Review of Finger millet (*Eleusine coracana* (L.) Gaertn): A powerhouse of health benefiting nutrients

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Abstract

The bulk of the world’s millet crop is produced by India, Nigeria, Niger, Mali, Burkina Faso, Chad, and China. Finger millet (*Eleusine coracana* (L.) Gaertn), little millet (*Panicum sumatrense* Roth ex Roem. & Schult.), foxtail millet (*Setaria italica* (L.) P. Beauvois) and proso millet (*Panicum miliaceum* L.) are most commonly found species among various millet varieties. In India, finger millet occupy the largest area under cultivation among the small millets. Finger millet stands unique among the cereals such as barley, rye and oats with higher nutritional contents and has outstanding properties as a subsistence food crop. It is rich in calcium (0.34%), dietary fiber (18%), phytates (0.48%), protein (6%–13%) minerals (2.5%–3.5%), and phenolics (0.3%–3%). Moreover, it is also a rich source of thiamine, riboflavin, iron, methionine, isoleucine, leucine, phenylalanine and other essential amino acids. The abundance of these phytochemicals enhances the nutraceutical potential of finger millet, making it a powerhouse of health benefiting nutrients. It has distinguished health beneficial properties, such as anti-diabetic (type 2 diabetes mellitus), anti-diarrheal, antiulcer, anti-inflammatory, antitumorogenic (K562 chronic myeloid leukemia), atherosclerogenic effects, antimicrobial and antioxidant properties.

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Keywords: Finger millet; Dietary fiber; Antioxidant; Diabetes; Health benefit

1. Introduction

A millet crop includes grasses like finger millet, (*Eleusine coracana* (L.) Gaertn), pearl millet (*Pennisetum glaucum* (L.) R.Br), foxtail millet (*Setaria italica* (L.) P. Beauvois), kodo millet (*Paspalum scrobiculatum* L.), bahiagrass (*Paspalum notatum* Flugge), little millet (*Panicum sumatrense* Roth ex Roem. & Schult.), proso millet (*Panicum miliaceum* L.), barnyard millet (*Echinochola crusgalli* (L.) P. Beauv), guinea grass (*Panicum maximum* Jacq), elephant grass (*Pennisetum purpureum* Schumach.) that belong to the family Poaceae of the monocotyledon group. India is considered as pivot for these minor crops. The world total production of millet grains in year 2013 was 762,712 metric tons and the top producer was India with an annual output of 334,500 tons contributing 43.85% [1]. Finger millet commonly known as ragi and mandua in India is one of the minor cereals a native of Ethiopia, but grown extensively in various regions of India and Africa, constitutes as a staple food that supply a major portion of calories and protein to large segments of the population in these countries especially for people of low income groups [2]. In India, Karnataka is the leading producer of finger millet accounting to 58% of its global production, yet only a few Indians are aware about its health benefits and nutritional value. The production area of finger millet in India stands sixth after wheat, rice, maize, sorghum and bajra.

In world, finger millet ranks fourth in importance among millets after sorghum, pearl millet and foxtail millet [3]. It is widely cultivated in Africa and South Asia under varied agro-climatic conditions and it is estimated that some 10% of the world’s 30 million tons of millet produced is finger millet [4]. The crop
was domesticated around 5000 years BC. It is an allopolyploid with chromosome number $2n = 4x = 36$ and evolved from a cross between two diploid species, *Eleusine indica* (AA) and *Eleusine floccifolia* or *E. tristachya* (BB) as genome donors [5–9].

Millets are important but underutilized crops in tropical and semiarid regions of the world due to their greater resistance to pests and diseases, good adaption to a wide range of environment and their good yield of production, can withstand significant levels of salinity, short growing season, resistant to water logging, drought tolerant, requires little inputs during growth and with increasing world population and decreasing water supplies represents important crops for future human use. The drought tolerance of finger millet may be attributed to an efficient antioxidant potential and increased signal perception. Being as hardy crop it is relatively easy to grow finger millet under stressful regimes, without hampering the net productivity. There is vast potential to process millet grains into value-added foods and beverages in developing countries. Furthermore, millets, as they do not contain gluten and therefore it is advisable for stomach (abdominal) patients [10]. In current review attempt has been made to collect the available information from existing literature either online or offline related to the nutraceutical importance and health benefiting properties of finger millet and trying to present the collected data in an easily-documented pattern.

2. Nutritional significance of finger millet

The main constituents of the millet kernel are seed coat (testa), embryo and endosperm. Among several varieties of finger millets such as yellow, white, tan, red, brown, or violet color, only the red-colored are cultivated extensively throughout world. The presence of five layered testa in finger millet makes it unique compared to other millets such as foxtail millet, pearl millet, kodo millet and proso millet. This could be one of the possible reasons for the higher dietary fiber content in finger millet [11]. A comparative nutritional (Table 1), mineral and vitamin (Table 2), and amino acid (Table 3) profile of finger millet with other minor millets, cereals and pseudo-cereals are summarized in said table.

The nutraceutical importance of finger millet lies in its high content of calcium (0.38%), protein (6%–13%), dietary fiber (18%), carbohydrates (65%–75%), minerals (2.5%–3.5%), phytates (0.48%), tannins (0.61%), phenolic compounds (0.3–3%) and trypsin inhibitory factors, and is recognized for its health beneficial effects, such as anti-diabetic, antitumorogenic, anti-diarrheal, antiulcer, anti-inflammatory, atherosclerogenic effects, antioxidant and antimicrobial properties [15,23,24]. Earlier it was believed that polyphenols, phytates, tannins and dietary fiber contents of finger millet act as anti-nutrients because of their metal chelating and enzyme inhibition activities but now it has been confirmed that these constituents can contribute to antioxidant activity, which is an important factor in resisting aging and metabolic diseases [25,26]. Moreover, finger millet is also useful in management of various physiological disorders such as diabetes mellitus, hypertension, vascular fragility, hypercholesterolemia, prevention of oxidation of low-density lipoproteins (LDLs) and also improves gastrointestinal health [27].

Finger millet is milled with the testa which is generally rich in dietary fiber and micronutrients to prepare flour and the whole meal is utilized in the preparation of traditional foods, such as roti (unleavened breads), ambali (thin porridge) and mudde (dumpling) [15]. On daily consumption of whole grain of finger millet and its products can protect against the risk of cardiovascular diseases, type II diabetes, and gastrointestinal cancers and other health issues [28]. The dietary fiber, minerals, phenolics and vitamins concentrated in the outer layer of the

<p>| Table 1 |</p>
<table>
<thead>
<tr>
<th>Nutrient composition of finger millet with other minor millets, pseudo-cereals and cereals grain.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Protein (%)</strong></td>
</tr>
<tr>
<td><strong>Minor millets</strong></td>
</tr>
<tr>
<td>Finger millet</td>
</tr>
<tr>
<td>Pearl millet</td>
</tr>
<tr>
<td>Proso millet</td>
</tr>
<tr>
<td>Foxtail millet</td>
</tr>
<tr>
<td>Kodo millet</td>
</tr>
<tr>
<td>Little millet</td>
</tr>
<tr>
<td>Barnyard millet</td>
</tr>
<tr>
<td>Amarath</td>
</tr>
<tr>
<td>Quinoa</td>
</tr>
<tr>
<td>Pseudo-cereals</td>
</tr>
<tr>
<td>Cereals</td>
</tr>
<tr>
<td>Rice</td>
</tr>
<tr>
<td>Maize</td>
</tr>
<tr>
<td>Sorghum</td>
</tr>
<tr>
<td>Oats</td>
</tr>
<tr>
<td>Rye</td>
</tr>
</tbody>
</table>

Sources [12–20].
Table 2
Mineral and vitamin composition of finger millet with other minor millets, pseudo-cereals and cereal grains (mg/100 g).

<table>
<thead>
<tr>
<th>Mineral/Vitamin</th>
<th>Minor millets</th>
<th>Pseudo-cereals</th>
<th>Cereals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca</td>
<td>344</td>
<td>180</td>
<td>41</td>
</tr>
<tr>
<td>P</td>
<td>283</td>
<td>557</td>
<td>306</td>
</tr>
<tr>
<td>Fe</td>
<td>3.9</td>
<td>9.2</td>
<td>3.9</td>
</tr>
<tr>
<td>Mg</td>
<td>137</td>
<td>279.2</td>
<td>120</td>
</tr>
<tr>
<td>Na</td>
<td>11</td>
<td>22</td>
<td>3</td>
</tr>
<tr>
<td>K</td>
<td>408</td>
<td>5</td>
<td>264</td>
</tr>
<tr>
<td>Cu</td>
<td>0.47</td>
<td>0.86</td>
<td>0.9</td>
</tr>
<tr>
<td>Mn</td>
<td>2.9</td>
<td>364</td>
<td>1.23</td>
</tr>
<tr>
<td>Thiamine</td>
<td>5.47</td>
<td>0.22</td>
<td>0.40</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>2.3</td>
<td>1.69</td>
<td>0.3</td>
</tr>
<tr>
<td>Niacin</td>
<td>1.0</td>
<td>0.97</td>
<td>0.3</td>
</tr>
<tr>
<td>Minor millets</td>
<td>Finger millet</td>
<td>Pearl millet</td>
<td>Proso millet</td>
</tr>
<tr>
<td>Foxtail millet</td>
<td>31</td>
<td>8</td>
<td>31</td>
</tr>
<tr>
<td>Kodo millet</td>
<td>29</td>
<td>206</td>
<td>38</td>
</tr>
<tr>
<td>Little millet</td>
<td>17</td>
<td>290</td>
<td>35</td>
</tr>
<tr>
<td>Barnyard millet</td>
<td>22</td>
<td>206</td>
<td>35</td>
</tr>
<tr>
<td>Pseudo-cereals</td>
<td>Amarath</td>
<td>Quinoa</td>
<td>Buckwheat</td>
</tr>
<tr>
<td>Cereals</td>
<td>Wheat</td>
<td>Rice</td>
<td>Maize</td>
</tr>
<tr>
<td>Oats</td>
<td>54</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Rye</td>
<td>33</td>
<td>160</td>
<td>10</td>
</tr>
</tbody>
</table>

Sources (USDA database [12–14,21,22]).

2.1. Polyphenols and dietary fiber

The growing public awareness toward nutritional and health benefits of finger millet is attributed to its polyphenols and dietary fiber content. Among cereals such as rice, wheat, barley and maize, finger millet grain has higher contents of polyphenols. These phenolics compound are not stored in the grain but their location is mainly in the outer aleurone layer, testa and pericarp of fruit which form the main components of the bran fraction and exist as free, soluble conjugates and insoluble bound forms [32,35]. Finger millet grain genotypes have varied total tannin and phenolic contents. The major bound phenolics present in finger millets are ferulic acid (64%–96%) and p-coumaric acid (50%–99%). Varieties of finger millets also contain proanthocyanidins (condensed tannin), a high-molecular weight polyphenols that consist of polymerized flavan-3-ol and/or flavan-3, 4-diol units [50]. Three classes of phenolic found in finger millet-hydroxybenzoic acid derivatives, hydroxycinnamic acid derivatives and flavonoids. These derivative compounds identified as p-hydroxybenzoic acid, proanthocyanidins, ferulic acid, gallic acid, protocatechuic acid, vanillic acid, syringic acid, trans cinnamic acid–coumaric acid, etc.

Table 3
Essential amino acid profile of finger millet with minor millets, pseudo-cereals and cereals grains (g/100 g).

<table>
<thead>
<tr>
<th>Essential Amino Acid</th>
<th>Arginine</th>
<th>Histidine</th>
<th>Lysine</th>
<th>Tryptophan</th>
<th>Phenylalanine</th>
<th>Tyrosine</th>
<th>Methionine</th>
<th>Cystine</th>
<th>Threonine</th>
<th>Leucine</th>
<th>Isoleucine</th>
<th>Valine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor millets</td>
<td>Finger millet</td>
<td>0.300</td>
<td>0.130</td>
<td>0.220</td>
<td>0.100</td>
<td>0.310</td>
<td>0.220</td>
<td>0.210</td>
<td>0.140</td>
<td>0.240</td>
<td>0.690</td>
<td>0.400</td>
</tr>
<tr>
<td>Pear millet</td>
<td>0.300</td>
<td>0.140</td>
<td>0.190</td>
<td>0.110</td>
<td>0.290</td>
<td>0.200</td>
<td>0.150</td>
<td>0.110</td>
<td>0.240</td>
<td>0.750</td>
<td>0.260</td>
<td>0.330</td>
</tr>
<tr>
<td>Proso millet</td>
<td>0.290</td>
<td>0.110</td>
<td>0.190</td>
<td>0.050</td>
<td>0.310</td>
<td>0.160</td>
<td>0.160</td>
<td>0.150</td>
<td>0.760</td>
<td>0.410</td>
<td>0.410</td>
<td>0.410</td>
</tr>
<tr>
<td>Foxtail millet</td>
<td>0.220</td>
<td>0.130</td>
<td>0.140</td>
<td>0.060</td>
<td>0.420</td>
<td>0.180</td>
<td>0.100</td>
<td>0.190</td>
<td>1.040</td>
<td>0.480</td>
<td>0.430</td>
<td>0.430</td>
</tr>
<tr>
<td>Kodo millet</td>
<td>0.270</td>
<td>0.120</td>
<td>0.150</td>
<td>0.050</td>
<td>0.430</td>
<td>0.180</td>
<td>0.110</td>
<td>0.200</td>
<td>0.650</td>
<td>0.360</td>
<td>0.340</td>
<td>0.340</td>
</tr>
<tr>
<td>Little millet</td>
<td>0.250</td>
<td>0.120</td>
<td>0.110</td>
<td>0.060</td>
<td>0.330</td>
<td>0.180</td>
<td>0.090</td>
<td>0.190</td>
<td>0.760</td>
<td>0.370</td>
<td>0.350</td>
<td>0.350</td>
</tr>
<tr>
<td>Barnyard millet</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Pseudo-cereals</td>
<td>Amarath</td>
<td>1.470</td>
<td>0.380</td>
<td>0.830</td>
<td>0.181</td>
<td>0.610</td>
<td>0.540</td>
<td>0.340</td>
<td>0.190</td>
<td>0.430</td>
<td>0.860</td>
<td>0.550</td>
</tr>
<tr>
<td>Quinoa</td>
<td>1.200</td>
<td>0.360</td>
<td>0.700</td>
<td>0.052</td>
<td>0.500</td>
<td>0.410</td>
<td>0.310</td>
<td>0.150</td>
<td>0.370</td>
<td>0.840</td>
<td>0.480</td>
<td>0.570</td>
</tr>
<tr>
<td>Buckwheat</td>
<td>0.982</td>
<td>0.309</td>
<td>0.672</td>
<td>0.192</td>
<td>0.520</td>
<td>0.241</td>
<td>0.172</td>
<td>0.229</td>
<td>0.506</td>
<td>0.832</td>
<td>0.498</td>
<td>0.678</td>
</tr>
<tr>
<td>Cereals</td>
<td>Wheat</td>
<td>0.480</td>
<td>0.130</td>
<td>0.230</td>
<td>0.080</td>
<td>0.280</td>
<td>0.290</td>
<td>0.150</td>
<td>0.090</td>
<td>0.230</td>
<td>0.500</td>
<td>0.300</td>
</tr>
<tr>
<td>Rice</td>
<td>0.290</td>
<td>0.130</td>
<td>0.170</td>
<td>0.070</td>
<td>0.280</td>
<td>0.180</td>
<td>0.090</td>
<td>0.140</td>
<td>0.180</td>
<td>0.410</td>
<td>0.220</td>
<td>0.280</td>
</tr>
<tr>
<td>Maize</td>
<td>0.131</td>
<td>0.089</td>
<td>0.137</td>
<td>0.023</td>
<td>0.150</td>
<td>0.123</td>
<td>0.067</td>
<td>0.026</td>
<td>0.129</td>
<td>0.348</td>
<td>0.129</td>
<td>0.185</td>
</tr>
<tr>
<td>Sorghum</td>
<td>0.355</td>
<td>0.246</td>
<td>0.229</td>
<td>0.124</td>
<td>0.546</td>
<td>0.321</td>
<td>0.169</td>
<td>0.127</td>
<td>0.346</td>
<td>1.491</td>
<td>0.433</td>
<td>0.561</td>
</tr>
<tr>
<td>Barley</td>
<td>0.496</td>
<td>0.223</td>
<td>0.369</td>
<td>0.165</td>
<td>0.556</td>
<td>0.284</td>
<td>0.190</td>
<td>0.219</td>
<td>0.337</td>
<td>0.673</td>
<td>0.362</td>
<td>0.486</td>
</tr>
<tr>
<td>Oats</td>
<td>1.192</td>
<td>0.405</td>
<td>0.701</td>
<td>0.234</td>
<td>0.895</td>
<td>0.573</td>
<td>0.312</td>
<td>0.408</td>
<td>0.575</td>
<td>1.284</td>
<td>0.694</td>
<td>0.937</td>
</tr>
<tr>
<td>Rye</td>
<td>0.500</td>
<td>0.400</td>
<td>0.600</td>
<td>0.100</td>
<td>0.400</td>
<td>0.200</td>
<td>0.200</td>
<td>–</td>
<td>0.300</td>
<td>0.600</td>
<td>0.200</td>
<td>0.300</td>
</tr>
</tbody>
</table>

Source (USDA database [12,13]).
2.2. Glycemic response (GR) of finger millet

High dietary fiber and phenolic content makes finger millet very beneficial for diabetic patients. Apart from this it also has low glycemic index (GI) that makes it an ideal snack to prevent late night food thirst and help to maintain blood sugar at a constant ratio. A study on small sample size (n = 6) where finger millet preparations such as chapathi (unleavened flat bread), sevai (rice string hoppers), idli (fermented, steamed rice cake), dosai (fermented rice pancakes), and kozhukattai (steamed rice balls) to type 2 diabetes mellitus (formerly called NIDDM-non-insulin dependent diabetes mellitus) showed a significant decrease in the postprandial blood glucose levels after finger millet administration for a month [52]. Thus, regular consumption of finger millet product can decrease fasting glucose by 32% and can eliminate insulin resistance by 43%. Finger millet malting and fermentation processes improve the carbohydrate digestibility and attributed the higher glycemic response (GR) of finger millet dosa and roti compared to the normal whole finger millet dosa and roti. The reason of higher GR is due to the conversion of starch to dextrins and maltose during germination. The polished finger millet in grain form as a formulation with legumes gave a higher GI of 93.4 as compared to wheat-based formulations with legumes 55.4 [53,54]. The glycemic index for foxtail millet incorporated biscuit was 50.8 compared to 68.0 for both barnyard millet (dehulled) incorporated biscuits and control refined flour wheat biscuits and on the other hand, GI for the dehulled and heat-treated barnyard millet, were 50.0 and 41.7 respectively [55,56].

2.3. Antitumorigenic effect of finger millet against K562 chronic myeloid leukemia (CML)

Chronic myeloid leukemia (CML) is a form of leukemia (vireulent blood disease) characterized by increased and unregulated growth of myeloid cells in the bone marrow leading to their accumulation in the blood. The individual suffered from CML showed resistance toward available treatments has created a substantial need for developing new natural therapeutic options.
Finger millet is a highly nutritious cereal and has long been used as a remedy for many infections including the leukemia. Recently seed purified extract of finger millet gained the importance of anti-proliferative activity on K562 chronic myeloid leukemia because finger millet seeds contain a bifunctional complex of α-amylase-trypsin inhibitor more commonly called RBI (ragi bifunctional inhibitor), that inhibits α-amylase and trypsin simultaneously. Basically, RBI is a monomeric protein made of 122 amino acid containing five intra-molecular disulfide bonds and the gene responsible for the encoding RBI has been cloned from finger millet seeds and expressed functionally in *Escherichia coli* [58–63]. Broadly speaking, the plant protease inhibitors (PIs) are multifunctional proteins required in diverse biological processes, such as redness, infection, extracellular matrix degradation, blood coagulation, apoptosis, tumor invasion and cancer metastasis and play very significant role in human health and disease management [64,65]. Consequently, plant protease inhibitors useful in inhibiting the different stages of carcinogenesis, including initiation, promotion and progression in vitro and in vivo.

Numerous study revealed that a trypsin–chymotrypsin inhibitor from buckwheat (*Fagopyrum esculentum*) also demonstrated anti-proliferative effect on T-acute lymphoblastic leukemia cells, Jurkat cells (immortalized line of human T lymphocyte) and solid tumors cells like hepatoma (HepG2), cervical carcinoma (HeLa) and esophageal squamouscell carcinoma (EC9706) cells [66,67]. The mechanism associated in the cytotoxic activity was found to be upregulation of Caspase-3, Caspase-9, disruption of mitochondrial membrane potential and increased DNA fragmentation. Thus, plant protease inhibitors are considered as nutraceuticals, providing both nutrition and pharmaceuticals, specifically in the prevention and/or treatment of malignant neoplastic disease. It is also suggested that the ingestion of seeds containing protease inhibitors can lower the incidence of breast, colon, prostate, oral and pharyngeal cancers [68].

2.4. Other miscellaneous uses

From an Ayurvedic perspective finger millet promotes weight loss, healthy choice for vegans, mental relaxation, lowers triglycerides, reduced blood pressure, reverts skin aging, pregnancy, improves lactation, child growth and weaning, promotes hair growth, women friendly, geriatric tonic, gluten free food, lowers the risk of gall stones and fights diseases or prevent cancer.

3. Conclusion

The finger millet’s dietary fiber and polyphenols have been recognized to offer several health benefits such as anti-diabetic, protection from diet related chronic diseases, hypocholesterolaemic, antioxidant, and antimicrobial effects to its regular consumers. Moreover, it is likewise rich in carbohydrate, energy and nutrition, making finger millet an important ingredient of dietary and nutritional balanced foods. The regular use of finger millet as a nutrient and its products helps in managing different disorders of body by maintaining blood glucose homeostasis. Also the whole meal-based finger millet products may be desirable due to the protective role of seed coat matter that have health enhancing benefits.

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