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FOOD SCIENCE & TECHNOLOGY | RETRACTED ARTICLE

RETRACTED ARTICLE: Nutritional, technological, and medical approach of finger millet (*Eleusine coracana*)

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Abstract: Finger millet (*Eleusine coracana* L.) is also known as African millet and is commonly called “ragi” in India. It has excellent nutritional value and is even superior to other common cereals. It is a richest source of calcium (344 mg) and magnesium (408 mg) than other millets. Predominant fatty acids of this millet are oleic (49%), linoleic (25%), and palmitic acids (25%). Finger millet contains both water-soluble and lipo-soluble vitamins. Emerging bakery products prepared from this millet are pasta, noodles, vermicelli, and bread. Being gluten free, it is suitable for individuals suffering from celiac disease. Finger millet grain is a rich source of several phytochemicals. Finger millet possesses blood glucose lowering, cholesterol lowering, and antiulcerative, wound healing properties as indicated by *in vitro* and *in vivo* studies. Commonly used processing techniques for this millet are milling, malting, popping, and decortications.

Subjects: Food Additives & Ingredients; Food Chemistry; Food Engineering; Food Laws & Regulations

Keywords: finger millet; calcium; magnesium; pasta; cholesterol lowering; blood glucose

1. Introduction

Finger millet (*Eleusine coracana* L.) is also known as African millet and is commonly called “ragi” in India. Being one of the ancient grains, it is believed to be originated in East Africa and introduced

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PUBLIC INTEREST STATEMENT

Finger millet (*Eleusine coracana* L.) has excellent nutritional value. It is a richest source of calcium (344 mg) and magnesium (408 mg) than other millets. This minor millet is known for having several health benefits such as blood glucose lowering, cholesterol lowering, antiulcerative, and wound healing properties which are attributed to its polyphenol and dietary fiber contents. Being gluten free, it is suitable for individuals suffering from celiac disease. Therefore, the aim of the current study was to review the nutritional, technological, and medical approach of finger millet (*E. coracana*).

into India by sea traders around 3000 B.C. The word ragi originated from a Sanskrit word “raga” meaning red. In India, it is commonly grown for human consumption and also in many other arid and semi-arid areas of the world. This millet can grow in almost all types of soils and climatic conditions including alkaline soils with pH as high as 11 and at an altitude of 2,500 m from sea level, with average annual rainfall ranging from 800 to 1,200 mm. It is known as the poor man’s food because of its long sustenance as it can be stored safely for many years without infestation by insects and pests. This property makes it a very necessary famine reserve food. The world production of finger millet is about 4.5 million tons per annum, out of which India produces nearly 55% of the total production. Finger millet is commonly cultivated in India, Nepal, Sri Lanka, East China and Bangladesh, Kenya, Tanzania, Rwanda, Uganda, Burundi, Ethiopia, Sudan, Zimbabwe, Malawi, and Madagascar. *E. coracana* is the most common species of this millet cultivated for food. Other wild and semi-wild species of this millet are *Eleusine indica* and *Eleusine african*. The grain has distinct morphological features. It is a small seeded grain and its kernel is not having a true caryopsis but a utricle. Its pericarp (glumes) in the utricles is not fused with the seed coat or testa, thus its pericarp can be easily removed by rubbing or by soaking in water or sometimes it gets detached from the seed during threshing. Large variations in color, appearance, and size of this millet kernel have been observed among varieties. Its grain color varies from white to orange, deep brown, and purple to almost red. But the most common color of the seed is bright red. Its endosperm is white in color, similar to rice. The kernel shape may be spherical, globular, or oval and varies in size from 1 to 1.8 mm. Its seed coat contains five layers and these are attached tightly to the endosperm (McDonough, Rooney, & Earp, 1986). Embryo, endosperm, and seed coat of this millet account for about 15% of the kernel mass. The endosperm of this millet is soft and fragile and is divided into three parts namely, peripheral, corneous, and flourey. Flourey endosperm comprises about 83% of whole grain. The endosperm of finger millet is mostly filled with starch granules. The shape of starch granules may be spherical, polygonal, or lenticular in flourey area, corneous and at peripheral regions. According to the data of United States Department of Agriculture (USDA), world millet production, which was 32.5 million tons in 2010/11 season, declined to 27.4 million tons in 2011/12 season and reached 30.4 million tons with an increase in approximately 3 million tons in 2012/13 season. USDA projects that world millet production decreased to 29 million tons in 2013/14 season, which will reach 30.3 million tons level again in 2014/15 season. Millet is intensely produced in India, Nigeria, and Niger. These three countries realize 63.7% of world millet production. Solely India realized 10.6 million tons of 30 million ton world millet production in 2013/14 season. Ranking second after India, Nigeria realized 5 million tons of millet production in 2013/14 season, while Niger realized 2.9 million tons of production.

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2. Nutritional value of finger millet

Finger millet has excellent nutritional value. It contains 6–8% protein, 1–1.7% fat, starch 65–75%, minerals 2–2.25%, and dietary fiber 18–20%. Its proximate composition is superior to wheat, maize, sorghum, and rice with regard to dietary fiber, calcium, and few micronutrients. The seed coat of this millet is a rich source of phenolic compounds, minerals, and dietary fiber (Shobana, Sreerama, & Malleshi, 2009).

2.1. Protein

Protein content of finger millet normally ranges between 6 and 8%, although low protein content of 5% and high protein content of 12% have been reported in different varieties (Hulse, Laing, & Pearson, 1980). Prolamins content is about 35–50%, albumins and globulins constitute 8–15% of total proteins. Amino acid composition of this millet is good as it contains lysine (2.5%), tryptophan (13%), methionine (2.9%), threonine (3.1%), leucine, and isoleucine (4%).

2.2. Lipids

Finger millet is having a lipid content of 1.5%. Predominant fatty acids of this millet are oleic (49%), linoleic (25%) and palmitic acids (25%). About 72% of total lipids are present as neutral lipids, 13% as glycolipids, and 6% as phospholipids (Mahadevappa & Raina, 1978). Lipids of finger millet are mostly triglycerides and these are known to reduce the incidence of duodenal ulcer.

2.3. Carbohydrates

Finger millet is a rich source of carbohydrates and comprises free sugars (1.04%), starch (65.5%), and non-starchy polysaccharides (Malleshi, Desikachar, & Tharanathan, 1986) or dietary fiber (11.5%) (Gopalan, Rama, & Balasubramanian, 1989). Wankhede, Shehnaj, and Raghavendra Rao (1979) studied the carbohydrate profile of a few varieties of finger millet and reported 59.5–61.2% starch, 6.2–7.2% pentosans, 1.4–1.8% cellulose, and 0.04–0.6% lignins. The dietary fiber content of finger millet is much higher (11.5%) than the fiber content of brown rice, polished rice, and all other millets such as foxtail, little, kodo, and barnyard millet. The carbohydrate content of finger millet is 72% while that of wheat, 71.2%. Finger millet starch comprises amylose and amylopectin in the range of 25–75%.

2.4. Dietary fiber

Total dietary fiber content of finger millet grain is 22.0% and is relatively higher than most of other cereal grains, e.g. 12.6% wheat, 4.6% rice, 13.4% maize, and 12.7% sorghum, respectively. Dietary fibers are categorized as water soluble or insoluble. Chethan and Malleshi (2007) reported that finger millet grain contained 15.7% insoluble dietary fiber and 1.0% soluble dietary fiber, while (Shobana & Malleshi, 2007) reported 22.0% total dietary fiber, 19.7% insoluble dietary fiber, and 2.5% soluble dietary fiber in finger millet.

2.5. Vitamins

Finger millet contains both water-soluble and lipo-soluble vitamins viz., thiamin, riboflavin, niacin, and apparently vitamin C plus the tocopherols, vitamin E Obilana and Manyasa (2002). Water-soluble B-vitamins of finger millet are concentrated in the aleurone layer and germ, while lipo-soluble vitamins are mainly located in the germ.

3. Post harvesting operation of finger millet

The harvesting of finger millet crop takes place mainly during October through November. There are two methods of harvesting.

3.1. Harvesting of only panicles

After crop maturity, the panicles (ear heads) of finger millet are collected by cutting with the help of a sickle, leaving the plant stalks as such in the field. The operation is being carried out at one time or at intervals depending on the uniformity of maturity. The harvested panicles are gathered in a container such as bamboo baskets (tokri) before heaping them in a convenient place. The panicles stacked in heaps are left for sun drying for a period ranging from one week to more than a month. The heat generated within the heap will help in easy separation of grains during threshing.

3.2. Harvesting of stalks along with panicles

This is the most commonly used method. In this method, harvested stalks are spread in rows in the field for sun drying for a couple of days depending on the weather conditions. After sun drying, the harvested stalks are bundled and staked near the threshing yard. During rainy days, a stacking practice involving arranging the bundles in the field in closed lines in slanting position and covering with dried straw to prevent dampening is practiced. After few days, the cover is removed and allowed to dry for one to two days before staking at the yard.

3.3. Threshing of finger millet grains

Separation of grains from panicles (ear heads) is done by spreading panicles or stalk in the morning and threshing starts from 10 o'clock. Threshing of panicles or stalks is usually done using bullocks (4–5 in number) for trampling or by a stone roller drawn by a pair of bullocks. For large-scale operation, in some places, tractors are used by farmers for grain separation. Farmers also use paddy threshers. Bamboo sticks are also used for threshing in small-scale operations.

3.4. Storage

Before storage, grains of finger millet are sun dried. Various types of structures (Bhakari, Kalanjiam, Semiliguda, turjhulla, Dumbriguda, and Chatka) are used by farmers for storage of this millet. Closed structures are commonly used for storage of seeds. In present days, gunny bags or nylon-woven sacs are used by farmers for grain storage. However, storage period for this millet varies from region to region.

4. Traditional food products from finger millet

Finger millet is usually pulverized and wholemeal is utilized for the preparation of traditional foods. In addition to traditional foods, it is also processed to prepare popped, malted, and fermented products. Noodles for diabetic patients were successfully developed from finger millet by Shukla and Srivastava (2011). Thirty-fifty percent finger millet proportion was blended with refined wheat flour for the preparation of noodles. On the basis of sensory evaluation, 30% finger millet-incorporated noodles were selected and evaluated for glycemic response compared to control. Results revealed that 30% finger millet-incorporated noodles have low glycemic index as compared to control. Finger millet seed coat is an edible material and contains a good proportion of dietary fiber, minerals, and phytochemicals. Seed coat matter (SCM) forms a by-product of the millet milling, malting, and decortication; this can be utilized as composite flour in biscuit making. Krishnan, Dharmaraj, Sai Manohar, and Malleshi (2011) developed biscuit from finger millet seed coat. On the basis of sensory evaluation, they found that 10% of SCM from native and hydra-thermally processed millet and 20% from malted millet could be used in composite biscuit flour. Saha et al. (2011) prepared biscuit from composite flours containing 60:40 and 70:30 (w/w) finger millet:wheat flour and these were evaluated for dough characteristics and biscuit quality. They reported that a composite flour of finger millet:wheat flour (60:40) was best particularly regarding biscuit quality. Muffins were also prepared by replacing wheat flour with 20, 40, 60, 80, and 100% finger millet flour (FMF), emulsifiers, and hydrocolloids (Rajiv, Soumya, Indrani, & Rao, 2011). Effect of finger millet, emulsifiers, and hydrocolloids on the batter microscopy, rheology, and quality characteristics of muffins was also studied. They found that a combination of additives with 60% FMF significantly improved the volume and quality characteristics of muffins. New food products made from finger millet which are currently being explored are noodles, vermicelli, prepared either from finger millet alone or in combination with refined wheat flour (Shukla & Srivastava, 2011; Sudha, Vetrirani, & Rahim, 1998), pasta products (Gull, Prasad, & Kumar, 2015; Krishnan & Prabhasankar, 2010), halwa mixes (a sweet dish prepared with flour, sugar, and clarified butter) and composite mixes (Itagi, Singh, Indiramma, & Prakashan, 2013), papads (flattened and dried dough products which are toasted or deep fried and used as adjuncts with a meal) (Kamat, 2008; Vidyavati, Mushtari, Vijayakumari, Gokavi, & Begum, 2006), finger-dried finger millet-based soup mixes (Guha & Malleshi, 2006), bakery products such as muffins (Jyotsna, Soumya, Indrani, & Venkateswara, 2011), bread, and biscuits (Krishnan et al., 2011; Saha et al., 2011; Singh, Mishra, & Mishra, 2012), and complementary foods (Stephen et al., 2002) are also being prepared and marketed in selected markets. Breads from millet-based composite flours, wheat in combination with finger millet, barnyard millet, and proso millet were also prepared. Ready-to-eat nutritious supplementary food from popped FMF was also prepared by Malleshi (2007). This is a whole-grain product rich in macronutrients, micronutrients, dietary fiber, and usually mixed with vegetable or milk protein sources such as popped bengal gram, milk powder, and oil seeds sweetened with jaggery or sugar. Expanded finger millet has also been recently developed (Ushakumari, Rastogi, & Malleshi, 2007) from the decorticated finger millet. Its dietary fiber content is lower than that of popped finger millet, as it is prepared from decorticated finger millet which is devoid of seed coat. Ragi soup is prepared by mixing ragi flour in water. Then, this mixture is heated for 15 min and stirred frequently to avoid lump formation. After that the mixture is removed from heat; curd and salt are then added to it. Finally, it is served either warm or cold. In addition to the above-mentioned products, many other local preparations are in practice making use of finger millet depending upon the local habits. Few modern products incorporating finger millet are now available in the market such as, ragi health drink (baby vita), foodles, multigrain noodle, and ragi biscuit.

5. Medicinal properties of finger millet

Chronic metabolic disorder “Diabetes mellitus” is characterized by hyperglycemia with alterations in carbohydrate, protein, and lipid metabolism. It is a most common endocrine disorder and results in deficient insulin production (Type 1) or combined resistance to insulin action and the insulin secretory response (Type 2). Whole-grain foods are suggested to be beneficial for the prevention and management of diabetes mellitus and epidemiologically lower incidence of diabetes has been reported in millet-consuming populations (American Diabetes Association, 2005; Kim, Hyun, & Kim, 2011; Shobana et al., 2009). Consumption of finger millet-based diets resulted in significantly lower plasma glucose levels, mean peak rise, and area under curve that might be due to higher fiber content of finger millet than rice and wheat. This lower glycemic response of whole finger millet-based diets may have been due to the presence of antinutritional factors in the EMF which are known to reduce starch digestibility and absorption (Lakshmi Kumari & Srinathi, 2006). Role of finger millet feeding on skin antioxidant status, nerve growth factor, and wound healing parameters in healing impaired early diabetic rats has been reported. Increased levels of oxidative stress markers accompanied by decreased levels of antioxidants play a vital role in delaying wound healing in diabetic rats. However, finger millet feeding to the diabetic animals for 4 weeks controlled the glucose levels and improved the antioxidant status which hastened the dermal wound healing process (Rajasekaran, Nithya, Rose, & Chandra, 2004). Almost all countries of the world are facing increase in rates of cardiovascular disease. It has been demonstrated that rats fed with a diet of native and treated starch from barnyard millet had the lowest blood glucose, serum cholesterol, and triglycerides compared with rice and other minor millets (Kumari & Thayumanavan, 1997). Serum triglycerides concentrations in finger and proso millet groups of hyperlipidemic rats were significantly lower than those of white rice and sorghum groups. In addition, serum concentrations of high density lipoprotein (HDL) and low density lipoprotein (LDL) cholesterol were significantly higher in the sorghum group than in the white rice, finger millet, and proso millet groups. Thus, finger millet and proso millet may prevent cardiovascular disease by reducing plasma triglycerides in hyperlipidemic rats (Lee, Chung, Cha, & Park, 2010). Phenolic extracts from kodo, finger, proso, foxtail, little, and pearl millets were evaluated for their inhibitory effects on lipid peroxidation *in vitro*, copper-mediated human LDL cholesterol oxidation, and several food model systems namely cooked comminuted pork, stripped corn oil, and a linoleic acid emulsion. At a final concentration of 0.05 mg/ml, millet extracts inhibited LDL cholesterol oxidation by 1–41%. All varieties exhibited effective inhibition of lipid oxidation in food systems used in this study and kodo millet exhibited superior inhibition of lipid peroxidation, similar to butylated hydroxyanisole at 200 ppm (Chandrasekara & Shahidi, 2011b). Millet grains are known to be rich in phenolic acids, tannins, and phytate that act as “antinutrients” (Thompson, 1993). It has been established that these antinutrients reduce the risk for colon and breast cancer in animals (Graf & Eaton, 1990). Van Rensburg (1981) reported that populations consuming sorghum and millet have lower incidences of esophageal cancer than those consuming wheat or maize. There is a growing demand for novel, tasty, and healthy foods. People suffering from celiac disease have given birth to a new market consisting of cereal products made from grains other than wheat and rye. For this reason, oat, sorghum, and millet have gained a special position (Angioloni & Collar, 2012). Celiac disease is an immune-mediated enteropathy, triggered by the ingestion of gluten in genetically susceptible individuals. It is a lifelong disorder worldwide. Since millets are gluten free, these are suitable for individuals suffering from celiac disease (Chandrasekara & Shahidi, 2011a, 2011b; Taylor & Emmambux, 2008; Taylor, Schober, & Bean, 2006). Therefore, millet grains and their fractions have a potential to be useful for producing food products for celiac people. Millet grains are rich in antioxidants and phenolics; however, it has been established that phytates, phenols, and tannins can contribute to antioxidant activity important in health, aging, and metabolic syndromes (Bravo, 1998). Methanolic extracts from finger millet and kodo millet have been found to inhibit glycation and cross-linking of collagen (Hegde, Chandrakasan, & Chandra, 2002). Therefore, there is a potential usefulness of millets in protection against aging. Extracts and fractions of millet grain were found to have antimicrobial activity. In one study, phenolic acids from finger millet-milled fractions (whole flour, seed coat, 3, 5, and 7%) were isolated. Seed coat extracts of finger millet showed higher antimicrobial activity against *Bacillus cereus* and *Aspergillus flavus* than whole flour extract. Therefore,

the results indicated that potential exists to utilize finger millet seed coat as an alternative natural antioxidant and food preservative (Viswanath, Urooj, & Malleshi, 2009).

6. Processing technologies for finger millet

6.1. Milling

Generally, finger millet is pulverized to flour for preparation of food products. First, it is cleaned to remove foreign materials such as stones, chaffs, stalks, etc., then passed through abrasive or friction mills to separate out glumes (non-edible cellulosic tissue), and then pulverized. Normally, it is pulverized in stone mill or iron disk or emery-coated disk mills. Sometimes, pearling or decortications is used to dehusk the finger millet grain; it results in pulverization of both seed coat and endosperm. Hence, finger millet is invariably pulverized along with the seed to prepare wholemeal. Centrifugal sheller can also be used to dehull/decorticate the small millets.

6.2. Decortication

This is a very recent process developed for finger millet (Malleshi, 2006). It is also known as debranning. This method is used for debranning all cereals, but it is not effective for finger millet, owing to its seed coat being intactly attached to the bran endosperm. However, hydrothermal processing is used to decorticate finger millet; this involves hydration, steaming, and drying which harden the endosperm of grain and enable it to withstand mechanical impact. The decorticated finger millet could be cooked as such, as rice is cooked.

6.3. Popping

Popping is one of the traditional methods to prepare popped FMF. In this process, millet is mixed with 3–5% additional water to raise the moisture content, tempered for 2–4 h, and then popped by high temperature and short time treatment by agitation in sand to about 230°C. This process results in the development of highly desirable aroma because of the Maillard reaction between sugars and amino acids. Popped finger millet is a precooked ready to eat product. Also, it can be pulverized and mixed with protein rich sources to prepare ready nutritious supplementary food (Premavalli, Majumdar, Madhura, & Bawa, 2003). However, popping contaminates the product with particles of sand, which is used as a heat transfer media, and thus affects its eating quality. To overcome this drawback, air popping in a suitable mechanical process that has been successfully explored. But this method lacks the characteristic aroma compared to that using sand (Malleshi & Desikachar, 1981). Popped finger millet can be prepared at household community or at industrial level.

6.4. Malting

Malting of finger millet is commonly practiced for specialty foods. During this process, bioavailability of proteins, carbohydrates, and minerals are enhanced. Some B-group vitamins are synthesized and concentration of antinutritional factors is also reduced. Malting involves soaking of viable seeds in water to hydrate and to facilitate sprouting. These sprouts are then kiln dried. Finally, the rootlets are separated from the grain manually by rubbing with hand. All these operations influence the quality of malt. Seed germination is the most important step because during this process, the hydrolytic enzymes are developed which cause endosperm modification and increase nutritional properties. Malting of finger millet has been successfully utilized for developing various health foods such as infant food, weaning food, milk-based beverages, and confectionary products (Malleshi, 2007).

7. Economic status of finger millet

Millets are generally consumed in the region where they are produced. Thus, the millet amount subjected to the world trade is significantly low. USDA doesn't have open data for world millet trade. World millet trade announced by United Nations Food and Agriculture Organization (FAO) with formal, semi-formal, and forecast data and import and export amounts are not equivalent. FAO's current data belong to the year 2011. While the export was 385,000 tons, the import was 416,000 tons. An important factor in this difference is that the data cannot be obtained in a healthy way. According

to the data of FAO, India ranks first in world millet export, the USA with 60,000 tons, Russia with 54,000 tons, following India, which exported 132,000 tons of millet in 2011. Sudan ranks first in imports, Pakistan with 33,000 tons, Belgium with 32,000 tons, and Germany with 19,000 tons, following Sudan which imported 67,000 tons.

8. Conclusion

Potential health benefits and nutritive value of millet grains were found comparable to major cereals. Several processing technologies were found to improve nutritional characteristics of millets. Utilization of millet grains as food is still limited to populations in rural areas. This is due to the lack of innovative millet processing technologies. This review provides a scientific rationale use of finger millet as a therapeutic and health-promoting food. In addition, to promote the utilization of millet grains in urban areas to open new markets for farmers to improve their income, developing highly improved products from millets is needed. Finger millet can be used in different food formulations for making value-added products due to its well-balanced protein profile and gluten-free properties. Although the consumption pattern of this millet is specific and continuous remain as such; therefore, its popularization in the broader range is essential and specific design of foods acceptable to the population can help in promoting the consumption of this millet.

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Competing interests

The authors declare no competing interest.

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References

- American Diabetes Association. (2005). Diagnosis and classification of diabetes mellitus. *Diabetic Care*, 28, 37–42.
- Angioloni, A., & Collar, C. (2012). Promoting dough viscoelastic structure in composite cereal matrices by high hydrostatic pressure. *Journal of Food Engineering*, 111, 598–605. <http://dx.doi.org/10.1016/j.jfoodeng.2012.03.010>
- Bravo, L. (1998). Polyphenols: Chemistry, dietary sources, metabolism and nutritional significance. *Nutrition Reviews*, 56, 317–333.
- Chandrasekara, A., & Shahidi, F. (2011a). Antioxidant phenolics of millet control lipid peroxidation in human LDL cholesterol and food systems. *Journal of the American Oil Chemists Society*, 89, 275–285.
- Chandrasekara, A., & Shahidi, F. (2011b). Antiproliferative potential and DNA scission inhibitory activity of phenolics from whole millet grains. *Journal of Functional Foods*, 3, 159–170. <http://dx.doi.org/10.1016/j.jff.2011.03.008>
- Cherian, S., & Malleshi, N. G. (2007). Finger millet polyphenols: Optimization of extraction and the effect of pH on their stability. *Food Chemistry*, 105, 862–870. <http://dx.doi.org/10.1016/j.foodchem.2007.02.012>
- Gopalan, C., Rama, S. B. V., & Balasubramanian, S. C. (1989). *Nutritive value of Indian foods* (p. 50–59). Hyderabad: National Institute of Nutrition, Indian Council of Medical Research.
- Graf, E., & Eaton, J. W. (1990). Antioxidant functions of phytic acid. *Free Radical Biology and Medicine*, 8, 61–69. [http://dx.doi.org/10.1016/0891-5849\(90\)90146-A](http://dx.doi.org/10.1016/0891-5849(90)90146-A)
- Guha, M., & Malleshi, N. G. (2006). A process for preparation of pre-cooked cereals and vegetables based foods suitable for use as instant soup mix or of similar type foods. *Indian Patent* 257/NF/06.
- Gull, A., Prasad, K., & Kumar, P. (2015). Effect of millet flours and carrot pomace on cooking qualities, color and texture of developed pasta. *LWT Food Science and Technology*, 63, 470–474. <http://dx.doi.org/10.1016/j.lwt.2015.03.008>
- Hegde, P. S., Chandrakasan, G., & Chandra, T. S. (2002). Inhibition of collagen glycation and crosslinking in vitro by methanolic extracts of Finger millet (*Eleusine coracana*) and Kodo millet (*Paspalum scrobiculatum*). *The Journal of Nutritional Biochemistry*, 13, 517–521. [http://dx.doi.org/10.1016/S0955-2863\(02\)00171-7](http://dx.doi.org/10.1016/S0955-2863(02)00171-7)
- Hulse, J. H., Laing, E. M., & Pearson, O. E. (1980). *Sorghum and the millets: Their composition and nutritive value*. London: Academic Press.
- Itagi, H. B. N., Singh, V., Indiramma, A. R., & Prakash, M. (2013). Shelf stable multigrain halwa mixes: Preparation of halwa, their textural and sensory studies. *Journal of Food Science and Technology*, 50, 879–889. <http://dx.doi.org/10.1007/s13197-011-0423-z>
- Jyotsna, R., Soumya, C., Indrani, D., & Venkateswara, R. G. (2011). Effect of replacement of wheat flour with finger millet flour (*Eleusine coracana*) on the batter microscopy, rheology and quality characteristics of muffins. *Journal of Texture Studies*, 42, 478–489.
- Kamat, S. S. (2008). *A study on documentation and evaluation of indigenous method of preparation of papad with special reference to cereals and millets* (MSc dissertation thesis). University of Agricultural Sciences, Dharwad.
- Kim, J. S., Hyun, T. K., & Kim, M. J. (2011). The inhibitory effects of ethanol extracts from sorghum, foxtail millet and proso millet on α -glucosidase and α -amylase activities. *Food Chemistry*, 124, 1647–1651. <http://dx.doi.org/10.1016/j.foodchem.2010.08.020>

- Krishnan, M., & Prabhasankar, P. (2010). Studies on pasting, microstructure, sensory, and nutritional profile of pasta influenced by sprouted finger millet (*Eleusine coracana*) and green banana (*Musa paradisiaca*) flours. *Journal of Texture Studies*, 41, 825–841.
<http://dx.doi.org/10.1111/jts.2010.41.issue-6>
- Krishnan, R., Dharmaraj, U., Sai Manohar, R., & Malleshi, N. G. (2011). Quality characteristics of biscuits prepared from finger millet seed coat based composite flour. *Food Chemistry*, 129, 499–506.
<http://dx.doi.org/10.1016/j.foodchem.2011.04.107>
- Kumari, S. K., & Thayumanavan, B. (1997). Comparative study of resistant starch from minor millets on intestinal responses, blood glucose, serum cholesterol and triglycerides in rats. *Journal of the Science of Food and Agriculture*, 75, 296–302.
[http://dx.doi.org/10.1002/\(ISSN\)1097-0010](http://dx.doi.org/10.1002/(ISSN)1097-0010)
- Lakshmi Kumari, P., & Sumathi, S. (2002). Effect of consumption of finger millet on hyperglycemia in non-insulin dependent diabetes mellitus (NIDDM) subjects. *Plant Foods for Human Nutrition*, 57, 205–213.
<http://dx.doi.org/10.1023/A:1021805028738>
- Lee, S. H., Chung, I. M., Cha, Y. S., & Park, Y. (2010). Millet consumption decreased serum concentration of triglyceride and C-reactive protein but not oxidative status in hyperlipidemic rats. *Nutrition Research*, 20, 290–296.
<http://dx.doi.org/10.1016/j.nutres.2010.04.002>
- Mahadevappa, V. G., & Raina, P. L. (1978). Lipid profile and fatty acid composition of finger millet (*Eleusine coracana*). *Journal of Food Science and Technology*, 15, 100–102.
- Malleshi, N. G. (2006). Decorticated finger millet (*Eleusine coracana*) and process for preparation of expanded finger millet. *United States Patent 2006/029720 B2*.
- Malleshi, N. G. (2007). Nutritional and technological features of ragi (finger millet) and processing for value addition. In K. T. Krishne Gowda & A. Srinivaram (Eds.), *Food uses of small millets and sorghum for further processing and value addition* (Bangalore: Project Coordination Cell, All India Coordinated Small Millet Improvement Project, ICAR, UAS, GKVK).
- Malleshi, N. G., & Desikachar, H. S. R. (1981). Varietal differences in pasting quality of ragi (*Eleusine coracana*). *Journal of Food Science and Technology*, 18, 30–32.
- Malleshi, N. G., Desikachar, H. S. R., & Tharanathan, R. N. (1986). Free sugars and non-starchy polysaccharides of finger millet (*Eleusine coracana*), pearl millet (*Pennisetum glaberrimum*), foxtail millet (*Setaria italica*) and their malts. *Food Chemistry*, 20, 253–261.
[http://dx.doi.org/10.1016/0308-8146\(86\)90095-6](http://dx.doi.org/10.1016/0308-8146(86)90095-6)
- McDonough, C. M., Rooney, L. W., & Earp, C. A. (1986). Structural characteristics of *Eleusine coracana* (finger millet) using scanning and fluorescence microscopy. *Food Microstructure*, 5, 247–256.
- Obilana, A. B., & Manyasa, E. (2002). Millets. In P. S. Belton & J. R. N. Taylor (Eds.), *Pseudo cereals and less common cereals: Grain properties and utilization potential* (pp. 177–217). New York, NY: Springer-Verlag.
- Premavalli, K. S., Majumdar, T. K., Madhura, C. V., & Bawa, A. S. (2003). Development of traditional products. V Ragi based convenience mixes. *Journal of Food Science and Technology*, 40, 361–365.
- Rajasekaran, N. S., Nithya, M., Rose, C., & Chandra, T. S. (2004). The effect of finger millet feeding on the early responses during the process of wound healing in diabetic rats. *Biochimica et Biophysica Acta (BBA) - Molecular Basis of Disease*, 1689, 190–201.
<http://dx.doi.org/10.1016/j.bbadis.2004.03.004>
- Rajiv, J., Soumya, C., Indrani, D., & Rao, G. V. (2011). Effect of replacement of wheat flour with finger millet flour (*Eleusine coracana*) on the batter microscopy, rheology and quality characteristics of muffins. *Journal of Texture Studies*, 42, 478–489.
- Saha, S., Gupta, A., Singh, S. R. K., Bharti, N., Singh, K. P., & Mahajan, V. (2011). Compositional and varietal influence of finger millet flour on rheological properties of dough and quality of biscuit. *LWT-Food Science and Technology*, 44, 616–621. <http://dx.doi.org/10.1016/j.lwt.2010.08.009>
- Shobana, S., & Malleshi, N. G. (2007). Preparation and functional properties of decorticated finger millet (*Eleusine coracana*). *Journal of Food Engineering*, 79, 529–538. <http://dx.doi.org/10.1016/j.jfoodeng.2006.01.076>
- Shobana, S., Sreerama, Y. N., & Malleshi, N. G. (2009). Composition and enzyme inhibitory properties of finger millet (*Eleusine coracana*) seed coat phenolics: Mode of inhibition of α -glucosidase and pancreatic amylase. *Food Chemistry*, 111, 1268–1273.
<http://dx.doi.org/10.1016/j.foodchem.2009.01.042>
- Shukla, J., & Srivastava, S. (2011). Evaluation of finger millet incorporated noodles: Nutritive value and glycemic index. *Journal of Food Science and Technology*, 51, 521–524.
- Singh, K. P., Mishra, Aninav, & Mishra, H. N. (2012). Fuzzy analysis of sensory attributes of bread prepared from millet-based composite flours. *LWT-Food Science and Technology*, 48, 276–282.
<http://dx.doi.org/10.1016/j.lwt.2012.03.026>
- Stephen, M. M., John, V. C., Peter, R. S. M., Wilfried, O., Patrick, K., & Andre, H. (2002). Evaluation of the nutritional characteristics of a finger millet based complementary food. *Journal of Agricultural and Food Chemistry*, 50, 3030–3036.
- Sudha, M. L., Vetrmani, R., & Rahim, A. (1998). Quality of vermicelli from finger millet (*Elusine coracana*) and its blend with different millet wheat fractions. *Food Research International*, 31, 99–104.
[http://dx.doi.org/10.1016/S0963-9969\(98\)00066-0](http://dx.doi.org/10.1016/S0963-9969(98)00066-0)
- Taylor, J. R. N., & Emmambux, M. N. (2008). Gluten free foods and beverages from millets. In E. Gallagher (Ed.), *Gluten-free cereal products and beverages* (pp. 1–27). Burlington, MA: Elsevier.
- Taylor, J. R. N., Schober, T. J., & Bean, S. R. (2006). Novel food and non-food uses for sorghum and millets. *Journal of Cereal Science*, 44, 252–271.
<http://dx.doi.org/10.1016/j.jcs.2006.06.009>
- Thompson, L. V. (1993). Potential health benefits and problems associated with antinutrients in foods. *Food Research International*, 26, 131–149.
[http://dx.doi.org/10.1016/0963-9969\(93\)90069-U](http://dx.doi.org/10.1016/0963-9969(93)90069-U)
- Ushakumari, S. R., Rastogi, N. K., & Malleshi, N. G. (2007). Optimization of process variables for the preparation of expanded finger millet using response surface methodology. *Journal of Food Engineering*, 82, 35–42.
- Van Rensburg, S. J. (1981). Epidemiological and dietary evidence for a specific nutritional predisposition to esophageal cancer. *Journal of National Cancer Institute*, 67, 243–251.
- Vidyavati, H. G., Mushtari, J., Vijayakumari, J., Gokavi, S. S., & Begum, S. (2004). Utilization of finger millet in the preparation of papad. *Journal of Food Science and Technology*, 41, 379–382.
- Viswanath, V., Urooj, A., & Malleshi, N. G. (2009). Evaluation of antioxidant and antimicrobial properties of finger millet polyphenols (*Eleusine coracana*). *Food Chemistry*, 114, 340–346. <http://dx.doi.org/10.1016/j.foodchem.2008.09.053>
- Wankhede, D. B., Shehraj, A., & Raghavendra Rao, M. R. (1979). Carbohydrate composition of finger millet (*Eleusine coracana*) and foxtail millet (*Setaria italica*). *Qualitas Plantarum. Plant Foods for Human Nutrition*, 28, 293–303.
<http://dx.doi.org/10.1007/BF01095511>

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