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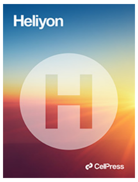

Review article

Varietal and processing influence on nutritional and phytochemical properties of finger millet: A review

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ABSTRACT

Food and nutrition insecurity is a problem for the majority of developing nations; incidentally, some underutilized crops have the potential to increase food security. A minor cereal grain called finger millet (*Eleusine coracana* L.) is widely cultivated in various regions of India and Africa and is consumed for its numerous health advantages. There is a wealth of research on the nutritional and health benefits of this crop, but little is known about how varietal difference and processing affect these qualities. Therefore, this study reviewed the effects of variety and different processing methods on the nutrition, antinutrients, phytochemicals, and antioxidative properties of finger millet and its probable uses in ensuring nutrition and food security. Finger millet is a nutritious cereal with relatively high values of protein, vitamins, minerals, fibre, and energy. The amount of minerals, particularly calcium and potassium, is larger than what is found in the most popular grains, including wheat and rice. The grain of finger millet is non-glutinous and contains only 1.3% fat; in contrast to other types of millet which are noticeably higher in dietary fibre, protein, ash, and fat. The coloured varieties particularly have high levels of minerals, antioxidants, and phytochemicals. The nutritional and phytochemical qualities of finger millet are affected by the cultivars, varieties, and geographical locations. This study elucidates the qualities of finger millet varieties and methods of processing which will help in the selection of appropriate cultivars for food applications.

1. Introduction

Finger millet (*Eleusine coracana* L.) is a nutritious cereal grain with potential health benefits cultivated in different parts of India and Africa (Devi et al., 2014; Chandra et al., 2016; Puranik et al., 2017; Ceasar et al., 2018; Ramashia et al., 2019). Some of its common names are 'bulo', 'ragi', and 'wimbi' (Uganda), 'tamba', 'pwana', and'sarga' (Nigeria), 'dagussa' (Ethiopia), 'ragi' and'mandua' (India), 'wimbe' (East Africa), and 'rapoko' in South Africa, while the common English names are African millet, birdsfoot, and coracana (Jideani et al., 1996; Obilana and Manyasa, 2002; Shiihii et al., 2011; Blench, 2012).

Finger millet is placed in fourth place behind sorghum, pearl millet, and foxtail millet on a scale of cereal production in Africa and Asia (Upadhyaya et al., 2007; Ramashia et al., 2018; Ceasar et al., 2018). Its annual production is at 4.5 million tons where 2.5 million and 1.2 million tons are produced in Africa and India, respectively (Ramashia et al., 2019). Additionally, the grains are grown in Nepal, Sri Lanka, and India's Himalayan regions (Adhikari, 2012; Jideani, 2012; Abah et al., 2020). Today, it is farmed in South Carolina, Taiwan, China, and Japan (Mathur, 2012), and 55 to 60 per cent of the world's production of finger millet comes from sub-Saharan Africa (Mathur, 2012; Dlamini and Siwela, 2015).

Finger millet is nutrient-rich, and the nutritional value can be increased through processing. Vital nutrients like carbohydrates, dietary fibre, essential amino acids, and minerals are present in sufficient amounts in finger millet (Chandra et al., 2016; Sood et al., 2016; Ramashia et al., 2019). According to Manjula and Visvanathan (2014), Muthamilarasan et al. (2016), and Ramashia et al. (2019), the grains are a good option for those with celiac disease because they are free of gluten and are simple to digest (Jideani and Jideani, 2011; Muthamilarasan et al., 2016). The calcium content of entire finger millet seeds is 0.34 per cent, compared to 0.01 to 0.06 per cent for other major grains (Kumar et al., 2016; Gupta et al., 2017; Ceaser et al., 2018). The hypoglycemic and hypocholesterolemic effects of the grains as well as their established anti-ulcerative properties are among their health advantages (Chethan and Malleshi, 2007). The presence of polyphenols and tannins in the

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cereal has been linked to some of these health benefits (Thompson, 1993; Devi et al., 2014). The seed coat is also edible and rich in phytochemicals (Hadimani and Malleshi, 1993; Ramachandra et al., 1977) and can contribute to the antioxidant activity of food products from the millet (Bravo, 1998).

The flour obtained from the grains is used to produce cakes, bread, infants' foods and other pastry products (Mgonja et al., 2007). There are reviews on the nutritional composition, anti-nutritional factors, nutraceuticals, health benefits and processing of finger millet (Rathore et al., 2019; Jagati et al., 2021); however, those reviews fail to highlight the effects of variety and rocessing methods on the stated parameters. While Jayawardana et al. (2019) described the nutritional composition of three varieties of finger millet grown in Sri Lanka, they failed to pay attention to the effect of processing methods on the cereal. Also, the authors did not examine variants grown in other countries; they solely examined those in Sri Lanka. The nutritional and health advantages of finger millet reviewed by Ramashia et al. (2019) did not look into how its nutritional makeup varies by variety or how processing affected the nutrients. The writers focused on the applications and uses of finger millet rather than how processing impacts the nutritional value of the cereal. Thapliyal and Singh (2015) assessed the nutritional value, various polyphenolic forms, and dietary fibres of three finger millet varieties. This study, therefore, looked at how variety and processing methods affected the nutrients, antinutrients, phytochemicals, and antioxidative potential of finger millet.

2. Agricultural conditions for the growth of finger millet

Finger millet is an annual crop which belongs to the grass family, Poaceae (Dida et al., 2008; Shiihii et al., 2011; Medson and Gary, 2019). In most African and Asian regions, the height of a finger millet plant ranges between 30 and 150 m (Medson and Gary, 2019). The seeds are in different colours, such as white, light brown, or dark brown, and they are consumed in different forms. Finger millet grain is mostly grown in areas with little or moderate rainfall and can easily adapt to different agro-climatic conditions (Baker, 2003; Zerihun, 2016; Ramashia et al., 2019). It was domesticated about 5000 years ago from the wild subspecies in the highlands of Ethiopia and Uganda (Hilu et al., 1979). About 3000 years ago, finger millet was originally cultivated in the lowlands of Africa and later taken to India, a country which became a secondary centre for its diversity (Hilu et al., 1979; Singh, 2016). The seeds are a smart crop in Africa since they are resistant to drought and insect damage and can be kept for a long time (Latha et al., 2005; Ceasar et al., 2018; Medson and Gary, 2019; Adeboye et al. (2021). Finger millet is resistant to storage pests and can last up to 10 years without damage, which makes it available round the year and can even serve as a famine crop (Gupta et al., 2017).

3. Overview of nutritional composition of finger millet

Finger millet ranks higher in nutritional composition than other cereal grains, although it is grossly underutilized (Sood et al., 2016).

3.1. Carbohydrate

According to Malleshi et al. (1986) and Gopalan et al. (1999), finger millet contains free sugar (1.04%), starch (65.5%), and dietary fibre (11.5%). The finger millet's carbohydrate composition includes 59.5–21.1% starch, 1.4–1.8% cellulose, and 0.04–0.6% lignins (Wankhede et al., 1979). The starch concentration ranges from 59.4 to 70.2% dry matter, with 80–85% amylopectin and 15% amylose (Antony et al., 1996a; Nirmala et al., 2000; Mittal, 2002). According to Singh and Raghuvanshi (2012), non-starchy polysaccharides account for 20–30% of the carbohydrates in finger millet. Finger millet has about 1.5% reducing sugar and 0.03% non-reducing sugar (Nirmala et al., 2000). Other authors reported values of carbohydrates in the range of 65.00–83.3% (Hulse et al., 1980; Bhatt et al., 2003; Singh and Raghuvanshi, 2012; Devi et al., 2014; Audu et al., 2018; and Ramashia et al., 2019). Total sugar in finger millet has been reported to range between 0.59 and 0.69 g/100 g, with sucrose being the main sugar (0.20–0.24 g/100 g) (Murty et al., 1985; Himanshu et al., 2018; Hassan et al., 2021).

3.2. Protein

Most finger millets had a crude protein level that ranged from 5.6 to 12.70% (Ravidran, 1991; Antony et al., 1996b; Bhatt et al., 2003). Protein content ranged from 6.7 to 12.3%, with a mean value of 9.7%, according to Vadivoo et al. (1998). In their analysis of 16 distinct cultivars, Singh and Srivastava (2006) found that the protein content ranged from 4.88 to 15.58%. Other authors reported protein values varying between 5 and 13% (Chethan and Malleshi, 2007; Shobana et al., 2013; Devi et al., 2014; Chandra et al., 2016; Ramashia et al., 2019). The kinds of essential amino acids and protein digestibility are used to evaluate the quality of protein in most plant crops (Reeds et al., 2000; Schaafsma, 2000; Hoffman and Falvo, 2004). Essential amino acids make up 44.7% of all the amino acids in finger millet (Mbithi-Mwikya et al., 2000; Singh and Raghuvanshi, 2012; Jideani, 2012; Mamatha and Begum, 2013; Manjula et al., 2015; Sood et al., 2017; Ramashia et al., 2018). The amounts of the essential amino acids are phenylalanine (4.1–5.2 g/100 g), histidine (2.2 g/100 g), isoleucine (4.3 g/100 g), leucine (6.6.-9.5 g/100 g), lysine (2.2 g/100 g), methionine (2.5–3.51 g/100 g), threonine (3.4–4.2 g/100 g) while the non-essential amino acids are aspartic acid (6.5–7.90 g/100 g), glutamic acid (20.3–27.1 g/100 g), alanine (6.1–6.2 g/100 g), arginine (2.77–4.5 g/100 g), cystine (1.7–2.5 g/100 g), glycine (2.14–4.0 g/100 g), proline (7.0–9.9 g/100 g), serine (3.6–5.1 g/100 g) and tyrosine (2.79–3.6 g/100 g) (Ramashia et al., 2019; Jagati et al., 2021).

The necessary amino acids, lysine and methionine, which are lacking in other plant diets are abundant in finger millet (McDonough et al., 2000). It includes a sufficient amount of the essential amino acids as advised by the FAO/WHO (1991), though lysine, leucine, and threonine supplementation may be necessary (Audu et al., 2018). The methionine content of the grain (194 mg/g) is higher than that of other millet species (Singh et al., 2012; Prashantha and Muralikrishna, 2014; Ramashia et al., 2019). The primary protein fraction of finger millet, prolamin, accounts for between 24.6 and 36.2% of the total protein (Lupien, 1990). According to Antony and Chandra (1998), finger millet contains a significant amount of tryptophan and threonine, which are lacking in other cereals, and 99.1 mg of soluble proteins per 100 g. The finger millet's sulfur-containing amino acids are comparable to those found in dairy milk (Antony et al., 1996). The cereal's protein digestibility ranged from 50 to 65% (Antony and Chandra, 1999).

3.3. Fat content

Finger millet has superior keeping qualities than other minor cereals like pearl millet, barnyard millet, and foxtail millet since it has a lower fat content. Its claimed fat content is between 1.3 and 1.8% (Malleshi and Desikachar, 1986; Singh et al., 2003; Thapliyal and Singh, 2015; Rathore et al., 2019). Free lipids (2.2%), bound lipids (2.4%), and structural lipids (0.6%) make up the total lipid in finger millet (Sridhar and Lakshminarayana, 1994). Antony et al. (1996) observed that the total crude fat in finger millet was 2.1% with a high percentage of polyunsaturated fatty acids. The brown and white varieties had fat contents in the range of 1.2–1.4% (Seetharam, 2001). Finger millet contains predominantly oleic, palmitic and linoleic acids with a little quantity of linolenic acid. Saturated and unsaturated fatty acids account for 25.6% and 74.4% of total fatty acids, respectively (Sridhar and Lakshminarayana, 1994). The valuable amount of unsaturated fatty acids further increases the health-benefit potential of the grain. The seeds are abundant in linoleic and α-linolenic acids which are responsible for the proper functioning of the central nervous system (Fernandez et al., 2003; Birch et al., 2007; Jacobson et al., 2008).

3.4. Mineral components

The ash level of finger millet is higher than that of the other major cereal grains. Its ash concentration has been estimated to be between 1.7 and 4.13% (Rao, 1994; Samantaray and Samantaray, 1997; Mushtari, 1998; Thapliyal and Singh, 2015); however, Singh and Srivastava (2006) found ash values between 1.47 and 2.58%. According to Roopa and Premavalli (2008), Manjula et al. (2015), Devi et al. (2014), and Ramashia et al. (2019), the amounts of phosphorus, potassium, magnesium, calcium, sodium, zinc, iron, manganese, and copper in finger millet are 130–283, 430–490, 78–201, 162–398, 49, 2.3, 3.3–14.39, 17.61–48.43, and 0.47 mg/100 g, respectively. When compared to rice and wheat, finger millet has a greater nutritional density (Antony and Chandra, 1998; Vadivoo et al., 1998). According to many studies (Babu et al., 1987; Bhatt et al., 2003; Manjula et al., 2015; Rajiv et al., 2011; Roopa and Premavalli, 2008; Shukla and Srivastava, 2014; Singh and Srivastava, 2006; Jayawardana et al., 2019), the grains had greater proportions of calcium (162.0–358.0 mg/100 g), phosphorus (130.0–283.0 mg/g), iron (3–20%) and magnesium (124. 45–161.3 mg/100 g) than other millet species.

3.5. Fibre

Finger millet is a source of carbohydrates like any other cereals. However, the proportion of dietary fibre in finger millet is higher than in many other kinds of cereal. The dietary and crude fibres of finger millet as reported by Rathore et al. (2019) are 18.6% and 4.3%, respectively. Ramulu and Rao (1997), however, reported 12% total dietary fibre, 11% insoluble dietary fibre, and 2% soluble dietary fibre in finger millet.

3.6. Vitamins

Despite having a minor amount of vitamins A and B, finger millet grains are not a particularly abundant source of vitamins (Chappalwar et al., 2013; Devi et al., 2014; Siwela, 2009). The grains are lacking in vitamin C but have higher levels of riboflavin, niacin, thiamine, and folic acid (Vidyavati et al., 2004). According to Ramashia et al. (2021), the milky cream, brown, and black kinds of finger millet have vitamin B1 content of 0.27, 0.27, and 0.43 mg/100 g, respectively. Asharani et al. (2010) also reported finger millet has a tocopherol concentration of 4.1 mg/100 g.

Finger millet contains 6 retinol equivalents of vitamin A and 45 μg/100 g of carotene (Thapliyal and Singh, 2015). The 'indaf' cultivar of finger millet had 0.229 mg/100 g thiamine, 0.093 mg/100 g riboflavin, 2.22 mg/100 g niacin, and 0.11 mg/100 g ascorbic acid (Malleshi and Klopfenstein, 1998). The dearth of information on finger millet's vitamin content and the poor values reported in the scant research that do exist are indications that it is not an excellent source of vitamins.

4. Finger millet varieties

4.1. Nutritional composition of finger millet as affected by varieties

"Africana" and "coracana" (L.) Gaertn are the two main subspecies of finger millet (Hilu and de Wet, 1976). The two races of the Africana are "africana" and "spontanea," and the four races of the Coracana subspecies are "elongata," "plana," "compacta," and "vulgaris" (Prasada et al., 1993). Finger millet was shown to be highly rich in dietary fibre, carbs, ash, and certain vitamins, according to a variety of nutritional compositions described by numerous authors (Hiremath et al., 2018; Jayawardana et al., 2019; Ravidran 1991; Devi et al., 2014).

Considering the number of different varieties documented (Hiremath et al., 2018; Lansakara et al., 2016; Ramashia, 2018), it becomes very imperative to assess the impact of varietal differences on the nutritional, antinutritional, phytochemical and antioxidative properties of finger millet.

The proximate constituents of two varieties of finger millet (Ravana and Oshawa) in Sri Lanka was reported by Lansakara et al. (2016). These two varieties differed significantly in protein and ash, as Oshawa had higher protein (6.48%) and ash (2.01%) values than Ravana which contained 4.63% of protein and 1.61% of ash. These two types contain less protein and ash than the Daffo finger millet grown in Nigeria, which has a protein level of 10.28% and an ash content of 2.37% (Bwai et al., 2014). The values of protein reported by Bwai et al. (2014) were within the values (9.2–10.6%) documented for Sri Lankan finger millet varieties (CO 10, KM1 and M1) (Ravidran, 1991).

The crude fibre contents of these latter varieties (4.2–4.5%) were also higher than values obtained in 'Ravana', 'Oshawa', and 'Daffo' cultivars, while the ash contents ranged from 2.5 to 3.1% (Ravidran 1991). 'Ravana' variety contained 3.14% fat, which is higher than the value documented for Oshawa and other cultivars (1.5–1.6%) reported by Ravindran (1991), Bwai et al., 2014 (0.83%) Mushtari et al., 2017 (1.3 g/100 g). Chauhan and Sarita (2018) observed another Indian cultivar of finger millet contained 13.1 g/100 g moisture, 6.3 g/100 g protein, 2.8 g/100 g ash, 18.9 g/100 g crude fibre, 71.9 g/100 g carbohydrates, and 1.3% fat.

In another assessment carried out by Barbeau and Hilu (1993), the proximate compositions of 7 different cultivars of Ethiopia, Kenya, and India were evaluated. African cultivars had protein contents ranging from 7.5 to 11.0%, while Indian cultivars had protein contents ranging from 9.0 to 11.7%. No doubt, varieties influence the proximate compositions of finger millets, with considerably higher values of protein, ash, crude fibre and fat. Jayawardana et al. (2019) observed little or no difference in the dietary fibre of Sri Lankan finger millet varieties (‘Ravi’, ‘Rawana’ and ‘Oshadha’) analysed. ‘Rawana’, ‘Ravi’ and ‘Oshadha’ finger millet had values ranging from 13.01 to 13.79% for dietary fibre on a dry basis. Values obtained were similar to the dietary fibre of the Indian finger millet variety (13.44%) (Thippeswamy et al., 2016). The high value obtained in all varieties has been attributed to the five-layered testa structure in finger millet (Chandra et al., 2016).

Among the many health advantages of dietary fibre is its capacity to reduce blood sugar and cholesterol levels (Shobana et al., 2010). On a dry weight basis, values obtained in finger millet types are greater than those found in regularly consumed cereals like wheat and rice, which have a dietary fibre content of 8.3 and 3.0%, respectively, on a dry weight basis (Yadav et al., 2010). The total dietary fibre content in Indian finger millet types ranged from 16.28 (VL324) to 18.06% (VL315) (Panwar et al., 2016). These types have greater dietary fibre than the ones that were previously mentioned.

Additionally, Barbeau and Hilu (1993) assessed the amino acids of three-finger millet varieties from Kenya, Kerala, and Uganda. A total of sixteen amino acids, of which nine were essential, were found in the three kinds. Of all the amino acids examined, Kenya cultivars had the greatest value. Serna-Saldivar (2010) reported eighteen amino acids in another variety of finger millet and nine essential amino acids were identified. Tryptophan concentrations in other finger millet varieties ranged from 53.57 (VL149) to 59.44 g/g (VL315), and methionine content ranged from 176.18 (VL324) to 296.73 g/g (VL315), as shown in Table 1. When finger millet was added to composite flour in the amount of 20%, chapatti's nutritional quality improved (Panghal et al., 2019). According to Ravindran (1991), finger millet contains lysine, threonine, and valine, making it a crop with relatively balanced protein.

Roopa and Premalli (2008) investigated the total starch contents of the finger millet varieties ‘VL 146’, ‘VL 149’, and ‘VL 204’ growing in the hilly region of India. The values obtained ranged from 44.1 to 50.1% of all the types, with "VL-149" having the greatest starch content. Another study discovered that the Sri Lankan varieties Ravi’, ‘Rawana’, and Oshada’ contain more resistant and digestible starch than Indian-grown varieties (Table 1). The variances in the nutrients of some kinds may have been caused by the diverse geographical regions, soil types, and agronomic practises of the various cultivars. Jayawardana et al. (2019) also reported that Sri Lankan finger millet varieties contain both amylose and amylopectin with values ranging from 16.67 to 18.90% and 81.10–83.33% for 'Ravi', 'Ravana' and 'Oshadha' varieties. Singh and Raghuvanshi (2012) documented another Indian variety that contained 80–85% of amylopectin and 15–20% amylose. From all indications, finger millets contain more amylopectin than amylose. 'Ravi', 'Rawana' and 'Oshada' Sri Lankan varieties have more soluble digestible and resistant starch (Jayawardana et al., 2019) than 'VL 146', 'VL 149' and 'VL204' Indian finger millet varieties (Roopa and Premavalli, 2008). Resistant starch of pharmaceutical importance can be obtained from finger millet.

Ravidran (1991) reported that finger millet contained a considerable amount of potassium, magnesium, and calcium. In another work analysed by Kazi and Auti (2017), finger millets were screened for higher mineral elements. The authors identified 8 mineral elements (Cu, Zn, Fe, Mn, K, Ca, Mg and Na) and the elements with the highest concentration were calcium (159.7–364.6 mg/100 g), iron (10.2–424.16 mg/100 g), potassium (26–184 mg/100 g) and sodium (107–268.23 mg/kg). Barbeau and Hilu (1993) found that the calcium contents of African cultivars (401–515 mg/100 g) were significantly higher than the Indian accession (376 mg/100 g). Three major mineral elements identified in other cultivars of finger millet were calcium (344 mg/100 g), phosphorus (283 mg/100 g) and iron (3.9 g/100 g) (Mushtari et al., 2017). This further buttresses the claim that calcium and iron are abundant in millet irrespective of the variety. The water-soluble vitamins and pro-vitamin A are among those found in finger millet (Ramashia 2018). The RAU-8 type of finger millet, the India type (Hiremath et al., 2018), has a significant quantity of minerals, including phosphorus (187.33 mg/100 g), calcium (297.67 mg/100 g), magnesium (155.22 mg/100 g), manganese (11.82 mg/100 g), and iron (2.90 mg/100 g). When compared to other reported varieties, Sri Lankan finger millet cultivars "CO 10," "KMI," and "MI 302" have higher mineral concentrations, especially potassium (Table 2). According to the majority of researchers in the Asian region, calcium, potassium, and phosphorus are the most common mineral components with relatively high concentrations. From Nigeria, the 'Daffo' variety has higher levels of potassium (14.19 mg/g), sodium (6.89 mg/g), and magnesium (6.25 mg/g) (Bwai et al., 2014). The mineral contents of four varieties obtained from Kenya differed significantly (Makokha et al., 2002). Kenya varieties (U 15, EKR 228, EKR 227, and Ikhulule) also contained higher potassium, sodium, and magnesium than other mineral elements analysed. African varieties seem to contain more sodium than most Asian varieties. According to Panwar et al. (2016), the calcium content of 5 Indian cultivars ('VL 146', 'VL 149', 'VL 204', 'VL 315', and 'VL 324') ranged from 276.60 (VL324) to 331.92 (VL204) mg/100 g. The values for zinc ranged from 2.00 (VL324) to 2.96 (VL146) mg/100 g (Table 3), whereas copper was deficient in some kinds of finger millets. The maximum value for iron is 4.08 (VL149) and the minimum value is 5.56 (VL204) mg/100 g (Table 2). The manganese concentration ranged from 7.01 mg/100 g (VL315) to 7.62 mg/100 g (VL149) (Table 2). This cereal has great potential to solve the menace of micronutrient deficiencies in developing countries if appropriately utilized. It can also be used in fortifying flours that have low mineral content.

4.2. Bioactive compounds in finger millet

When compared to main cereals like rice and wheat, minor cereals like finger millet have been found to be among the richest in nutrients and bioactive components (Oghbaei and Prakash, 2012). It is one of the minor cereals that is becoming more and more popular as a functional food ingredient with numerous health advantages linked to its polyphenol and dietary fibre concentrations (Chethan and Maleshi, 2007; Devi et al., 2014; Chandra et al., 2016; Balasubramaniam et al., 2019; Ramashia et al., 2019). Finger millet has tremendous but under-explored nutraceutical properties (Kumar et al., 2016). The bioactive compounds play a major role in minimising the risk of diabetes mellitus and the deposition of high cholesterol in the body (Ramasha et al., 2019; Mutshiyani et al., 2020). The abundance of bioactive ingredients in finger millet has attracted lots of research interest.

4.2.1. Phytochemicals and antioxidants of finger millet

Xiang et al. (2018) reported the antioxidant properties of four Malawi varieties (white, brown, reddish, and red). Values obtained for total phenolic content, total flavonoids, and total catechin tannin for the four varieties ranged from 292.29 and 302.42 mg ferric acid eq/100 g, 90.24–202.94 mg catechin acid eq/100 g and 31.76–83.59 mg catechin acid eq/100 g, respectively. The brown variety had the highest values of total phenolic content, total flavonoids, and total catechin tannin than the other varieties. The white variety had the lowest values of all the antioxidant properties evaluated (Xiang et al., 2018). This was expected as coloured varieties contain more carotenoids and polyphenols, which are rich sources of antioxidants (Thapliyal and Singh 2015). In the 'Ravana' and 'Oshawa' Sri Lankan varieties reported by Lansakara et al. (2016), the Oshawa variety had higher flavonoid and antioxidant activity than the Ravana variety. The total phenolic and flavonoid contents for 'Oshada' were 8.08 and 1.05 mg/GAE/g, respectively. The phenolic content of the 'Bala' and 'Wadimal' Sri Lankan varieties ranged from 160.20 to 181.39 mg GAE/100g (Jayawardana et al., 2018). The 'Wadimal' variety exhibited a stronger radical scavenging activity when compared (5.64) with Bala (4.67). 'Bala' exhibited the highest antioxidant activity in the FRAP assay (58.18 mg/100 g/GAE compared to Wadimal's 43.81 mg/100 g/GAE). Ascorbic acid was found in some

Table 1. Nutritional composition of finger millet varieties.

Parameter	Finger millet variety												
	Ravi	Ravana	Oshadha	CO 10	KM 1	M1 302	Ravana	Oshadha	Dafo	VL146	VL149	VL204	HR911
Moisture %	13.16	11.25	10.60	12.54	12.52	12.13	-	-	6.99	-	-	-	12.06
Protein %	8.13	8.74	8.42	9.5	10.6	9.2	6.48	4.63	10.28	-	-	-	8.30
Crude fat %	1.41	1.40	1.41	1.5	1.6	1.6	1.3	3.14	0.83	-	-	-	2.73
Ash %	3.22	2.95	3.01	2.7	2.5	3.1	2.0	1.61	2.37	-	-	-	2.28
Crude fiber %	3.73	3.79	3.82	4.5	4.2	4.3	3.4	3.17	3.10	-	-	-	3.38
Total carbohydrate %	87.24	86.92	87.17	81.8	81.1	81.8	85.64	85.64	76.43	-	-	-	71.25
Dietary fiber %	13.01	13.58	13.79	-	-	-	-	-	-	-	-	-	15.4
Starch fractions %													
Total starch %	-	-	-	-	-	-	-	-	-	44.4	50.1	47.8	_
SDS %	43.38	48.49	49.15	-	-	-	-	-	-	32.3	35.3	33.7	_
RS %	3.75	4.19	4.58	-	-	-	-	-	-	0.9	0.9	0.9	_
References	[1]			[2]			[3]		[4]	[5]			[6]

-: Not reported; ND: Not detected; SDS: Soluble digestible starch; RS: Resistant Starch; [1] Jayawardana et al. (2019); [2] Ravidran (1991); [3] Lansakara et al. (2016) [4] Bwai et al. (2014); [5] Roopa and Premalli (2008); [6] Panghal et al. (2019).

Table 2. Mineral compositions of finger millet varieties.

Parameter	Finger millet variety																
	Ravi mg/ 100 g	Ravana mg/100 g	Oshadha mg/100 g	*CO 10	*KM1	*M1 302	Dafo mg/g	U15 mg/ 100 g	EKR 228	EKR227 mg/100 g	Ikhulule mg/100 g	VL146 mg/100 g	VL149 mg/100 g	VL204 mg/100 g	VL315 mg/100 g	VL324 mg/100 g	HR911 mg/100 g
Sodium	10.23	12.46	13.44	90	80	50	6.86	311.9	380.6	274.0	346.9	-	-	-	-	-	_
Magnesium	139.58	124.45	161.3	140	130	130	6.25	128.7	172.1	179.3	150.5	-	-	-	-	-	_
Potassium	402.45	407.23	411.77	560	580	570	14.19	391	484.4	472.8	489.0	302.4	309.7	331.92	298.22	276.60	_
Calcium	337.53	345.93	353.41	250	250	240	6.86	105	126.6	132.2	112.2	-	-	-	-	-	310
Iron	3.28	3.86	3.33	5	5	4	1.13	1.9	4.5	4.6	2.6	4.82	4.08	5.56	5.30	5.27	7.8
Phosphorus	337	341.70	314.46	280	200	230	-	-	-	-	-						298
Zinc	1.96	1.80	1.93	2	3	5	-	-	-	-	-	2.96	2.82	2.72	2.24	2.00	1.38
Copper	-	-	-	2	4	5	0.11					0.012	ND	0.012	ND	0.012	_
Manganese	-	-	-	6	4	4	0.32	3.7	15.6	121.3	4.4	7.11	7.62	7.12	7.01		_
References	1, 6			2				3				4, 6, 7					5

-: not reported; ND: not detected; * mg/100 g; [1]Jayawardana et al. (2019);[2] Ravidran (1991) [3] Makokha et al. (2002) [4] Panwar et al. (2016) [5] Panghal et al. (2019) [6] Hassan et al. (2021); [7] Ramashia et al. (2021).

Table 3. Selected compounds with health benefits in finger millet.

Health compounds	Functions	References
Ferulic acid, quercetin, and ferulic-rich arabinoxylan	Have special therapeutic effects. such as antioxidative, anti-inflammatory, and antimicrobial properties	Banerjee et al., (2012); Shahidi and Chandrasekara (2013)
Phytates, phenols and Tannins	Lowers body cholesterol, high blood pressure and blood sugar. Aids healing and maintenance of ageing and metabolic syndrome. Prevents deterioration of human health, cancer and cardiovascular diseases. Decreases tumour.	Amadou et al. (2013), Sarita and Singh (2016), Chandra et al. (2018) Siwela et al. (2007), Thilagavathi et al. (2015).
Soluble dietary fibre	It possesses hypoglycemic and hypolipidemic effect as well as lowering of serum cholesterol. Prevents cardiovascular diseases such as atherosclerosis, antitoxic effect and anticancerous effect.	Amadou et al. (2013) Thilagavathi et al. (2015), Udeh et al. (2017).
Nutraceutical foods	Promotes better health by reducing the problems associated with chronic disease which include obesity. Enhances the antioxidant status and lowers the risk of cardiovascular diseases and better controls the blood glucose levels,	Sarita and Singh (2016). (Rajasekaran et al., 2004).
Magnesium	Lowers associated risk of cardiovascular diseases such as heart attack.	Chandra et al. (2018)
Phosphorus	Essential for the development of body tissue and energy metabolism.	Chandra et al. (2018).

Indian varieties of finger millet with values ranging from 54.49 (VL 324) to 64.92 μg/g (VL204). Ascorbic acid plays a crucial role in boosting the immune system and iron absorption (Chen et al., 2003). Finger millet is a powerhouse of vital nutrients such as micronutrients, resistant starch, dietary fibre, antioxidants and proteins, which explains its potential in the development of healthy foods and nutraceuticals (Chandra et al., 2016).

The trypsin inhibitors, phytate, tannins, and flavonoids in finger millet limit the bioavailability of minerals, which results in low nutritional quality (Palanisamy et al., 2012). In finger millet, the tannin concentration varies, with values ranging from 0.04 to 3.74% of catechin equivalents (Abdullahi et al., 2015; Ekta and Sarita, 2018; Kumar et al., 2016). Comparing the white grain variants of finger millet to the brown and dark varieties, the white grain varieties have lower tannin levels (0.05%) (Parida et al., 1989). Two African cultivars (IE927 and IE929) had tannins in the range of 3.42–3.47%. According to Wadikar et al. (2006), hilly and base region coloured variants had average tannin contents of 0.34 and 0.53%, respectively. The finger millet's seed coat contains tannins, which are important for the biological operation of living things and act as a barrier against the invasion of fungi (Devi et al., 2014). Nevertheless, it has been claimed to impair thyroid and pancreatic function and cause liver dysfunction. Tannin compounds, if present in high proportion, can affect the colour, flavour, nutrient digestibility, mineral absorption and quality of the food products prepared from finger millet (Devi et al., 2014). Poor bioavailability of iron observed in brown varieties of finger millet is due to high tannin content (Udayasekhara et al., 1988). The non-bioavailability of minerals has limited the utilisation of finger millet in some regions. Wadikar et al. (2006) found that the phytate content of most finger millet ranged between 240 and 300 mg/100 g. Phytate plays a major role in influencing the functional and nutritional properties of foods due to its strong binding capacity.

However, these anti-nutrients can be eliminated using different processing methods such as fermentation, germination, dehulling, and others.

Phytochemicals have health benefits if they are within the recommended dietary allowance. Most of the health benefits are traced to polyphenol and dietary fibre contents which possess functional properties with health benefits (Udeh et al., 2017). The health benefits of finger millets by different researchers are shown in Table 3.

McDonough et al. (1986) reported 0.55–0.59% and 0.17–0.32% for total polyphenols and tannins (catechin equivalent), respectively, in finger millet. Subsequently, Rao and Deosthale (1988) observed that the tannin (catechin equivalents) content in 12 brown-coloured varieties ranged from 0.35-2.4% but it was not detected in the white varieties. Shankara (1991) analysed about 85 varieties of finger millet from Karnataka state, India. A wide variability in the total polyphenol content (0.06–0.67% chlorogenic acid, 0.03–0.57% tannic acid, and 0.03–2.37% catechin equivalents) was observed. Sripriya et al. (1996) also reported the brown variety contained more (0.1%) polyphenols than the white variety (0.003%). Chethan and Malleshi (2007) worked on five brown and two white varieties and recorded 1.3–2.3% polyphenols as gallic acid equivalents in brown varieties and 0.3–0.5% in white varieties. Hithamani and Srinivasan (2014) reported the total polyphenol content of native finger millet to be 10.2 mg/g. There is a wide variation in the polyphenol contents of finger millet from different reports, indicating that considerable variations exist among different genotypes and methods of extraction.

Polyphenols are the most widespread compounds in plants and are characterized by their antioxidative properties. These properties play significant roles in the prevention of cancer, cardiovascular disease, and type II diabetes (Shahidi and Chandrasekara, 2013). The prominent polyphenols identified in finger millet are phenolic acids and tannins, while flavonoids are present in small quantities (Rao and Muralikrishna, 2007). Ferulic acid (64%–96%) and p-coumaric acid (50%–99%) in varying percentages have been identified as bound phenolics. Other classes of phenolics (Table 4) identified in finger millet are p-hydroxybenzoic acid, proanthocyanidins, gallic acid, protocatechuic acid, vanillic acid, trans-cinnamic acid–coumaric acid, caffeic acid, quercetin (Viswanath et al., 2009; Banerjee et al., 2012). The tannin content in the outer layer of finger millets serves as a barrier to fungal invasion and thus protects grains against fungal attack. Kumar et al. (2016) reported finger millets to be rich sources of flavonoids, phenolic acids and both free and conjugated forms of phenolic acids. The commonly found hydroxybenzoic acid and hydroxycinnamic acid present in finger millets are protocatechuic and *trans*-ferulic, respectively (Shahidi and Chandrasekara, 2013).

Considerable differences in polyphenol content have been reported with different varieties of finger millet. Variations in the polyphenol content of finger millet have been observed in different varieties. Ramachandra et al. (1977) studied 32 different varieties of finger millet comprising both brown and white seed coat sourced from India and Africa. The brown varieties contain 1.2–2.3% polyphenols, while the white varieties contain 0.3–0.5%. The Indian varieties had values of polyphenol in the ranges of 0.08–0.96% while the African varieties ranged from 0.54 to 3.47%. In another study, Rao and Deosthale (1988) indicated that the tannin (catechin equivalents) content in 12 different variants of brown-coloured finger millet ranged from 0.35-2.4%, but tannin was not detected in the white varieties. The Indian State of Karnataka varieties had wide variability in the total polyphenol content (Shankara, 1991). According to Banerjee et al. (2012), different extraction procedures increased the polyphenol content of finger millet, with values ranging from 1.74 to 13.20%. The types and processing techniques of finger millets affect their polyphenol content. Lansakara et al. (2020) examined two types of finger millet (Ravana and Osadha), and the total phenolic content of these varieties ranged from 0.39 to 1.05 (mg CE/g).

Table 4. Phenolic and flavonoid compound identified in finger millet.

Class	Compounds	Reference
Phenolic acids Hydroxybenzoic acid derivatives	Gallic acid, protocatechin p-hydroxybenzoic acid, vanillic acid, syringic acid	Banerjee et al., (2012); Shahidi and Chandrasekara (2013); Devi et al., (2014)
Hydroxycinnamic acid derivatives	Ferulic acid, trans—cinnamic acid, p- coumaric acid, caffeic acid, sinapic acid, Quercetin	Rao and Muralikrishna (2007), Chethan and Malleshi (2007a), Shobana et al. (2009)
Flavonoids	Proanthocyanidins (Condensed tannins), anthocyanins, flavonols, flavones, flavanones	Chethan et al. (2008), Dykes and Rooney (2006), Chandrasekara and Shahidi (2010), Devi et al., (2014)

Different grain structures have very different polyphenol distributions. There is a higher concentration of polyphenols in the bran (the aleurone layer, testa, and pericarp) than in other portions of the grain. According to Kumar et al. (2016), 60% of the millet's polyphenols are contained in the seed coat tissue and take the form of glycosides. In addition, it has been discovered that finger millet contains phenolic compounds, the majority of which are benzoic acid derivatives with some antioxidant action (Hegde and Sandra, 2005; Chandrasekara and Shahidi, 2011). In another study conducted by Oghbaei and Prakash (2012), polyphenol content was highest in whole finger millet flour (4.18 g/kg), followed by sieved finger millet flour (3.89 g/kg) and vermicelli made from whole finger millet and sieved finger millet (Table 5). The development of other products from whole flour using simple processing methods reduced the phenolic content significantly. Whole finger millet has a higher polyphenol concentration than sieved finger millet flour because the majority of the polyphenols are contained in the brans. According to Dykes and Rooney (2006), cereal bran has three times as much phenolic acid as other grain components. Oghabei and Prakradh (2012) also affirmed that processing increased the bioaccessibility of polyphenols. The bioaccessibility of unprocessed flour was extremely low. In contrast to bound phenolic acids, which must be treated with mechanical, thermal, physical, and acid/alkaline processes in order to be removed from cell walls and internal layers of most grains, free phenolic acids are simply extracted from the exterior layer of most grains. According to Chethan and Mallesh (2007), the solvents employed to extract polyphenols had an impact on how extractable they were. Refluxing was shown to be more effective at extracting the polyphenols, and acidification of the solvent enhanced the extractability (Table 6). After sprouting or pressure-boiling native finger millet, Hithamani and Srinivasan (2014) found that the overall amount of polyphenols was reduced by 50%. However, with open-pan boiling, the degree of decrease (12–19%) varied. By pressure cooking and open-pan boiling, the bio-accessibility of phenols was dramatically reduced (30–35%), but it rose (by 67%) with sprouting. The use of an appropriate processing method for finger millet will enhance the bio-accessibility of phenols. There was a noticeable reduction in the total flavonoids of the grain after sprouting, pressure-cooking, or open-pan boiling. Mutshinyan et al. (2020) discovered that the bioactive compounds in finger millet flour increased significantly with fermentation time. The increase in total polyphenolic content varied from 166 to 488 mg/100 g and 420–606 mg/100 for light brown and dark brown varieties, respectively. There was an increase in total flavonoid content from 160 to 330 mg/100 g and from 249 to 465 mg/100 g for light brown and dark brown varieties, respectively.

The flavonoids in finger millet include anthocyanins, flavonols, flavones, flavanones, chalcones, and aminophenol compounds (Shahidi and Chandrasekara, 2013). An estimated 2 mg/g of flavonoid content can be found in a defatted meal made from finger millet (Chandrasekara and Shahidi, 2011). Others including flavonoids and total phenols have considerable health potential despite the possibility that bioactive molecules in food will reduce the bioavailability of nutrients (Shashi et al., 2007). However, the high quantities of anti-nutrients can be reduced to the bare minimum levels using processing techniques as cooking,

Table 5. Total phenols and flavonoids of finger millet flour and their products.

Parameters	Total polyphenols	Bioaccessible polyphenols	Total flavonoids	Bioaccessible flavonoids	References
Whole FM (g/kg)	3.88	0.41	14.71	0.78	1
Sieved FM (g/kg)	3.60	0.41	11.52	1.21	1
Whole FM Wafer (g/kg)	3.19	0.38	13.77	1.62	1
Sieved FM vermicelli (g/kg)	2.85	0.46	12.17	2.3	1
Fermented light brown FM flour (mg/100 g)	166–488	NR	160–330	NR	2
Fermented dark brown FM mg/100 g	420–606	NR	249–465	NR	2
Indian White FM flour (%)	0.04–0.09	NR	NR	NR	3
Brown grain varieties (%)	0.08–3.47	NR	NR	NR	3
Malawi Whole FM (ferric acid eq/100 g)	292–302	NR	90.24–202.94	NR	4

FM: Finger millet; NR: Not reported; Ref: 1- Oghbaei and Prakash (2012); 2- Mutshinyan et al. (2020); 3- Ramachandra (1977); 4- Xiang et al. (2018).

Table 6. Polyphenols of finger millet extracted by different solvents.

Solvents	Extraction under ambient condition		Extraction by refluxing	
	Pure	Acidified with 1% HCl	Pure	Acidified with 1% HCl
Water	0.17 (7.4)	0.34 (14.8)	0.25 (10.9)	0.45 (19.6)
Acetone	0.30 (13.0)	0.50 (21.75)	0.90 (39.0)	1.04 (45.2)
Propanol	0.24 (1.0)	0.58 (25.2)	0.86 (37.3)	1.23 (53.5)
Ethanol	0.30 (13.1)	0.74 (31.3)	1.02 (44.3)	1.38 (60.0)
Methanol	0.30 (13.1)	0.90 (39.5)	1.38 (53.9)	2.30 (100)

Chethan and Mallesh (2007).

soaking, milling, fermentation, extrusion, and alkali and acidic treatments (Fasasi, 2009).

4.2.2. Dietary fibre

Dietary fibre of plant origin has a greater influence on maintaining normal blood glucose after the consumption of carbohydrate foods (Udeh et al., 2017). Soluble polysaccharides can be metabolized in the small and large intestines by the action of bacterial enzymes. The products of metabolism aid digestion and maintain healthy microflora in the colon. Dietary fibre as a bioactive compound is now very popular in nutrition due to its positive contributions to health and quality of life (Udeh et al., 2017). Kamath and Belavady (1980) reported the dietary fibre of finger millet grain as 18.6%.

The dietary fibre of ten varieties was studied by Premavalli et al. (2004), and the values were in the range of 7–21.2%, with base region varieties showing higher dietary fibre than hilly region varieties. Researchers have shown that DF constitutes about 22.0% of the millet, which includes the non-starch polysaccharides, cellulose, pectin, and lignin (Amadou et al., 2013). The non-starch polysaccharides are mostly arabinoxylans, with a few -d-glucans thrown in for good measure. Both arabinoxylans and d-glucans are major components of the grain's soluble dietary fibre fraction (Rao and Muralikrishna, 2007; Amadou et al., 2013). Bacha et al. (2013) reported a very highly significant variation in the fibre content among the accessions millet of the Gabes Oasis, Tunisia studied. The non-dietary fibre content also varied from 22.92 to 57.25% of DM.

4.3. Nutritional composition of finger millet and other cereals

The proximate makeup of various major and minor grains, as well as finger millet, is shown in Table 7. When compared to other grains, finger millet contains 72.6% more carbohydrates, and its fat level (1.5 mg/100 g) is lower than the values seen in maize, brown rice, and sorghum (Ramashia et al., 2021). The protein content is within the range reported for some major cereals such as wheat, sorghum and maize. Its protein content is higher than the values reported for rice which is a staple food in Africa (Premavalli 2012). Finger millet is a rich source of protein and its amino acids are higher than FAO/WHO recommended standards. The presence of some essential amino acids such as methionine, tryptophan and lysine which are lacking makes it superior to rice and wheat (Fernandez et al., 2003). The proximate composition of finger millet with other varieties of millet (Table 7) (foxtail, Kodo and barnyard) reveals finger millet is higher in protein, ash and dietary fibre, however, the dietary fibre of pearl millet is higher (11.3 g/100 g) than the dietary fibre of finger millet (8.5 g/100 g).

When compared to other grains, finger millet has a considerably higher mineral content (Table 8). In comparison to the figures reported for wheat, maize, rice, and sorghum, it has higher levels of phosphorus, potassium, magnesium, zinc, and iron (Table 8). Its calcium concentration is roughly 91% higher than that of wheat, compared to levels seen in other major and minor grains (Premavalli, 2012); Jideani (2012) and Ramashia et al. (2021). Finger millet has higher iron and potassium contents than values reported for all minor cereals and this indicates that finger millet can contribute significantly to the reduction of food and nutrition insecurity if its potential as a nutrient-dense crop is fully harnessed.

5. Modulation of chemical components of finger millet

On essential body enzymes, distinct meals have specific effects. Foods are referred to as "bi-functional modulators" because of their potent detoxification-inducing or -inhibiting effects on enzyme activity. A therapeutic effect may not always follow from eating the same meal frequently in large quantities or at high doses. Lower levels of certain chemicals may be more therapeutic and supportive of biochemical pathways than higher levels of chemicals, which may override signals from high nutrient concentrations. Studies on finger millet have uncovered a variety of therapeutic advantages that may be useful for treating some food-dependent illnesses like obesity, diabetes, and digestive issues (Shobana et al. 2010). Low insulin secretion causes diabetes mellitus, a complex metabolic disorder that affects the metabolism of proteins, carbohydrates, and lipids. Diabetes mellitus is characterised by elevated systemic glucose levels (Devi et al., 2014). One of the preventive methods for treating diabetes mellitus involves lowering postprandial hyperglycemia, or the spike in blood sugar, by preventing the action of the enzymes amylase and glucosidase, which convert carbohydrates into glucose for absorption in the human stomach.

Due to the grain's high polyphenol content and dietary fibre level, frequent consumption of finger millet has been speculated to be linked to a lower risk of diabetes over time (Chethan et al., 2008b). According to research, finger millet's natural phenolic chemicals have been demonstrated to potentially modulate glucose metabolism. This is accomplished

Table 7. Proximate composition of finger millet and other cereals.

Food	Protein (g)	Fat (g)	Ash (g)	Crude fibre(g)	Carbohydrate (g)	Energy (kcal)	References
Rice (brown)	7.9	2.7	1.5–2.0	1.0	76.0	362	1, 3, 4, 7
Rice	6.8–7	0.5–1	0.6	4.1	78.0–79.0	370	1, 2, 3, 7
Wheat	11.6–11.8	1.5–2.0	1.5–2.0	2.0–12.6	71.0–71.2	348	1, 2, 3, 7
Maize	8.1–10.5	3.8–4.6	1.2	2.8–4.1	73.0	358	1, 2, 3, 5 7
Sorghum	7.9–10.4	2.8–3.1	1.6	2.0–12.3	70.7–73.0	329	1, 2, 4,5, 7
Pearl millet	11.6–11.8	4.8–5.0	2.2	2.3–11.3	67.0–67.5	363	1, 2, 4, 7
Finger millet	6.10–10.99	1.5	2.6	3.6	72.6	336	1, 2, 3, 4, 7,8
Foxtail millet	11.2–12.34	2.38–4.3	0.47–3.3	2.6–8.5	60.9–75.2	351	1, 2, 3, 7,9
Barnyard millet	6.2–11.0	2.2–3.9	4.4–4.5	1.98–13.6	55.0–65.5	300	1, 3, 4, 7
Kodo millet	9.8	1.3–3.6	2.6–3.3	2.47–5.2	65.9–66.6	353	1, 3, 4, 7
Fonio millet	8.7	3.5	3.8	8.5	73.6	360	4, 7
Teff	8 .5	2.2	-	2.2	73.0	345	4, 7

[1] Ramashia et al., (2021); [2] Hassan et al., (2021); [3] Gupta et al., (2017); [4] Premavalli. (2012); [5] Jideani (2012); [6] Patel et al., (2014) [7] (Saldivar, 2003); [8] Amadou et al., (2013); [9] Li et al. (2021).

Table 8. Mineral contents of finger millet and other cereals.

Food	Calcium (mg/100 g)	Iron (mg/100 g)	Phosphorus (mg/100 g)	Potassium	Thiamine	Riboflavin	Niacin	References
Rice (brown)	33	1.8–12	1030	1500	0.41	0.04	4.3	1,4, 5, 7
Wheat	30–170	3.5–12	1170	1550	0.41	0.10	5.1	1,4, 5, 7
Maize	26–60	2.7–11	990	1200	0.38	0.20	3.6	1,4, 5, 7
Sorghum	11–25	504	350		0.38	0.15	4.3	1,4, 5, 7
Pearl Millet	0.33–42	11.0	296	307	0.38	0.21	2.8	4, 5, 7
Finger millet	350	3.9	341	402–411.77	0.42–48	0.19	1.1	1,4, 5, 7,8
Foxtail	31	2.8	290	250	0.59	0.11	3.2	4, 7
Barnyard millet	22	5.0–18.6	280	-	0.33	0.10	4.2	4, 7
Kodo millet	35	1.7	188	144	0.15	0.09	2.0	4, 7
Fonio	30	3.4			0.30	0.10	3.0	4,7
Teff	110	90			0.50	0.10	2.0	4, 7

[1] Ramashia et al., (2021); [2] Hassan et al., (2021); [3] Gupta et al., (2017); [4] Premavalli. (2012); [5] Jideani (2012); [6] Patel et al., (2014) [7] Saldivar 2003; [8] Amadou et al., (2013); [9]Adeboye et al., (2021).

by blocking the main enzymes needed to convert carbohydrates into glucose (Devi et al., 2014). The occurrence frequently influences the digestion of carbohydrates, which delays the systemic absorption of glucose and controls the postprandial blood glucose spike. Aldose reductase is the main enzyme associated with diabetes-induced cataractogenesis, and it has been discovered that the phenolics in the finger millet seed coat can inhibit it in a non-competitive method that is reversible (Chethan and Malleshi 2007). The mechanism of the inhibition of millet polyphenols on aldose reductase is implicated in the prevention of the enzymatic conversion of glucose to sorbitol and glyceraldehydes to glycerol. According to Chethan et al. (2008b), while the individual phenolic components showed an uncompetitive inhibition, it was discovered that the phenolic extracts from finger millet exerted a mixed non-competitive form of inhibition on the malt amylases. A methanolic extract of finger and Kodo millet's impact on glycation and collagen cross-linking was documented by Hedge and Chandra (2005). Collagen's glycation was inhibited when it was treated with 50 mM glucose and 3 mg of finger millet extract. The finger millet's inhibitory impact is brought on by the phenolic compounds in the extract and other phytochemicals that were taken from the seed coat that has antioxidant properties. Additionally, Hedge and Chandra (2005) investigated the impact of a finger millet methanolic extract on collagen cross-linking. Comparing the extract to synthetic antioxidants, the findings revealed that the extract significantly slowed the glycation response (aminoguanidine and butylated hydroxyanisole). The phenolic compounds, particularly ferulic acid, were assumed to be the cause of the inhibitory action because they have been proven to provide renal protective benefits through improved glycaemic management and kidney structural modifications that prevent oxidative stress (Hedge and Chandra 2005). Researchers found that people with non-insulin-dependent diabetes mellitus who included finger millet in their meals had significantly reduced blood plasma glucose levels (Kumari and Sumathi, 2002). Among the investigated phenolic compounds, trans-cinnamic acid displayed the highest level of inhibition (79.2%), but syringic acid displayed a lower level of inhibition (56 per cent) (Shobana et al., 2009). Consistently with this report, an earlier work by Geetha and Parvathi (1990) indicated that the supplementation of diets with ragi (finger millet) showed a higher reduction in fasting and postprandial glucose levels than supplementation with other millet. The finger millet's hyperglycaemic, hypocholesterolemic, nephroprotective, and anti-cataractogenic effects were demonstrated by Shobana et al. (2010). In the study, reduced fasting hyperglycaemia and partial reversal of abnormalities in serum albumin, urea, and creatinine status were observed in strepto zotocin-induced diabetic rats. Shobana et al. (2010) and Devi et al. (2014) reported that hypertriacylglycerolaemia, hypercholesterolaemia, nephropathy and neuropathy associated with diabetes were remarkably reversed in a diabetic group fed with the diet containing the finger millet seed coat. Additionally, it was discovered that finger millet-based meals improved rats' antioxidant status and improved blood glucose regulation.

5.1. Clinical application

Toxins play a part in the development of chronic diseases, therefore, clinicians must quickly learn how to use therapeutic modalities to help patients with high toxin loads. Finger millet contains essential amino acids with therapeutic properties. The essential amino acids methionine, cysteine, tryptophan, isoleucine, leucine, phenylalanine, and lysine are all present in finger millet grains in amounts of 44.7% (Manjula et al., 2015; Sood et al., 2017; Ramashia et al., 2018). Additionally, it contains threonine, which lowers cholesterol, prevents obesity, and lowers the risk of cancer in humans (Mathanghi and Sudha, 2012; Thapliyal and Singh, 2015). Some researchers reported that the grains contain the highest amount of methionine (194 mg/g) when compared to other millet species (Singh et al., 2012; Prashantha and Muralikrishna, 2014). Finger millet grains contain linolenic and palmitic acids, which are essential for the development of the brain and neural tissue (Muthamilarasan et al., 2016). Finger millet grains also contain moderate fat, which contributes to better storage properties and helps to prevent the risk of obesity and regulate body weight (Verma and Patel, 2013; Gunashree et al., 2014). Conversely, other millet grains contain a higher amount of fat, ranging from 3.5 to 5.2% (Shahidi and Chandrasekara, 2013). The low-fat content and high dietary fibre with higher amounts of carbohydrates which are available in the form of non-starchy polysaccharides are essential in providing nutritional and physiological benefits such as hypoglycemic and hypocholesterolemic effects (Banusha and Vasantharuba, 2013).

6. Common processing methods and their effects on quality attributes of finger millet

6.1. Soaking

Soaking has been commonly used to lower the content of antinutrients in food, and the process involves the addition of distilled water to finger millet grains to steep the grains for a period of 12 h or more at 30–60 °C. After soaking, the grains are drained, the water is discarded, and the grains are thoroughly washed. The grains are dried for 90 min at 60 °C before being milled into flour (Banusha and Vasantharuba, 2013). Soaking finger millet in water for one to two days at room temperature reduced some anti-nutritional elements, which in turn increased the bioavailability and bioaccessibility of minerals and the nutritional quality (Hotz and Gibson, 2007). The bioavailability of zinc was improved and the amount of phytic acid was lowered after soaking (Saleh et al., 2013). Shigihalli et al. (2018) demonstrated a 15–18% reduction in phytic acid after a 48-hour soaking time in three different types of finger millet. According to Patel et al. (2018), phytate and trypsin inhibitor activity in soaked finger millet decreased by 13.22 and 13.51 per cent, respectively. According to Rathore et al. (2019), the tannin and phytic acid content of finger millet were dramatically reduced after soaking in distilled water or a NaOH solution for 8 h. The soaking procedure will improve the nutritional composition of finger millet by lowering the antinutritional component. This is a simple technology that can be used by all food processors, especially in the rural areas where these crops are mostly grown.

6.2. Germination

In healthy seeds with the ability to grow into seedlings, germination occurs naturally (Echendu et al., 2009). The whole grains in this procedure are steeped in water for two to 24 h, and then they are conditioned for roughly 48 h. Incubating the soaked seeds for 48 h at 30 °C, according to Shimray et al. (2012), may also speed up germination. It is simple to modify the procedure, and it is a low-cost operation. Germination of seed requires moisture, oxygen, and a favourable temperature for enhancement of nutritional composition and improvement of functional properties (Mbithi-Mwikya et al., 2000; Chove and Mamiro, 2010; Pushparaj and Urooj, 2011). This processing method is a good choice for the development of finger millet products. It can retain major minerals and some vitamins when compared with other processing methods (El-Adawy, 2002). Germination enhances the anti-oxidant of finger millet and reduces various anti-nutritional factors in the crop (Abioye et al., 2018). The reduction of antinutritional factors increases protein content (Abioye et al., 2018; Alozie et al., 2009; Enujiugae et al., 2003).

A decrease in pH and an increase in TTA have been reported during germination (Nefale and Mashau, 2018; Owheruo et al., 2019). The change in pH and TTA was a result of catabolic reactions of complex organic compounds (lipids and protein), while an increase in acidity could be due to the hydrolysis of complex compounds (Adeyemo et al., 1992). Hydrolytic enzymes are produced more quickly during germination, and they also release sugars and amino acids when they interact with the starch and protein that serve as the food source for lactic acid bacteria and yeast (Adewara and Ogunbanwo, 2013; Gernah et al., 2011). The germination process hydrolyzes complex substances such as phytate, polypeptides, and lipids, which results in the synthesis of acid phosphate, amino acids, and fatty acids (Gernah et al., 2011; Nefale and Mashau, 2018). This leads to improvement in the digestibility of germinated finger millet products (Adedeji et al., 2014).

Mbithi-Mwikya et al. (2000) reported a significant variation in proximate composition and a high decrease in starch content of sprouting finger millet seeds. Germination uses energy produced by the breakdown of carbohydrates in the first phase of germination, reducing total carbohydrate content and increasing -amylase activity (Mubarak, 2005; ;Inyang and Zakari, 2008; Onwuka et al., 2009; Oghbaei and Prakash, 2016; Zhang et al., 2015). During germination, protein levels increased rapidly (Laxmi et al., 2015; Otutu et al., 2014). Owheruo et al. (2019) reported an appreciable increase in protein, fibre, and ash content of the germinated millet. The values reported were within the range of 7.61–7.81%. The increase in protein may be due to the production of new enzymes (Jan et al., 2017) and the synthesis of amino acids during germination (Ongol et al., 2013). An increase in crude fibre during the germination process has been reported (Laxmi et al., 2015; Owheruo et al., 2019), which is due to the breakdown of complex polysaccharides. Germination also improves fibre content (Jan et al., 2017; Chinma et al., 2009; Rumiyati et al., 2012). The increase in fibre in food is desirable as it delays the absorption of glucose from ingested food (Riccardi and Rivellese, 1991) which is beneficial for diabetic patients. The metabolic activity that takes place during germination lowers the fat content of Nepalese finger millet types while increasing the total reducing sugar (Chinma et al., 2009; Karki and Kharel, 2012).

Research has shown that germination improved finger millet's mineral content (Chauhan and Sarita, 2018; Ijarotimi, 2012; Nkhata et al., 2018; Obiajunwa et al., 2005). The calcium content of finger millet was reported to increase significantly ($p < 0.05$) during germination as a result of a decrease in oxalic acid during sprouting because oxalic acid is a calcium chelating agent (Proietti et al., 2009). This makes germinated finger millet flour a good source of calcium. Owheruo et al. (2019) observed a decrease (510.0–150.0 ppm) and an increase (470.0–2295.0 ppm) in the sodium and potassium contents of germinated finger millet. The ratio of sodium to potassium in germinated finger millet flour was found to be 0.07, which is below the recommended maximum value of 1.0 (NRC, 1989). Sodium and potassium aid blood pressure regulation and nerve function, hence they are very important in human nutrition (Yoshimura et al., 1991). The sprouting which occurs during germination can improve the bioaccessibility of iron (Suma and Urooj, 2014), which makes germinated finger millet a good food supplement for infants to combat iron deficiency (anaemia) in children (Tatala et al., 2007). During the germination of finger millet, Chauhan and Sarita (2018) observed an increase in calcium and iron and a decrease in phosphorus.

Germination has been reported to increase protein and ash content. Trang et al. (2022) reported germination increased enzyme activities in all the millets, thereby increasing protein digestibility. The process of germination has been associated with the enhancement of nutrients due to an increase in enzyme activities. The increase in enzymic action also helps in lowering the antinutritional content of finger millet such as tannin, phytic acid and trypsin inhibitors activity which in turn improves the bioaccessibility of essential minerals such as zinc, iron and calcium.

One of the ways to increase the mineral bioaccessibility of food is to reduce the antinutritional factors (Suma and Urooj, 2014). When compared to other processing methods, Chauhan and Sarita (2018) revealed that germination is an effective method for reducing anti-nutrients (Chauhan and Sarita, 2018). The reduction in tannin content has been linked to two factors, which are the leaching of soluble tannin during soaking and germination (Hussain et al., 2011; Sade, 2009). Phytate is reduced during germination due to the hydrolytic action of phytase on phytate to produce phosphate and myoinositol phosphates (Abioye et al., 2018; Chauhan and Sarita, 2018; Abd et al., 2007). This increases the availability of phosphorus and makes the food more nutritious.

Oxalic acid has also been reported to decrease significantly during germination due to the leaching of soluble oxalate content during steeping (Suma and Urooj, 2014). The reduction in oxalate content is very important in finger millet because it interferes with calcium bioavailability. Kumar et al. (2016) reported a reduction in the activity of trypsin inhibitors during germination. The decrease is attributed to the alternative usage of trypsin inhibitors as an energy source in the germination process. Kunjal and Dhan (2019) who determined the effects of germination on six different varieties of Nepalese finger millet reported that germination of finger millet seeds for 72 h at 28 ± 2 °C had an impact on the anti-nutritional factors of the grain. Phytic acid, total oxalates, total polyphenols and total flavonoid contents decreased by 63.54%, 53.41%, 58.71% and 11.34%, respectively after germination while tannin content increased by about 33.21% on average for all six varieties.

In a similar work, Abioye et al. (2018) reported that total phenols and tannin content reduced in germinated finger millet from 42.63% to 38.46% and 61.66%–33.33%, respectively while an increase was observed in flavonoid (26.66%–33.33%) and antioxidant activity (48.30%–51.13%). Germination also increased the alkaloids (36.03%–68.44%) of finger millet. Alkaloids are useful in the production of depressants, stimulants, relaxants, and tranquillizers. The preference for alkaloids in medicine is due to their prompt action in targeting affected areas of the nervous system (Onwheruo et al., 2019). The phenolic content for germinated finger millet was 1.57–5.70 mg/g. Bound phenolic compounds are released by the enzymatic reaction that occurs during germination (Maillard and Berset, 1995). Phenols have an anti-oxidative property and can extend the shelf-life of cereal products (Chethan and Malleshi, 2007). Free radical scavenging activity in grains increased from 70.0%; to 72.14% after germination. The ferric-reducing power of finger millet flour also increased from 46.91 to 53.54 mg/g) after germination. This indicates anti-oxidative potential in germinated finger millet.

6.3. Fermentation

When creating complementary foods in developing nations, fermentation is a crucial processing technique that is frequently used. By employing microorganisms and their enzymes to biochemically alter food composition, this technique increases nutrient availability and bioaccessibility. Additionally, it may be able to preserve food and increase shelf life (ChavesLopez et al., 2014; Li et al., 2007; Steinkraus, 1994). Starter cultures are neither necessary nor required for the process (Frazier and Westhoff, 1986). Finger millet has been fermented using cultures of different strains (Antony and Chandra, 1999; Mbithi-Mwikya et al., 2000).

6.3.1. Microbial flora in fermentation

Finger millet is fermented for 48 h by lactic acid bacteria, which results in a drop in pH and a rise in titratable acidity. Leuconostoc, Lactobacillus, and Pediococcus, the minor bacteria discovered, predominated (>80%) the remainder of the fermentation (Antony and Chandra, 1997). The pH decreased as the amount of lactic and acetic acid increased during fermentation; this pattern persisted even when finger millet was fermented without a starter culture (Antony et al., 1996a). Lactic and acetic acids were the most prevalent organic acids, while valeric, butyric, and isobutyric acids were found in very little amounts. Finger millet, when fermented under similar conditions to other types of millet, had higher organic acids than other fermented millets (Antony et al., 1996b) which is an indication that finger millet has better ferment-ability properties. Higher acidity can increase the keeping quality of millet by inhibiting microbial growth. It also enhances the flavour of processed millet (Giese, 1994).

Antony and Chandra (1997) reported an increase in microbial population until 18–24 h of fermentation of finger millet. This led to a significant reduction in the contents of total and reducing sugars. The glucose content increased at the early stage of fermentation due to the action of maltase and α-amylase on carbohydrates (El-Hag et al., 2002; Osman, 2011). The glucose produced in the fermentation process served as a substrate for microbes which reduced the carbohydrate after 24 h of fermentation (Osman, 2011). On the other hand, the crude protein content is not affected by fermentation (Antony et al., 1996b). A similar observation was made by Chavan and Kadam (1989) on other minor cereals (Antony et al., 1996). Venkateswaran and Vijayalakshmi (2010) reported an increase in soluble proteins during the fermentation of finger millet with *M. purpureus*. Microbial and enzyme activities on protein increased the solubility of proteins leading to an increase in the free amino acid content. Hydrolytic enzyme activity on tannins and phytates could have contributed to the increase in amino acids (Chavan and Kadam, 1989).

Lactic acid fermentation has an impact on the amino acids of cereals and legumes. For instance, the lysine content in millet increased when fermented with lactic acid bacteria (Hamad and Fields, 1979). Fermentation of finger millet with Lactobacillus salivaricus increased tryptophan by 17.8% and lysine by 7.1%. On the other hand, the leucine-to-lysine ratio had a significantly reduced value during fermentation (Mbithi-Mwikya et al., 2000). When combined with additional B vitamins, fermented finger millet had increased biological value and net protein consumption (Rajyalakshmi and Geervani, 1990). Niacin, pantothenic acid, and riboflavin all had concentrations that were greater than those found in raw grains, with respective values of 0.62 mg/100 g, 1.6 mg/100 g, and 4.2 mg/100 g (Basappa et al., 1997). During the fermentation of finger millet, cyanocobalamin synthesis was also noted. According to Antony et al. (1996a), the amount of crude fat in fermented finger millet decreased by roughly 42.9%, and the amount of long-chain fatty acids also decreased. In the unfermented, fermented for 24 h, and fermented for 48-hours samples, the proportions of polyunsaturated fatty acids (PUFA) were 32.2, 33.4, and 30.8%, respectively. This suggests that PUFA may not be impacted by fermentation.

Fermentation increased the availability of iron, manganese, calcium, and magnesium for longer fermentation periods of finger millet (Makokha et al., 2002). Fermentation of finger millet with *M. purpureus* for ten days reduced phytate and tannin and reduction was achieved by 88.8% and 90.1%, respectively. This process increased the production of HCl-extractable minerals and the synthesis of the anti-hypercholesterolemic metabolite, statin. Fermentation can increase the bioavailability of some minerals (calcium, phosphorus, potassium, and iron) while others (magnesium, manganese, and zinc) can be reduced (Aisoni et al., 2018). Fermented finger millets products can therefore be used as functional foods and nutraceuticals, especially in some areas where there are gross micronutrient deficiencies. Probiotic foods can also be produced from fermented finger millet.

6.3.2. Effects on anti-nutrients

Fermentation reduced phytates, tannins, and trypsin inhibitor activity of finger millet by 20, 52, and 32%, respectively, after 24 h of fermentation (Antony and Chandra, 1998). This increased the mineral availability sporadically, especially for calcium, phosphorous, zinc and iron. Makokha et al. (2002) reported that fermentation as a processing method is effective in reducing phytic acid in finger millet and also increases mineral availability. He reported a 54.3% and 72.3% mean decrease in phytic acid after 72 and 96 h of fermentation.

6.4. Malting

Malting is a technique that employs a combination of processes. Steeping, germination, kilning, milling, and sieving are among the unit operations used to create a relatively nutritious quality product with improved starch digestibility, sensory attributes, and reduced anti-nutrients (Ramashia et al., 2019). Banusha and Vasantharuba (2013) discovered that malting increases nutrient content via induced hydrolytic activity (Banusha and Vasantharuba, 2013). Thapliyal and Singh (2015) and Sarkar et al. (2015) have used malted finger millet for brewing local beverages among rural dwellers. The brewed grains are refreshment drinks used in community ceremonies, especially by farmers (Rurinda et al., 2014). Modern technology allows for the large-scale production of drinks with increased quality. In the study by Udeh et al. (2018), malting did not significantly lower the pH of the different kinds of finger millet during the malting periods. Malting of finger millet for 72–96 h positively affected the mineral content (Platel et al., 2010). The bioaccessibility of iron increased by 3-fold with reduced bio-accessibility of zinc by the malting process. However, the bioavailability of copper was not affected. Hemalatha et al. (2007) reported that the phytate content of finger millet (417 mg/100 g) is higher than values reported for sorghum, barley, rice, and maize which ranged from 160-414 mg/100 g (Sripriya et al., 1997). Changes in phytic acid during malting are an indication of the dissociation of phytate rather than degradation (Udeh et al., 2018). Malting of finger millet at 26 °C for 48 h reduced the total phenol content to 25% and a linear correlation was observed between the phenol content and antioxidant activity (Hejazi and Orsat, 2016). Makokha et al. (2002) observed that malting decreased phenolic content by 23.9 and 45.3% at 72 and 96 h, respectively.

6.5. Roasting

Roasting is an age-long unit operation practised in households and rural areas in the processing of finger millet. Roasting involves dry frying and can drastically reduce anti-nutritional or toxic components such as goitrogenic compounds, cyanides, alkaloids, and saponins. It can also extend the shelf life of foods and increase the storage life of such foods (Huffman and Martin, 1994). The roasting process increased digestibility with minimal loss of nutritious components (Krantz et al., 1983).

The moisture, fat and protein of finger millet were observed to decrease slightly on roasting while total carbohydrate, ash and fibre content increased with an increase in calcium and iron bio-availability (Singh et al., 2018). However, Auko (2009) reported that roasting did not affect the proximate composition while in-vitro protein digestibility of finger millet increased as roasting time and temperature increased.

The total flavonoid content of finger millet was unaffected by 10 min of roasting, while the amount of total phenol dramatically increased (Hithamani and Srinivasan, 2014). According to Gahlawat and Sehgal (1994), when finger and barnyard millet were roasted as part of the preparation of weaning foods, the iron bioavailability increased. Roasting enhanced the release of phenolic acids from the food matrix thereby increasing their bioavailability (Hithamani and Srinivasan, 2014).

Phenols have an antioxidative effect against some pathophysiological conditions in biological systems (Shahidi and Chandrasekara, 2013). Polyphenols are attracting interest due to their ability to improve gut health and reduce the risks of heart-related diseases (Fava et al., 2006). They also contain anti-inflammatory, anticarcinogenic, and antioxidant activities (Serrano et al., 1998; Chandrasekara and Shahidi, 2013). Humans ingest around 1 g of polyphenols daily, which are primarily found in plant-based meals (Hithamani and Srinivasan, 2014).

In finger millet, there are several phenolic compounds with antioxidant properties (Chandrasekara and Shahidi, 2010; Hegde and Chandra, 2005). The antioxidant activity in unroasted finger millet (89.59%) decreased (86.78%) due to roasting (Singh et al., 2018). However, Vogrincic et al. (2010) had earlier reported a decrease in the DPPH of buckwheat with thermal processing. This could be due to the ability of phenols to bind with proteins, thereby reducing the number of extractable phenols from the grains after thermal processing.

7. Prospects of finger millet

The increase in consumer awareness of food that is high in nutritional value and health benefits has challenged the food industry in the production of functional food products. Finger millet has a great future in clinical and therapeutic applications due to its physiological advantages such as hypoglycemic and hypocholesterolemic effects. The dietary fibre, polyphenols, complex mixture of benzoic acid, cinnamic acid derivatives, and non-starchy polysaccharides in finger millet are known to offer several health benefits such as antidiabetic, antioxidant, hypocholesterolemic, antimicrobial, and protection from diet-related chronic diseases to its regular consumers (Devi et al., 2014). This potential of finger millet as a therapeutic and health-building food could be harnessed in diet therapy.

Finger millet's potential as an alternative food for celiac patients could also be considered (Kakade and Hathan, 2014). According to Yang et al. (2022), millet flour, which is a rich source of nutrients, can be used to develop novel gluten-free, high-fibre, high-phenolic, mineral-enriched, low-fat, and low-glycemic foods. This puts this technology in the segment of delivering functional foods to manage lifestyle diseases, particularly type-2 diabetes. Also, an increase in the research findings on the nutraceutical properties of finger millet could be considered in the formation of nutraceutical food.

8. Conclusion

Finger millet varieties are enormous, with a remarkable difference in nutritional and antioxidant properties. The varieties are mainly grown in Africa and Asia, where they have become staple foods in some regions of these continents. Processing methods enhance the nutritional contents of all varieties and reduce anti-nutritional factors that can affect the uptake and bioavailability of certain nutrients in the body. The presence of bioactive compounds in all varieties further emphasized the health potential of the cereal. All the varieties of finger millet contain fewer water-soluble vitamins but are high in calcium, potassium, and magnesium. The influence of varieties on the mineral composition of finger millet is significant. Therefore, varieties with higher mineral composition should be utilized for dietary purposes. The varieties with higher nutrients could be used in producing micronutrient-dense beverages and breakfast cereals.

Finger millets possess qualities that make them suitable for other advanced processing methods such as extrusion cooking, pulse electric field and other non-thermal treatments. These processing methods can further increase the potential of this cereal and also promote its acceptability in other regions where the crop is still minor. The grain can be used as an ingredient in developing breakfast cereals, bakery products, and snacks for schoolchildren. Finger millet grains are beneficial for improving the health status of those who rely on them as a staple food due to their high proportion of nutraceutical components such as antioxidants and polyphenols. The presence of flavonoids in finger millet increases its potential in the prevention and management of type 2 diabetes. The assessment of phenolic compounds of pearl and finger millets obtained from South Africa and Zimbabwe as determined by Hassan et al. (2020) confirmed their effective utilization as functional food ingredients for promoting health. Their health benefits will further increase their potential in the development of functional foods and nutraceuticals. In some African and Asian regions, the use of various finger millet varieties may help to reduce food insecurity.

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