains the highest amount of flavonoid (1896 µg/g). Along with polyphenols and flavonoids, presence of carotenoid and vitamin E enhances the antioxidant capacity of millets [35]. The average carotenoid content of proso millet is the highest amongst millet category, which is higher than wheat but lesser than maize, Table 5. Moreover, vitamin E characterisation reveals that the total anti-oxidant activity of finger millet is the highest. Further, tocopherols constitute the major component in vitamin E of millet grains [35].

Table 5. Average carotenoid content and total anti-oxidant activity of cereal grains.

Cereal grains	Average carotenoid content(µg/100g)	Avg. total anti-oxidant activity	Reference
Finger millet	199±77	15.3±0.6	[35, 36]
Foxtail millet	173±25	5.0±0.4	
Little millet	78±19	4.7±1.1	
Proso millet	366±104	15.3±0.6	
Wheat	150-200	13[a]	
Maize	1800-5500	10[a]	
Rice	-	29[a]	

Note: a The percentage contribution of free bound fraction to total anti-oxidant activity and the values are extracted from Adom and Liu [36].

4. HEALTH BENEFITS OF MILLETS

Urbanisation has significantly affected the consumption pattern in India [37] declining the consumption of some cereals like millets and increasing the consumption of animal-based products, oil, refined sugar, fat, and alcohol [37-39]. This pattern of consumption has contributed to the increased burden of non-communicable diseases [39] attributing around 71% of the total deaths globally [40]. Further, the present consumption pattern plays an important role in oxidative stress induction [41]. Oxidative stress is caused by imbalance between production and accumulation of reactive oxygen species (ROS) in cells and tissues [42]. Further, ROS contribute to cellular aging, diabetes, mutagenesis, Deoxy Ribonucleic Acid (DNA) damage, and carcinogenesis [43-46]. DNA, the genetic materials in human body when damaged leads to numerous diseases including cancer. In cue of above literature, it can be articulated that increase in the oxidative stress can significantly contribute to the inflammatory diseases (arthritis, vasculitis, adult respiratory disease syndrome), cardiovascular diseases, gastric ulcer, neurological disorder diseases (Alzheimer, parkinson, muscular dystrophy) , acquired immune deficiency syndrome, and many more [47].

To counteract oxidative stress, human body has several mechanisms of producing antioxidants (naturally produced/ externally supplied through food), which act as free radical scavengers in preventing and repairing the damages caused by ROS. Thus, it helps in enhancing the immune defence system lowering the risk of degenerative diseases [48]. Millets serve as a natural source of antioxidants [2, 7]. Moreover, free radical scavenging property of millets can not only reduce ROS, but also can provide effective means in the prevention and treatment of radical-mediated disease [11, 49]. Thus, millet consumption will inhibit the oxidative stress reducing the risk of the above degenerative diseases.

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4.1. Millets against Diabetes & Cardiovascular Disease

Diabetes mellitus is a chronic metabolic disorder characterised by hyperglycaemia with alteration of protein, carbohydrate and lipid metabolism [2, 50, 51]. Use of natural inhibiting diet is preferably safer in the management of hyperglycaemia [2] as dietary glycaemic load is directly correlated with increased risk of diabetes [50, 52]. Further, fibre plays a significant role in glycaemic control [53]. Richness of millets in dietary fibre and minerals [9] and slowly digestible starch [54] with leucine [50, 55] make millet a healthy diet for diabetics. Pradeep and Sreerama [33] in an *in vitro* study concluded millets as a functional food ingredient in regulating postprandial hypoglycaemia. Further, some *In vivo* studies [56-60] have shown hypoglycaemic effect of millet based food after intervention.

It is evident that diabetes increases the risk of cardio vascular disease (CVDs) by three to eight folds [61]. In the context of CVDs, low density lipoprotein (LDL) and high density lipoprotein (HDL) have opposite influences on the risk of CVDs. That means, every 1 mg/dL increase in LDL enhances the risk of CVDs by 2%; whereas, every 1 mg/dL increase in HDL declines the risk of CVDs by 2-3% [62]. Triglyceride is another factor responsible for the risk of CVDs; as association of increased level of triglyceride and the risk of CVDs exist from decades [63]. Amongst different strategies in combating against CVDs, lowering of LDL has received the highest success [64]. Therefore, diet that lowers LDL should be preferred to minimise the risk of CVDs. Niacin improves the lipoprotein abnormalities lowering LDL and triglyceride [65]. Thus, niacin rich food should be recommended in lowering the risk of CVDs. Millets, amongst the cereal category is a good source of Niacin [9]. Thus, millet has the potential to address CVDs lowering LDL.

In line with the above literature, *in vivo* studies [58, 66] provide evidence on the effect of millet based foods in lowering LDL and triglyceride increasing HDL (without enhancing LDL level). On the contrary, [67] in an *in vivo* study found a significant decrease in the blood glucose and lipid level without changing HDL. In a nut-shell, millets can be recommended to lower the risk of CVDs.

4.2. Millets against Cancer

Millet grains are rich with phenolic compounds like phenolic acids, flavonoids, and tannins which make it anti-nutrients [68] that reduces the risk of colon and breast cancer in animals [2, 69]. In an *in vivo* study [70] explained the anti-cancer property of a novel 35kD protein named Fibroin-modulator-binding protein (FMBP) extracted from foxtail millet supresses the growth of colon cancer cells inducing G_1 phase arrest and through the loss of mitochondrial trans membrane potential that results in apoptosis (programmed cell death) in the colon cancer cells through caspase activation. In another *in vivo* study, [71] concluded that dietary supplementation of foxtail millet helps in treating colitis-associated colorectal cancer through the activation of gut receptor. It was also found from the study that millet based diet helped in supressing Signal Transducer and Activator of Transcription (STAT) -3 signaling pathway[2]. STAT are a family of transcription factor that play a crucial role in uncontrolled cell proliferation, angiogenesis and evasion of apoptosis in cancer cells.

4.3. Millets and Antimicrobial Activity

The secondary metabolites of millets exhibit antibacterial and anti-fungal activities [11, 73]. Studies of Amadou, et al. [10]; Bisht, et al. [74] provide information on the inhibitory effect of millets against bacterial pathogens such as, *E.coli, B. cereus, L. monocytogens, P. mirabilis, S. typhi, P. aeruginosa, and Y. enteroclitica*. Moreover, antifungal effect of millet is reported in Viswanath, et al. [75].

[2] STAT3 plays a pivotal role in tumour growth and metastasis [72].

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4.4. Millets against Celiac Disease and Aging

Celiac disease is the most common disorder and has affected humans across the world [76]. It is an auto-immune disorder originated by an unusual adaptive response against gluten containing grains [77]. Gluten free diet can be a solution to this problem [78]. Since millets are gluten-free, millet based beverages can be the best suitable option for individuals suffering from celiac disease [2, 7, 79].

Richness of antioxidants and β carotene helps individuals in maintaining their health and age [80] and millet grains are rich in antioxidants [2]. In an *in vitro* study, [81] found the inhibitory effect of methanolic extract effect of finger millet and kodo millet on glycation and cross-linking of collagen. Hence, millet based diet can be useful for individuals in protecting against aging. From the above literature, in a nut-shell, it can be articulated that consumption of millet can help in protecting and combating against various diseases; and can act like a nutraceuticals. A summary on different health benefits of millets is presented in Table 6.

Table 6. Health benefits of millets in brief.

Disease	Millets responsible for	References
Diabetes	Proso millet, finger millet, little millet	[56-60]
Cardio vascular diseases	Proso millet, foxtail millet	[58, 66]
Cancer	Proso millet, foxtail millet	[71, 82]
Anti-microbial activity	Proso millet, finger millet, foxtail millet	[6, 10, 74, 75]
Aging	Finger millet and kodo millet	[81]

5. NUTRITIONAL BIOAVAILABILITY

Bioavailability refers to the quantity of ingested nutrients which get absorbed and utilised through normal metabolic pathways [12]. Therefore, in the assessment of adequacy of dietary intake, more importance is given to the bioavailability of nutrients than nutrient contents of the food [83]. Millets are good source of minerals [2, 3, 9]. However, due to the presence of anti-nutrients like phytates, polyphenols, and tannins, a very small quantity is available for human being via absorption [12]. Bioavailability of nutrients in millets is affected by both dietary and physiological factors [12]. Therefore, minimising the anti-nutrients and enhancement of nutrient content should be the objective. Further, it is evident that processing of millets significantly affects the bioavailability of nutrients in human [12]. Thus, the effect of various processing techniques on nutritional value and bioavailability is discussed below.

5.1. Effect of Processing of Millets on Nutritional Value and Bioavailability

Mechanical and traditional technologies are used to process the millets. Decortication, milling, and sieving are the mechanical processing techniques; whereas, germination, fermentation, malting, popping, and soaking & cooking are the traditional techniques [2].

5.2. Mechanical Processing Techniques

Decortication is a process where the pericarp of the crop is removed. Reduction of dietary fibre, minerals and anti-oxidant activity was evident after decortication, which declines the applicability of pearl millet as functional food. However, significant reduction in the phytic acid, poly phenols, & tannins were found [84, 85]. That means, decortication declines both nutrient and anti-nutrient contents. Milling is the most traditional method of processing where wooden or stool mortar and pestle is used to convert dried or moistened grains into flour. Reduction of anti-nutrients and enhancement in bio-accessibility of minerals was evident in semi refined pearl millet flour [12]. Further, increase in protein and starch digestibility was found to a significant extent after milling [86]. Sieving (another processing method) records increase in both nutrients and anti-nutrients in finger millet whole flour [87].

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5.3. Traditional Processing Techniques

Anti-nutrients are supposed to hinder the availability of minerals. However, they are catabolised through the process of germination and enhance mineral availability [88]. In line with Grewal and Jood [88] an increase the *in vitro* bio-accessibility of minerals like calcium, zinc, and iron was found in pearl millet and finger millet [89]. In proso millet, germination increased the total sugar, free amino acids, lysine, and tryptophan declining the starch content [90]. Further, a decline in the crude protein and fat content after germination was found in foxtail millet [91]. Fermentation is a natural traditional method of processing. Fermentation of pearl millet causing remarkable changes in the chemical composition enhances *in vitro* protein digestibility and nutritional value. Further, it declines anti-nutritional and mineral contents [92]. Duration of fermentation also affects the nutrient and anti-nutrient contents of pearl millet [93]. Soaking of grains is a popular technique for reducing anti-nutritional compounds and improving minerals bioavailability [2]. Soaking before dehulling and milling degrades phytates; however, no effect of increase in phytate degradation was found after cooking the flour with the water used for soaking [2, 84]. Popping or puffing is another traditional method used for the production of ready-to-eat products which are crunchy and porous [94]. Increment in the dietary fibre content and fall in the anti-nutritional factors is recorded in the final puffed products [91, 95].

In a comparative note, the reduction of tannin content in pearl millet, finger millet, and sorghum is found in the order: untreated > soaked > germinated millets [12, 96]. To enhance iron and zinc bioavailability, [97] advocates the use of fermentation as an ideal strategy. Further, combining fermentation with germination not only increased the nutrient content and energy densities of *fura* (a Nigerian food made with pearl millet) but also significantly declines the phytic acid. Thus, in a nut-shell it can be concluded that germination of millet can be used as a method of processing alone or in combination in preparing nutrient rich food products. Malting is an example of combination of methods used to process millet. It is a combination of germination, milling and sieving to achieve high quality nutritional and starch digestible product; as malting increases fibre, minerals and vitamins (B and C) content declining tannin and phytic acid significantly in brown finger millet [94].

Apart from the above mentioned processing techniques, exogenous enzymes (like phytases, poly phenol oxidase, tannases and cellulases, xylanases and proteases) can also be used in the processing of millets to improve the nutrient bioavailability. Addition of phytase in millet based food enhances zinc absorption [98]. Use of polyphenol oxidases (PPO) increases iron absorption and use of tannases is used to decline tannin content [12, 99]. Improvement in the protein digestibility, reduction in anti-nutritional factors enhancing mineral extractability is evident after the introduction of cellulases [100]. Alike phytases and PPO, diet supplemented with xylanase, enhances iron and zinc accessibility [101]. Presence of anti-nutritional factors of pearl millet, finger millet, barnyard millet, and foxtail millet inhibit the proteolytic enzyme in breaking down protein into amino acids; thereby declining amino acid accessibility in the body. This problem can be addressed through the supplementation of proteases in human [12].

6. CONSUMPTION OF MILLETS

From ancient times, millets have been used as a staple food in diets of Asian and African people. Millet porridge is the most common traditional food in India, China, Russia, & Germany [3]. Due to wide acceptance and awareness, millets have almost replaced commonly used cereals in local dishes like *idli, dosa,, putta.* Modernisation has changed the dietary pattern of people, which has increased the consumption of modern food items. With the changing pace of time, researchers have developed millet based modern food items (like cookies, bread, biscuit, snack foods) depending on the changed preference and interest of people. A summary on different millet based products is presented in Table 7.

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6.1. Acceptability of Millet Based Products

Development of modern food is not sufficient unless it is not consumed. Consumption depends on the acceptability of any product; and it is determined through the sensory evaluation [102]. Studies based on sensory acceptability of millet based products are scantly available. Mixed results have been found from the studies based on the sensory evaluations of millet based products. Pearl millet and sorghum based cookies [103, 104] finger millet based flakes, vermicelli, and *khakhra* [105, 106] and proso millet based pizza show decent acceptability in terms of taste, colour and texture. Similarly, from a study where millet based south Indian food items, i.e., *idli, upma, khichdi, and bisibela bath* were introduced replacing rice in school was accepted by the children [107]. However, McSweeney, et al. [108] doing the sensory evaluation of proso millet based snacks and biscuits found that the acceptability of the product in terms of texture and taste decreased due to the increase in millet proportion which made the taste bitter.

6.2. Studies Examining the Mineral Bioavailability of Millet Based Food

The acceptability of millet based products will be increased in terms of nutritional value along with taste if it could enhance the minerals' bioavailability; because it is evident that anti-nutrients content of millets affect the bioavailability [12]. Iron deficiency anaemia is a global public health threat affecting varied age group of male and female [13]. Moreover, osteoporosis remains a major public health concern among women due to low dietary calcium intake (less than 400 mg/day) in most of the Asian countries in general and India in particular [109-111]. Along with calcium and iron, zinc has been identified as a contributing factor to the burden of disease both at regional and global level [112].

Millets are good source of minerals. Thus, millet based food (both traditional and modern) can mitigate the above global health issue enhancing the bioavailability. *In vivo* studies report an increase in the haemoglobin level in the study participants intervening pearl and finger millet based *ladoo* [102, 113] pearl millet based *bhakri* [114] sorghum upma/ khichdi [115] finger millet based flakes and vermicelli [105] millet mix porridge taking little millet, finger millet, foxtail millet, and kodo millet [116] finger millet powder [117]. Moreover, from the interventions of finger millet based pan cake and ladoo, an increase in the calcium absorption are evident [118, 119]. Additionally, an increase in the zinc absorption is found after the intervention of zinc fortified millet based porridges [98]. Thus, it is evident from the above literature (*in vivo* studies) that the bioavailability of minerals (calcium, iron and zinc) derived from millet based food is not affected by the anti-nutrient contents of millets. Therefore, the problem of micronutrient deficiencies can be addressed through the millet consumption both at national and global level.

Table 7. Millet based modern food products.

Food items	Type of millets used	References
Cookies	Foxtail millet, finger millet, proso millet, pearl millet and barnyard millet	[7, 8]
Bread	Foxtail millet	[1]
Biscuits	Foxtail millet, finger millet, pearl millet and barnyard millet	[2]
Lohoh (fermented bread)	Pearl millet	[9]
Lajia noodles	Foxtail millet and pros millet	[10]
Appalu	Pearl millet and Bengal gram flour	[1]
Sami payasam	Little millet	

7. CONCLUSION

Millets have several agrarian importances than staple cereals in terms of productivity and climate susceptibility. Presence of essential amino acids (like leucine, isoleucine, valine, and phenylalanine), minerals (calcium, iron, and zinc), vitamins, phytochemical, and anti-oxidant properties make it superior than other cereals.

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Moreover, applications of millets can also be found in combating against chronic diseases like diabetes, CVDs, and cancer. Effectiveness of millets against antimicrobial activity, celiac disease and aging are also found. Notwithstanding all positive aspects of millet, presence of anti-nutrients is supposed to hinder the bioavailability of minerals. Different traditional and mechanical processing methods along with intervention of exogenous enzymes are available to decline the anti-nutrient contents enhancing bioavailability of minerals. However, more research needs to be carried out not only to develop a novel method of processing but also in examining the minerals bioavailability of millet based food through *in vivo* studies. Thus, the paper concludes with the recommendation of increasing millet consumption for healthy life and sustainable environment.

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