CHAPTER ONE

Finger Millet (*Ragi, Eleusine coracana* L.): A Review of Its Nutritional Properties, Processing, and Plausible Health Benefits

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Abstract

Finger millet or *ragi* is one of the ancient millets in India (2300 BC), and this review focuses on its antiquity, consumption, nutrient composition, processing, and health benefits. Of all the cereals and millets, finger millet has the highest amount of calcium (344 mg%) and potassium (408 mg%). It has higher dietary fiber, minerals, and sulfur containing amino acids compared to white rice, the current major staple in India. Despite finger millet's rich nutrient profile, recent studies indicate lower consumption of millets in general by urban Indians. Finger millet is processed by milling, malting, fermentation, popping, and decortication. Noodles, vermicilli, pasta, Indian sweet (*halwa*) mixes, *papads*, soups, and bakery products from finger millet are also emerging. *In vitro* and *in vivo* (animal) studies indicated the blood glucose lowering, cholesterol lowering, antiulcerative, wound healing properties, etc., of finger millet. However, appropriate intervention or randomized clinical trials are lacking on these health effects. Glycemic index (GI) studies on finger millet preparations indicate low to high values, but most of the studies were conducted with outdated methodology. Hence, appropriate GI testing of finger millet preparations and short- and long-term human intervention trials may be helpful to establish evidence-based health benefits.

1. INTRODUCTION

Millets are minor cereals of the grass family, Poaceae. They are small seeded, annual cereal grasses, many of which are adapted to tropical and arid climates and are characterized by their ability to survive in less fertile soil (Hulse, Laing, & Pearson, 1980). Millets include sorghum (*Jowar*), pearl millet (*Bajra*), finger millet (*Ragi*), foxtail millet (*Kakum*), proso millet (*Chena*), little millet (*Kutki*), kodo millet (*Kodon*), barnyard millet (*Sanwa*), and brown top millet (Gopalan, Rama Sastri, & Balasubramanian, 2009; Hulse et al., 1980; http://www.swaraj.org/shikshantar/millets.pdf; Accessed on 27.03.12). Ragi or finger millet (*Eleusine coracana* L.) is one of the common millets in several regions of India. It is also commonly known as *Koracan* in Srilanka and by different names in Africa and has traditionally been an important millet staple food in the parts of eastern and central Africa and India (FAO, 1995). Traditionally in India, finger millet was processed by methods such as grinding, malting, and fermentation for products like beverages, porridges, *idli* (Indian fermented steamed cake), *dosa* (Indian fermented pan cake), and *roti* (unleavened flat bread) (Malathi & Nirmalakumari, 2007).

Research evidence suggests that whole grains and cereal fiber consumption are inversely associated with BMI, waist circumference, total cholesterol, metabolic syndrome, mortality from cardiovascular diseases, insulin resistance, and incidence of type 2 diabetes (de Munter, Hu, Spiegelman, Franz, & van Dam, 2007; Newby et al., 2007; Pereira et al., 2002; Sahyoun, Jacques, Zhang, Juan, & McKeown, 2006). Whole-grain cereals such as brown rice and millets are nutritionally superior to the widely consumed polished white rice. Studies have also shown that the dietary glycemic load (a measure of both quality and quantity of carbohydrates) and the higher intake of refined grains such as white rice were associated with the risk of type 2 diabetes and metabolic syndrome among urban south Asian Indians (Mohan et al., 2009; Radhika, Van Dam, Sudha, Ganesan, & Mohan, 2009). Several studies have reported on the beneficial role of low glycemic index (GI—a measure of carbohydrate quality) foods/diets in the nutritional management of diabetes and several other chronic diseases. The rate of glucose absorption is usually decreased by low GI foods and hence reduced insulin demand (Augustin, Franceschi, Jenkins, Kendall, & Vecchia, 2002). A calorie-restricted diet, moderately lower in carbohydrate, was also found to be helpful in decreasing insulin resistance and other metabolic abnormalities in overweight South Asian Indians (Backes et al., 2008). Dixit, Azar, Gardner, and Palaniappan (2011) have given practical strategies to reduce the burden of chronic disease by the incorporation of whole, ancient grains such as sorghum and millets like finger millet into the modern Asian Indian diets. Kannan (2010) has discussed the various nutritional and health benefits of finger millet with special reference to chronic disease preventive potential.

Unfortunately, many of the traditional Indian grains including millets have not been evaluated for GI using appropriate methods. In addition, development and availability of low GI foods are limited especially from millets in India. Finger millet being a low cost millet with higher dietary fiber contents, several micronutrients and phytonutrients with practically no reports of its adverse effect, deserves attention. This review attempts to explore the plausible health benefits of processed finger millet with particular reference to its nutritional and glycemic properties. Literature search was conducted in Pubmed, Science Direct data bases, and Google searches using suitable keywords. Studies published from 1939 to 2012 are included in this review.

2. HISTORY OF FINGER MILLET

Finger millet, one of the oldest crops in India is referred as "*nrtta-kondaka*" in the ancient Indian Sanskrit literature, which means "Dancing grain," was also addressed as "*rajika*" or "*markataka*" (Achaya, 2009). Earliest report of finger millet comes from Hallur in Karnataka of India dating approximately 2300 BC (Singh, 2008). There is some debate as to the origin of finger millet, and there are theories that finger millet might have traveled to India by sea from Arabia or South Africa or across the Indian Ocean in both directions (Achaya, 2009). Fuller (2002, 2003) has extensively reviewed the archeological work carried out in India and elsewhere on the origin of *Eleusine,*and reports its African origin and provides linguistic evidence for the term "ragi" from the root source term-dègi for finger millet in a number of Bantu languages from southern Tanzania and northern Malawi and its other variants in Indian subcontinent. Fuller is skeptical about most of the findings on finger millet and reported that the grains isolated from Hallur (1000 BC), Malhar (800 BC–1600 BC), and Hulaskhera (700 BC) in India to be authentic (Fuller, 2003). Although *Ragi* (finger millet), *jowar* (sorghum), and *bajra* (pearl millet) are of African origin, they have long been domesticated in India (Achaya, 2009).

Finger millet was a well-domesticated plant in various states of India and popularly called as *nachni* (meaning dancer) in the state of Maharastra, "*umi*" in Bihar, etc. The grains were gently roasted (sometimes after it was sprouted and dried), ground, sieved. The pinkish flour (from red finger millet) was eaten as a ball or gruel, either sweetened or salted. Finger millet was also popular as weaning foods (Achaya, 2009). The ancient Tamil literature from India, "*Kuruntogai*," addresses red finger millet as "*Kelvaragu*". *Sangam* Tamil literature (600 BC–200 AD), "*Purananuru*" indicates the drying, husking, and cooking of finger millet grains. In ancient India, finger millet cooked in milk was served with honey to poets (Achaya, 1992). It was then and now being used in Karnataka.

3. MILLET CONSUMPTION IN INDIA

Reports of National Nutrition Monitoring Bureau (NNMB, 2006) indicated that consumption of millets in general was higher in the states of Gujarat (maize, pearl millet), Maharastra (sorghum), Karnataka (finger millet) but almost nil in the states of Kerala, West Bengal, Orissa, and Tamil Nadu where rice forms the major staple. The consumption of millets in Gujarat and Maharashtra (200 and 132 g/CU (consumption unit is a coefficient and 1 CU corresponds to energy requirement of 2400 kcal/day of an Indian male doing sedentary work) was higher compared to that of Karnataka (75 g/CU/day), Madhya Pradesh (32 g/CU/day), and Andhra Pradesh (16 g/CU/day). Tamil Nadu (3 g/CU/day) and Orissa (1 g/CU/day) showed negligible amounts of consumption.

Though Indians continue to consume cereals as the main staple providing 70–80% of total energy intake in majority of Indian diets

(Gopalan et al., 2009), the consumption of millets is very low compared to rice and as evident by our recent study on dietary profile of urban Indians (from the Chennai Urban Rural Epidemiology Study (CURES)) which revealed that, the millets contributed to only about 2% of total calories (6.7 g/d) (Radhika et al., 2011), while almost half of the daily calories were derived from refined grains such as polished white rice (253.4 g/day) (Radhika et al., 2009).

4. NUTRITIONAL SIGNIFICANCE OF STRUCTURAL FEATURES OF FINGER MILLET

The seed coat, embryo (germ), and the endosperm are the main botanical components of the millet kernel. Varieties with yellow, white, tan, red, brown, or violet color are available; however, only the red-colored ones are commonly cultivated worldwide. The pericarp (the outer most covering of the millet) is of little nutritional significance. The seed coat or the testa is multilayered (five layered), which is unique compared to other millets such as sorghum, pearl millet, proso millet, and foxtail millet (FAO, 1995) and may this could be one of the possible reasons for the higher dietary fiber content in finger millet. The seed coat is tightly bound to the aleurone layer (a layer between the seed coat and endosperm) and the starchy endosperm, which is further divided into corneous and floury regions. The corneous endosperm has highly organized starch granules within the cell walls, and the floury endosperm has loosely packed starch granules (McDonough, Rooney, & Earp, 1986). The sizes of the finger millet starch granule in different regions of the kernel greatly vary compared to pearl and proso millets and ranges from 3 to 21 μm (Serna-Saldiver, McDonough, & Rooney, 1994). The starch granules in the floury endosperm of millets in general are bigger compared to the ones present in the corneous endosperm and hence more susceptible to enzymatic digestion (FAO, 1995). However, further research is required to study the enzyme (digestive enzymes) susceptibility characteristics of starch present in the corneous and floury endosperm regions of finger millet individually. Generally, finger millet is milled with the seed coat (rich in dietary fiber and micronutrients) to prepare flour and the whole meal is utilized in the preparation of foods. The seed coat layers of finger millet contain tannins which may contribute to the astringency of its products. Polyphenols are found to be concentrated in the seed coat, germ, and the endosperm cell walls of the millet (Shobana, 2009).

5. NUTRIENT COMPOSITION OF FINGER MILLET

The detailed nutrient composition of finger millet compared to other cereals and millets is summarized in Table 1.1.

5.1. Carbohydrates

Finger millet is a rich source of carbohydrates and comprises of free sugars (1.04%), starch (65.5%), and non-starchy polysaccharides (Malleshi, Desikachar, & Tharanathan, 1986) or dietary fiber (11.5%) (Gopalan et al., 2009). Wankhede, Shehnaj, and Raghavendra Rao (1979a) 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 (11.5%) is much higher than the fiber content of brown rice, polished rice, and all other millets such as foxtail, little, kodo, and barnyard millet. However, the dietary fiber content of finger millet is comparable to that of pearl millet and wheat (Table 1.1). The carbohydrate content of finger millet is comparable to that of wheat but lower than that of polished rice (Table 1.1). Finger millet starch comprises amylose and amylopectin. The amylose content of finger millet starch is lower (16%) (Wankhede, Shehnaj, & Raghavendra Rao, 1979b) compared to the other millets such as sorghum (24.0%), pearl millet (21.0%), proso millet (28.2%), foxtail millet (17.5%), and kodo millet (24.0%) (FAO, 1995). Finger millet (Purna variety) starch had the highest set back viscosity (560 BU) during cooling (from 930 to 500 °C) which is suggestive of its tendency to retrograde (Wankhede et al., 1979b) (retrogradation of starch is known to induce resistance starch formation).

5.2. Proteins

Varietal variation exists in protein content of finger millet. Prolamins are the major fractions of finger millet protein (Virupaksha, Ramachandra, & Nagaraju, 1975). In general, cereals and millets contain lower amount of lysine compared to legumes and animal protein (ICMR, 2010). Albumin and globulin fractions contain several essential amino acids, while the prolamin fraction contains higher proportion of glutamic acid, proline, valine, isoleucine, leucine, and phenylalanine but low lysine, arginine, and glycine. The chemical score (a measure of protein quality, calculated as the ratio of amount of amino acid in a test protein over reference protein expressed as

Table 1.1 Nutrients, vitamins, minerals, and essential amino acid composition of finger millet (all values are per 100 g of edible portion)

Parameter	*Ragi*/finger millet	Proso millet	Foxtail millet	Little millet	Kodo millet	Barnyard millet	Pearl millet	Rice (raw) milled	Wheat
Proximates									
Moisture (g)	13.1	11.9	11.2	11.5	12.8	11.9	12.4	13.7	12.8
Protein (N × 6.25) (g)	7.3	12.5	12.3	7.7	8.3	6.2	11.6	6.8	11.8
Fat (g)	1.3	1.1	4.3	4.7	1.4	2.2	5.0	0.5	1.5
Minerals (g)	2.7	1.9	3.3	1.5	2.6	4.4	2.3	0.6	1.5
Dietary fiber (g)	11.5	–	2.4	2.53	2.47	1.98	11.3	4.1	12.5
Carbohydrates (g)	72.0	70.4	60.9	67	65.9	65.5	67.5	78.2	71.2
Energy (kcal)	328	341	331	341	309	307	361	345	346
Vitamins									
Carotene (μg)	42	0	32	0	0	0	132	0	64
Thiamine (mg)	0.42	0.20	0.59	0.30	0.33	(0.33)	0.33	0.06	0.45
Riboflavin (mg)	0.19	0.18	0.11	0.09	0.09	(0.10)	0.25	0.06	0.17
Niacin (mg)	1.1	2.3	3.2	3.2	2.0	4.2	2.3	1.9	5.5
Total B6 (mg)	–	–	–	–	–	–	–	–	(0.57)
Folic acid (μg)									

Continued

Table 1.1 Nutrients, vitamins, minerals, and essential amino acid composition of finger millet (all values are per 100 g of edible portion)—cont'd

Parameter	*Ragi*/finger millet	Proso millet	Foxtail millet	Little millet	Kodo millet	Barnyard millet	Pearl millet	Rice (raw) milled	Wheat
Free	5.2	–	4.2	2.2	7.4	–	14.7	4.1	142
Total	18.3	–	15.0	9.0	23.1	–	45.5	8.0	36.6
Vitamin C (mg)	0	0	0	0	0	0	0	0	0
Choline (mg)	–	748	–	–	–	–	–	–	–
Minerals and trace elements									
Calcium (mg)	344	14	31	17	27	20	42	10	41
Phosphorus (mg)	283	206	290	220	188	280	296	160	306
Iron (mg)	3.9	0.8	2.8	9.3	0.5	5.0	8.0	0.7	5.3
Magnesium (mg)	137	153	81	133	147	82	137	64	138
Sodium (mg)	11	8.2	4.6	8.1	4.6	–	10.9	–	17.1
Potassium (mg)	408	113	250	129	144	–	307	–	284
Copper (mg)	0.47	1.60	1.40	1.00	1.60	0.60	1.06	0.07	0.68
Manganese (mg)	5.49	0.60	0.60	0.68	1.10	0.96	1.15	0.51	2.29
Molybdenum (mg)	0.102	–	0.70	0.016	–	–	0.069	0.045	0.051
Zinc (mg)	2.3	1.4	2.4	3.7	0.7	3.0	3.1	1.3	2.7

Chromium (mg)	0.028	0.020	0.030	0.180	0.020	0.090	0.023	0.003	0.012
Sulfur (mg)	160	157	171	149	136	–	147	–	128
Chlorine (mg)	44	19	37	13	11	–	39	–	47
Essential amino acids (mg/g N)									
Arginine	300	290	220	250	270	–	300	480	290
Histidine	130	110	130	120	120	–	140	130	130
Lysine	220	190	140	110	150	–	190	230	170
Tryptophan	100	050	060	060	050	–	110	080	070
Phenyl alanine	310	310	420	330	430	–	290	280	280
Tyrosine	220	–	–	–	–	–	200	290	180
Methionine	210	160	180	180	180	–	150	150	090
Cystine	140	–	100	090	110	–	110	090	140
Threonine	240	150	190	190	200	–	240	230	180
Leucine	690	760	1040	760	650	–	750	500	410
Isoleucine	400	410	480	370	360	–	260	300	220
Valine	480	410	430	350	410	–	330	380	280

Source: Gopalan et al. (2009), Geervani and Eggum (1989).

percentage) of finger millet protein is 52 compared to 37 of sorghum and 63 of pearl millet (FAO, 1995). Finger millet contains higher levels of sulfur containing amino acids, namely, methionine and cystine, compared to milled rice (Table 1.1). The protein digestibility of finger millet is affected by the tannin content of the grain (Ramachandra, Virupaksha, & Shadaksharaswamy, 1977). However, Subrahmanyan, Narayana Rao, Rama Rao, and Swaminathan (1955) established that consumption of finger millet and pulse-based diet was sufficient to maintain a positive nitrogen (10.4% N), calcium (3.0% Ca), and phosphorus (8.7% P) balance in human adults. Doraiswamy, Singh, and Daniel (1969) also reported that supplementing finger millet diets with lysine or leaf (lucerne) protein improved the nutritional status, apparent protein digestibility, and N retention in children. Pore and Magar (1976) in their study reported a protein efficiency ratio (a measure of protein quality in terms of weight gain per amount of protein consumed) of 0.95 for B-11 variety of finger millet-based diet compared to 1.9 of control casein diet.

5.3. Fat

Mahadevappa and Raina (1978) reported 1.85–2.10% of total lipids in seven breeding varieties of finger millet. Finger millet lipids consist of 70–72% neutral lipids mainly triglycerides and traces of sterols, 10–12% of glycolipids, and 5–6% of phospholipids. On the whole, lipids contain 46–62% oleic acid, 8–27% linoleic acid, 20–35% palmitic acid, and traces of linolenic acid. Finger millet's fat content is lower compared to pearl millet, barnyard millet, little millet, and foxtail millet (Table 1.1), and this lower lipid content could be one of the factors contributing to the better storage properties of finger millet compared to other millets.

5.4. Micronutrients

Finger millet is exceptionally rich in calcium (344 mg%) compared to all other cereals and millets (eightfold higher than pearl millet) and contains 283 mg% phosphorus, 3.9 mg% iron (Gopalan et al., 2009), and many other trace elements and vitamins. Potassium content of finger millet is also high (408 mg%) compared to other cereals and millets (Table 1.1). High calcium finger millet varieties have also been reported elsewhere, and the "Hamsa" variety of finger millet was reported to contain much higher levels of calcium (660 mg%) (Umapathy & Kulsum, 1976). The phytic acid content of finger millet was lower than the levels present in common (proso) millet and foxtail millet and the values were in the range of 0.45–0.49 g% for different varieties of finger millet. The oxalate contents of finger millet were in the range of 29–30 mg% (Ravindran, 1991). Kurien, Joseph, Swaminathan, and Subrahmanyan (1959) reported that nearly 49% of total calcium content of finger millet is present in the husk. Sripriya, Antony, and Chandra (1997) reported that germination and fermentation of finger millet decreased the phytate content by 60% and improved bioavailability of minerals. Platel, Eipeson, and Srinivasan (2010) also reported increased bioaccessibility of minerals (iron, manganese) on malting of finger millet. Decortication of finger millet decreased the total mineral contents but increased the bioaccessibility of calcium, iron, and zinc, whereas popping of finger millet decreased the bioaccessibility of calcium but increased the bioaccessability of iron and zinc. Malting of finger millet increased the bioaccessibility of calcium, iron, and zinc (Rateesh, Usha, & Malleshi, 2012). A study conducted on 9- to 10-year-old girls showed that replacement of rice with finger millet diet apart from maintaining the positive nitrogen balance also improved calcium retention (Joseph, Kurien, Swaminathan, & Subrahmanyan, 1959).

Being rich source of calcium and iron, and the fact that the bioavailability can be improved by simple processing such as germination and fermentation, it should be considered as a good supplement for children and adolescents for improving bone health and hemoglobin.

6. PHYTONUTRIENTS/PHYTOCHEMICALS

6.1. Phenolics compounds

Varietal variations exist in phenolic content of finger millet (Chethan & Malleshi, 2007a; Ramachandra et al., 1977). Higher levels of phenolic compounds are reported in brown variety compared to white variety (Chethan & Malleshi, 2007a; Sripriya, Chandrasekharan, Murthy, & Chandra, 1996). Finger millet, in general, and the seed coat, in particular, contain several phytochemicals which may have health benefits (Chethan, 2008; Shobana, 2009; Shobana, Sreerama, & Malleshi, 2009). Finger millet is a very good source of variety of phenolic compounds (Chethan & Malleshi, 2007a, 2007b; Dykes & Rooney, 2007; Shobana, 2009; Shobana et al., 2009). Both free and bound forms of phenolic acids are reported in finger millet (Subba Rao & Muralikrishna, 2002). Caffeic acid is reported to decrease the fasting glycemia and attenuate the increase in plasma glucose in an intravenous glucose tolerance test in rats. It is also known to increase the glucose uptake in rat adipocytes and mice myoblasts. Catechin was found to improve the glucose tolerance in rats and quercitin inhibited glucose transport in transfected oocyte model and glucose absorption in rats (Matsumoto, Ishigaki, Ishigaki, Iwashina, & Hara, 1993; Scalbert, Manach, Morand, Remesy, & Jimenez, 2005). Finger millet contains these health potential polyphenols (Chethan & Malleshi, 2007b; Shobana et al., 2009). The impact of grain phenolics depends mainly on their bioavailability. Studies on the bioavailability of finger millet phenolics are scanty, and it is essential to study the nature of phenolic compounds in finger millet, their bioavailability, *in vivo* antioxidant functions, and the long-term effects of finger millet phenolics through human trials.

7. PROCESSING AND UTILIZATION

In India, usually finger millet is pulverized and the whole meal is utilized for the preparation of traditional foods, such as *roti* (unleavened flat breads), *kazhi* (finger millet balls), and *kanji* (thin porridge) (Fig. 1.1; Shobana, 2009). In addition to these traditional foods, finger millet is also processed to prepare popped, malted, and fermented products. The nonconventional products from finger millet are *papads* (rolled and dried preserved product), noodles, soup, etc. Recently, decorticated finger millet has been developed. The details of the different processing are presented in Fig. 1.2 (Malleshi, 2007; Rejaul, 2008; Shobana, 2009; Shobana & Malleshi, 2007; Ushakumari, 2009), and the nutrient composition of different finger millet products is presented in Table 1.2. A brief account of the nature of processing and the quality characteristics of the products are given below.

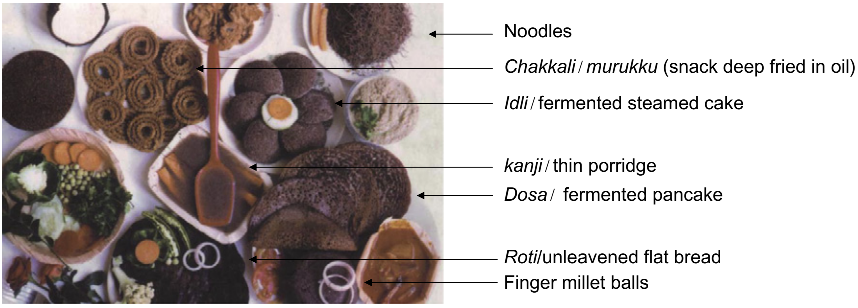

Figure 1.1 Prominent traditional Indian foods from finger millet. *Source: Photo courtesy Dr. N. G. Malleshi, Former Scientist, Department of Grain Science and Technology, Central Food Technological Research Institute, Mysore, India.*

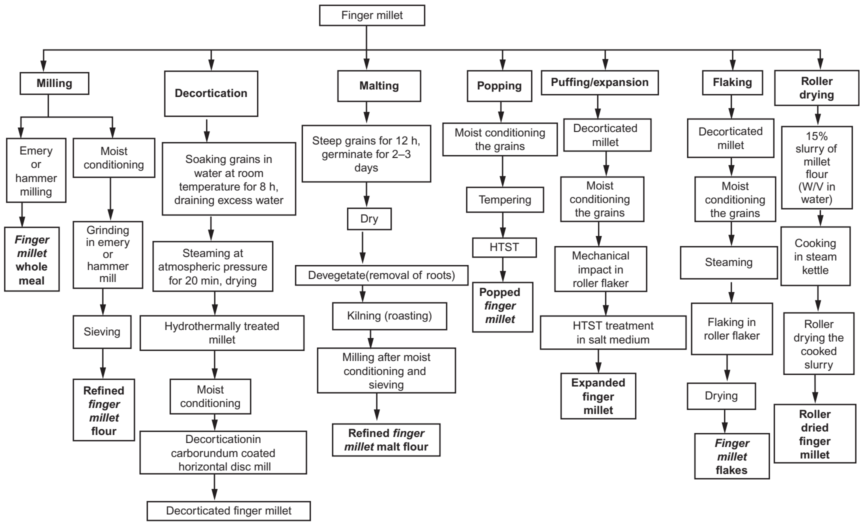

Figure 1.2 Different processing techniques adopted to develop products from finger millet. *Source:* *Malleshi (2007)*, *Shobana (2009)*, *Shobana and Malleshi (2007)*, *Ushakumari (2009)*, *Rejaul (2008)*.

7.1. Milling

Finger millet kernel has a fragile endosperm with an intact seed coat, and due to these characteristic features, the grain cannot be polished and cooked in the grain or grit form similar to rice or other cereals. Hence the grain needs to be invariably pulverized or milled for preparation of flour. Generally, foods based on whole meal finger millet are darker, less attractive (Fig. 1.1). In view of this and to overcome the drawbacks, efforts had been made to prepare refined or seed coat free flour similar to white flour or "*maida*" (refined wheat flour) (Kurien & Desikachar, 1966). The refined flour is comparatively whiter and fairly free from the seed coat matter (SCM). However, the refined flour may have higher glycemic responses (GRs) compared to the wholemeal-based products owing to its predominant starch content and lower levels of dietary fiber (Shobana, 2009). Nutritionally also whole flour is superior to the refined flour in terms of its dietary fiber, vitamins, and mineral contents (Table 1.2).

7.2. Decortication

This is a very recent process developed for finger millet (Malleshi, 2006). The debranning or decortication methods followed for most of the cereals were not effective in the case of finger millet owing to the intactness of the seed coat with highly fragile endosperm. Hence to decorticate, finger millet

Table 1.2 Nutrient content of few of the finger millet products

Nutrients	Native finger millet	Refined finger millet flour	Malted finger millet refined flour	Hydrothermally processed finger millet (*dwb*)	Decorticated finger millet (*dwb*)	Expanded finger millet	Popped finger millet	Flaked finger millet	Finger millet toasted flakes[a]	Roller dried finger millet
Moisture (g)	9.8	11.0	8.2	–	–	10.0	3.4	8.5	3.1	2.9
Protein (g)	8.7	3.6	4.5	8.3	6.5	4.7	6.4	6.5	6.2	5.8
Fat (g)	1.5	0.9	0.6	1.3	0.8	0.7	0.9	0.7	0.6	0.6
Starch (g)	72.0	87.0	77.9	68.5	81.3	NA	69.1	74.1	77.0	78.9
Dietary fiber (g)										
Total	19.6	6.8	NA	18.1	10.3	11.3	NA	10.7	9.9	NA
Soluble	3.5	1.6		0.9	2.8	1.8		3.2	2.7	
Insoluble	16.1	5.2		17.2	7.5	9.5		7.5	7.2	
Ash (g)	2.2	1.1	0.9	1.8	1.1	1.1	2.0	1.0	1.5	1.5
Calcium (mg)	321	163	350	311	185	190.0	250	272	273	270
Phosphorus (mg)	201	106	190	160	111	NA	125	103	100	146

[a]Finger millet flakes toasted in salt as the heat transfer media.
NA, information not available.
Source: Shobana (2009), Shobana and Malleshi (2007), Ushakumari (2009); Rejaul (2008).

is hydrothermally processed (hydration, steaming, and drying) to harden the soft endosperm to enable it to withstand the mechanical impact during decortication (Fig. 1.2). The decorticated finger millet could be cooked as discrete grains similar to rice (Shobana & Malleshi, 2007). The SCM formed as the major by-product of the decortication process is a rich source of health beneficial phenolic compounds, minerals, and dietary fiber (Shobana, 2009). However, the glycemic property of decorticated finger millet (cooked in the discrete form similar to rice grains) is yet to be established. The SCM can be used as a source of fiber and micronutrients in food formulations.

7.3. Malting

Among the various tropical cereals, finger millet has good malting characteristics. Generally barley is preferred among cereals for malting both in brewing and in food industries. However, attempts were made as early as 1939 to study the malting characteristics of finger millet, and Sastri (1939) reported the conditions of producing good quality malt. The author also reported that the smallness of finger millet grain was advantageous for obtaining even germination as well as for kilning—the processes involved in the malt preparation. The details of the malting process are given in Fig. 1.2. The malt flour is a good source of amylases and is hence termed as "Amylase-rich food." Malt flour is a substitute to maltodextrin and can be blended with milk and spray dried to prepare infant food (Malleshi, 2007). During germination, the amylases partially hydrolyze the starch to lower molecular weight carbohydrates such as oligo- and disaccharides, and thus the malt flour has reduced water holding capacity and thus high energy density. Due to this, the refined finger millet malt flour has scope for utilization in infant foods (Malleshi & Gokavi, 1999), weaning foods (Malleshi & Desikachar, 1982), and enteral foods (Malleshi, 2002; Malleshi & Chakravarthy, 1994). The millet malt flour has also been utilized in milk-based beverages, confectionary, and cakes (Desai, Kulkarni, Sahoo, Ranveer, & Dangde, 2010). Malted cereals contain highly digestible carbohydrates and may exhibit higher GRs (Lakshmi Kumari & Sumathi, 2002; Sumathi, Vishwanatha, Malleshi, & Venkat Rao, 1997) and hence may not be suitable for other metabolic conditions.

7.4. Popping

This is one of the important processing techniques widely used to prepare ready-to-eat products, which involves high-temperature short time treatment (HTST) to finger millet using sand as heat transfer media, where finger millet starch gelatinizes and the endosperm bursts open. Popped finger millet possesses a highly desirable flavor and aroma. It is used as a snack after seasoning with spices and condiments. Popped finger millet flour is commonly known as *hurihittu* in the state of Karnataka, India. It 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 to prepare ready-to-eat nutritious supplementary food (Malleshi, 2007). In recent days, finger millet is puffed using an air popper device also which is superior (in terms of quality with no sand and low salt in the product) compared to the product prepared using sand or salt as heat transfer media. Recently, expanded finger millet has also been developed from the decorticated finger millet (Ushakumari, Rastogi, & Malleshi, 2007). The dietary fiber content of the expanded finger millet is lower than that of popped finger millet as it is prepared from decorticated finger millet which is devoid of seed coat.

Fermented beverages from finger millet are also common. A traditional mild-alcoholic beverage prepared from finger millet (Kodo ko jaanr) is consumed in Eastern Himalayan areas of the Darjeeling hills and Sikkim in India, Nepal, and Bhutan (Thapa & Tamang, 2004). The relatively newer food products which are currently being explored are noodles; vermicilli prepared either out of finger millet alone or in combination with refined wheat flour (Shukla & Srivastava, 2011; Sudha, Vetrimani, & Rahim, 1998); pasta products (Krishnan & Prabhasankar, 2010); *halwa* mixes (a sweet dish prepared with flour, sugar, and clarified butter) and composite mixes (Itagi & Singh, 2011; Itagi, Singh, Indiramma, & Prakash, 2011); *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, 2004); roller dried finger millet-based soup mixes (Guha & Malleshi, 2006); bakery products such as muffins (Jyotsna, Soumya, Indrani, & Venkateswara Rao, 2011); bread and biscuits (Krishnan, Dharmaraj, Sai Manohar, & Malleshi, 2011; Saha et al., 2011; Singh, Abhinav, & 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 (Singh et al., 2012). Recently, attempts have been made for fortification of finger millet flour with iron and zinc. Fortication of iron (in the form of ferrous fumarate and ferric pyrophosphate) in finger millet flour with EDTA and folic acid as cofortificants significantly increased the bioaccessibility of iron from the fortified flours (Tripathi & Platel, 2011). And inclusion of EDTA as a cofortificant along with the zinc (zinc oxide or zinc stearate) significantly enhanced the bioaccessibility of zinc from the fortified flours (Tripathi & Platel, 2010). Studies on the double fortification of finger millet flour with zinc and iron with disodium EDTA as a cofortificant are also available in literature (Tripathi, Platel, & Srinivasan, 2012). Raghu and Bhattacharya (2010) computed the optimum conditions suitable for developing a flattened product and bread spread from finger millet. The authors reported that treating finger millet flour dough with bacterial α-amylase as an option to modify the attributes of finger millet flour dough related to processing and product development. They also added that enzyme-treated doughs were more sticky and had lower firmness compared to the untreated samples.

In summary, finger millet whole flour has considerable versatility and could be used for the preparation of traditional and contemporary food products in lieu of rice and wheat. If scientific evidence for health benefits is made available, finger millet products would have better market potentials.

8. HEALTH BENEFITS OF FINGER MILLET

Several *in vitro* (Table 1.3a) and *in vivo* studies (animal) (Table 1.3b) have been conducted to explore the health benefits of finger millet.

Several studies are available on the antioxidant properties (Chandrasekara & Shahidi, 2011; Hegde & Chandra, 2005; Sripriya et al., 1996; Subba Rao & Muralikrishna, 2002; Varsha et al., 2009; Veenashri & Muralikrishna, 2011) and antimicrobial properties of finger millet (Antony et al., 1998; Chethan & Malleshi, 2007a; Varsha et al., 2009). Production of statins (antihypocholestrolemic metabolites) from finger millet was attempted by Venkateswaran and Vijayalakshmi (2010). α-Glucosidase inhibitors play a vital role in the clinical management of postprandial hyperglycemia, and Shobana et al. (2009) established the α-glucosidase and pancreatic α-amylase inhibitory properties of finger millet phenolic extract, whereas Chethan et al. (2008) and Chethan (2008) in their study indicated that finger millet phenolics are inhibitors of aldose reductase and snake venom phospholipases (PLA_2). Protein glycation is one of the complications of diabetes, and protein glycation inhibitors are helpful in the management of this complication. Methanolic extracts of finger millet were found to exhibit protein glycation inhibitory properties (Hegde et al., 2002; Shobana, 2009).

Animal studies on the health beneficial aspects of finger millet feeding are also available in the literature. As early as 1975, Tovey et al. (1975) reported

Table 1.3 Some of the known health beneficial properties of finger millet

References	Functional property	Method	Key findings
(a) in vitro studies			
Chandrasekara and Shahidi (2011)	Antioxidant property	Singlet oxygen inhibition, oxygen radical absorbance capacity (ORAC), DPPH radical scavenging assay by electron paramagnetic resonance (EPR) spectroscopy, β-carotene linoleate model system	• Insoluble bound phenolic fractions of finger millet showed lower ORAC than that of free phenolic fraction due to their lower total phenolic content • The higher antioxidant capacity of the free phenolic fraction of finger millet—attributed to the high total phenolic content as well as flavonoids such as catechin, gallocatechin, epicatechin, and procyanidin dimmer contents detected in the free fraction of finger millet
Veenashri and Muralikrishna (2011)	Antioxidant property	1,1-Di phenyl-2 picryl-hydrazyl (DPPH), β-carotene linoleate emulsion, and ferric reducing antioxidant power (FRAP) assays	• Xylo-oligosaccharides (XO) from finger millet bran exhibited higher antioxidant activity of about 70% at 60 μg concentration, which is more than the antioxidant activity exhibited by rice, maize, and wheat bran XO mixtures (70% at 1000 μg concentration) in DPPH and FRAP assays
Venkateswaran and Vijayalakshmi (2010)	Production of antihypercholestrolemic metabolites	Finger millet (native and germinated)—used as substrates for solid state fermentation of *Monascus purpureus* at 28 °C for 7 days using 2% seed medium as inoculum for the production of its metabolites	• Germinated finger millet yielded higher total statin production of 5.2 g/kg dry weight with pravastatin and lovastatin content of 4.9 and 0.37 g/kg dry weight, respectively

Shobana et al. (2009)	Inhibition of intestinal α-glucosidase and pancreatic amylase	Enzyme kinetic studies	• Inhibition of intestinal α-glucosidase and pancreatic amylase by phenolics from finger millet seed coat matter—IC_{50} values 16.9 and 23.5 μg of phenolics • Noncompetitive type of inhibition for both the enzymes
Shobana (2009)	Antiprotein (albumin) glycation property	Fructose–bovine serum albumin model system	• Finger millet seed coat polyphenols (MSCP)—effective inhibitors of fructose-induced albumin glycation • Better restoration of tryptophan fluorescence (an index of inhibition of fructose-induced glycation of albumin) by MSCP (45 μg) compared to 15 mM aminoguanidine, a standard glycation inhibitor • 41% decrease in the AGE (advanced glycation end product) formation by 45 μg of MSCP compared to 54% decrease produced by 15 mM aminoguanidine
Varsha, Urooj, and Malleshi (2009)	Antibacterial and antifungal activity	Disc diffusion method, spore germination method	• Higher antimicrobial activity for polyphenol extract from finger millet seed coat compared to the polyphenol extract from finger millet whole flour against *Bacillus cereus* and *Aspergillus flavus*

Continued

Table 1.3 Some of the known health beneficial properties of finger millet—cont'd

References	Functional property	Method	Key findings
Varsha et al. (2009)	Antioxidant activity	Reducing power assay, β-carotene–linoleic acid assay	• High reducing power for seed coat polyphenol extract compared to the polyphenol extract from finger millet whole flour • Higher antioxidant activity for finger millet seed coat polyphenol extract (86%) compared to polyphenol extract from finger millet whole flour (27%)
Chethan, Dharmesh, and Malleshi (2008)	Aldose reductase enzyme inhibitory property	Enzyme kinetic studies	• Finger millet seed coat polyphenols inhibits aldose reductase extracted from cataracted human eye lenses by noncompetitive mode of inhibition • Quercitin from finger millet was more effective in inhibition with IC_{50} of 14.8 nM
Chethan (2008)	Inhibition of phospholipases A_2 (PLA_2) from snake venom (*Naja naja*)	Enzyme inhibitory studies	• Crude polyphenol extract from finger millet was a potent inhibitor of PLA_2 (IC_{50} 83.2 μg/ml) • Gallic acid and quercitin from finger millet was more potent inhibitors of PLA_2 (IC_{50} 62.3 and 16.8 μg/ml, respectively)
Chethan (2008) and Chethan and Malleshi (2007a)	Inhibition of pathogenic bacterial strains	Agar diffusion assay	• Antimicrobial activity of finger millet polyphenols on pathogenic bacterial strains: *Escherichia coli*, *Staphylococcus aureus*, *Listeria monocytogenes*, *Streptococcus*

			pyogenes, *Pseudomonas aeruginosa*, *Serrtia marcescens*, *Klebsiella pneumonia*, and *Yersinia enterocolitica* • Quercitin fractionated from finger millet inhibited the growth of all the pathogenic bacteria • Gallic, caffeic, protocatechuic, *para*-hydroxy benzoic acid showed their antimicrobial potentials restricted to only few bacterial strains
Hegde, Chandrakasan, and Chandra (2002)	Inhibition of collagen glycation and cross-linking	Phenol sulfuric acid method, pepsin digestion, and cyanogen bromide peptide mapping	• Methanolic extracts of finger millet inhibited both glycation and cross-linking of collagen
Subba Rao and Muralikrishna (2002)	Antioxidant activity	β-Carotene–linoleic acid assay	• Free phenolic acid content increased upon malting • Bound phenolic acid content decreased upon malting • Higher antioxidant activity for free phenolic acid mixture compared to that of bound phenolic acid mixture from finger millet • Malting influences antioxidant property of finger millet
Antony, Moses, and Chandra (1998)	Antimicrobial properties		• Inhibition of *Salmonella typhimurium* and *Escherichia coli* by fermented flour of finger millet

Continued

Table 1.3 Some of the known health beneficial properties of finger millet—cont'd

References	Functional property	Method	Key findings
Sripriya et al. (1996)	Free radical scavenging	Electron spin resonance (ESR) spectrometry	• The phenolic acid content of brown finger millet 96% higher compared to white variety • Germination and/or fermentation processes decreased the free radical quenching action of brown finger millet • Brown finger millet found to be more efficient in free radical quenching
(b) in vivo studies			
Shobana, Harsha, Platel, Srinivasan, and Malleshi (2010)	Blood glucose lowering effect	Streptozotocin-induced diabetic rat model fed with diet containing 20% finger millet seed coat matter for 6 weeks	• 39% reduction in the fasting blood glucose levels in diabetic experimental group of animals compared to the diabetic controls • Lower glycosylated hemoglobin levels (4.21%) compared to diabetic controls (6.31%)
	Decreases AGE (advanced glycation end product) formation		• 20% lower AGE products at the end of the study compared to the diabetic controls
	Delay of onset of cataractogenesis		• Lower aldose reductase enzyme activity in the eye lens compared to the diabetic control group • Very mild lenticular opacity and posterior subcapsular cataract compared to the significant mature cataract in the diabetic control group of animals

	Nephroprotective properties		• Decrease in the urinary volume and excretion of urinary metabolites (glucose, protein, urea, and creatinine) compared to the diabetic controls • Normal glomerular, tubular structures and absence of mucopolysaccharide depositions in the kidney compared to the shrunken glomeruli, tubular clarifications, vacuolizations, and mucopolysaccharide depositions in the kidney of diabetic controls
	Cholesterol lowering		• Lower serum cholesterol and triacyl glycerol levels (43% and 62%, respectively) compared to diabetic controls • Lower atherogenic index (1.82) compared to the diabetic controls (5.3)
Tatala, Ndossi, Ash, and Mamiro (2007)	Improvement on hemoglobin status in children	The effect of feeding germinated finger millet-based food supplement on hemoglobin status—assessed in children in rural Tanzania. The food consisted of finger millet flour, kidney beans, ground peanuts, and dried mangoes (75:10:10:5), diets were supplemented to children for 6 months	• Supplementing infants with the germinated finger millet-based food showed a general improvement on hemoglobin status

Continued

Table 1.3 Some of the known health beneficial properties of finger millet—cont'd

References	Functional property	Method	Key findings
Lei, Friis, and Michealsen (2006)	Natural probiotic treatment for diarrhea	Finger millet drink fermented by lactic acid bacteria used as a therapeutic agent among Ghanaian children with diarrhea (below 5 years). Children randomized to two groups, both groups received treatment for diarrhea and the intervention group in addition received up to 300-ml fermented millet drink (KSW) daily for 5 days	• No effects of the intervention were found with respect to stool frequency, stool consistency, and duration of diarrhea • Greater reported well-being 14 days after the start of the intervention with KSW • No effect of KSW on diarrhea could be because many were treated with antibiotics which could have affected the lactic acid bacteria, or the lactic acid bacteria in KSW had no probiotic effects • Effect after two weeks could be due to a preventing effect of KSW on antibiotic-associated diarrhea which could help reducing persistent diarrhea
Hegde, Rajasekaran, and Chandra (2005)	Cholesterol lowering	Alloxan-induced diabetic rat model, finger millet incorporated diets (55% in the basal diet) fed for 28 days	• 13% reduction in serum cholesterol levels compared to the controls
	Rat tail collagen glycation inhibitory property		• Rat tail tendon collagen glycation was only 40% in the finger millet fed rats compared to control group of animals
	Blood glucose lowering property		• 36% reduction in blood glucose levels
	Antioxidant property		• Levels of enzymatic (catalase, superoxide dismutase, glutathione peroxidase, and glutathione reductase) and nonenzymatic

			antioxidants (glutathione, vitamin E and C) restored to normal levels • Reduced levels of lipid peroxides
Hegde, Anitha, and Chandra (2005)	Wound healing property	Excision wound—rat model, finger millet flour (300 mg)—aqueous paste applied topically once daily for 16 days	• Significant increase in protein, collagen, and decrease in lipid peroxides • 90% rate of wound contraction compared to 75% for control untreated rats • Complete closure of wounds after 13 days compared to 16 days for untreated rats
Rajasekaran, Nithya, Rose, and Chandra (2004)	Wound healing property	Excision skin wound—hyperglycemic (alloxan-induced) rat model, 4 weeks' feeding	• Increased expression of NGF (nerve growth factor) • Epithelialization, increased synthesis of collagen, activation of fibroblasts, and mast cells • Control of blood glucose levels, improved antioxidant status, hastened dermal wound healing
Pore and Magar (1976)	Cholesterol lowering	Male albino rats fed with ragi diet for 8 weeks	• Lower serum cholesterol (65 mg/dl) compared to casein diet fed animals (95 mg/dl)
Tovey, Jayaraj, and Clark (1975)	Antiulcerative property	Experimental ulceration following pyloric ligation in female albino rats fed with ragi incorporated stock diet for 2 weeks	• Offered protection against mucosal ulceration

the antiulcerative potential of finger millet through animal feeding trials and Pore and Magar (1976) reported the cholesterol lowering properties of finger millet by animal feeding. The other health beneficial aspects of finger millet feeding, namely, the glucose lowering, cholesterol lowering, nephroprotective properties, antioxidant properties, wound healing properties, and anticataractogenesis properties of finger millet were reported by several authors (Hegde, Anitha, et al., 2005; Hegde, Rajasekaran, et al., 2005; Rajasekaran et al., 2004; Shobana et al., 2010). Improvement on the status of hemoglobin in children on feeding finger millet-based food was reported by Tatala et al. (2007). Whereas fermented finger millet drink as a natural probiotic treatment for diarrhea was reported by Lei et al. (2006). Even though there are many *in vitro* and *in vivo* studies on the health benefits of finger millet, there are very few human studies to the best of our knowledge.

9. *IN VITRO* STUDIES ON THE CARBOHYDRATE DIGESTIBILITY OF FINGER MILLET

Studies on the type of starch, its digestibility, and crystallinity demonstrated that the degree of crystallinity of finger millet and the amount of heat flow required to gelatinize starch was much higher as compared to rice. The molecular weight of the human salivary amylase digests of the finger millet starch was higher than that of rice starch digests (Mohan, Anitha, Malleshi, & Tharanathan, 2005). Further studies indicate that finger millet starch is the most difficult to be hydrolyzed in *in vitro* by fungal α-amylase (Singh & Ali, 2006). These results indicate a higher degree of crystallinity and slightly lower digestibility of finger millet starch by the digestive enzymes in *in vitro*.

Roopa and Premavalli (2008) studied the effect of processing on the starch fractions in finger millet and reported that puffing resulted in a mild increase in the rapidly digestible starch and decrease in the slowly digestible starch fractions compared to native finger millet flour, and the authors also reported that resistant starch (RS) content decreased during puffing. The study also indicated that the pressure cooking and roasting processes increased the RS fraction in finger millet compared to other processes. The finger millet product prepared by roasting contained the highest amount of RS compared to other products (3.1%).

Several *in vitro* and *in vivo* studies on the carbohydrate digestibility and glycemic properties of finger millet foods indicated that the rate of starch hydrolysis and glucose release (digestibility index, DI) are affected by degree of gelatinization (DG), added ingredient components and accompaniments (Roopa, Urooj, & Puttaraj, 1998; Sharavathy, Urooj, & Puttaraj, 2001). Finger millet *puttu* (steamed product made out of finger millet flour and consumed with grated coconut and sugar) registered a lower DG as compared to rice *puttu* and other finger millet and rice preparations (*roti*, *dosa*, dumpling) (Roopa et al., 1998). It is to be noted that wheat *chapathis* have better DI as compared to finger millet *roti* (Urooj & Puttaraj, 1999).

Urooj, Rupashri, and Puttaraj (2006) reported a high DG and DI for dumplings compared to the *roti* preparations from finger millet and sorghum. The study also reported a higher GI for dumplings compared to *roti* preparations. This clearly shows that DG affects the GI of the food. Similar studies on rice have indicated that rice with lower DG elicited a lower glucose and insulinemic responses compared to the rice with higher DG (Jung et al., 2009). Reports on potato starch indicate that the DG of starch strongly affects its digestibility *in vitro* (enzymatic digestion) and may influence the postprandial GR (Parada & Aguilera, 2008). The digestibility or hydrolysis of starch is considerably influenced by accompaniments. *Puttu* (a steamed cereal flour) with coconut and sugar resulted in higher DI as compared to the cereal foods with *chutney* or *sambar* as accompaniments (Roopa et al., 1998). In short, the food matrix influences the carbohydrate digestibility.

It needs to be observed that repeated cooking and cooling for several times for both rice and finger millet flour suspensions led to increased levels of RS (Mangala, Malleshi, Mahadevamma, & Tharanathan, 1999; Mangala, Ramesh, Udayasankar, & Tharanathan, 1999). The RS isolated from five-cycle autoclaved finger millet flour was found to be a linear α-1,4-D-glucan, probably derived from a retrograded amylose fraction of finger millet starch. The undigested material recovered from the ileum of rat intestine fed with processed finger millet flour exhibited a close similarity (almost comparable molecular weight) in some of its properties to that of RS isolated by an *in vitro* method (Mangala, Ramesh, et al., 1999). Lower GRs for cooled potatoes compared to hot potatoes are reported elsewhere (Nadine, Nada, & Nahla, 2004). Aarthi, Urooj, and Puttaraj (2003) reported an RS content of 4.5% in finger millet *roti*, and Platel and Shurpalekar (1994) reported an RS content of 1.79 g% (on dry weight basis) in pressure cooked finger millet. Foods containing RS have reduced digestible energy (hence reduced calorie density) compared to the foods containing readily digestible starch. Apart from these, RS produces lower glycemic and insulinemic responses and is known to be beneficial for individuals with diabetes and obesity (Birkett, 2007).

10. GLYCEMIC RESPONSE (GR) STUDIES ON FINGER MILLET (HUMAN STUDIES)

As early as 1957, Ramanathan and Gopalan (1957) reported low GR to cooked finger millet and finger millet starch isolates compared to milled rice, parboiled rice, and wheat diet when very little was known about the factors that influence the glycemic response. Though there were other studies on the GR to finger millet preparations, compared to other cereals and millets (Chitra & Bhaskaran, 1989; Kavita & Prema, 1995; Kurup & Krishnamurthy, 1992; Lakshmi Kumari & Sumathi, 2002; Mani, Prabhu, Damle, & Mani, 1993; Shobana, Ushakumari, Malleshi, & Ali, 2007; Shukla & Srivastava, 2011; Urooj et al., 2006), it is difficult to draw any conclusion as the number of subjects participated in the study was either too small or, even with sufficient sample size, the methodology adopted was inconsistent compared to the internationally valid GI protocols. Most of the studies were conducted with small number of individuals, and measurement of the glycemic response was done using venous samples instead of capillary blood samples as suggested by the new valid protocol. Capillary samples are generally preferred over venous samples as the rise in blood glucose values in response to foods is higher than in venous plasma and less variable in capillary blood samples as compared to that of venous plasma glucose. Hence, the differences between foods are larger and easier to detect statistically using capillary blood glucose (FAO/WHO, 1998; Venn & Green, 2007). In addition, the available carbohydrate content of the test foods was not estimated directly then, as the standardized protocol became available recently and the method of the food preparation and accompaniments were not adequately reported (potential factors to influence GI) in these studies.

Geetha & Easwaran (1990) in their study fed finger millet incorporated (20%) breakfast preparations, namely, *idli* (fermented, steamed rice cake), *dosai* (fermented rice pan cake), *chapathi* (unleavened flat bread), *sevai* (rice string hoppers), and *kozhukattai* (steamed rice balls) to NIDDM subjects (n = 6) for a month. The study showed a significant decrease in the postprandial blood glucose after finger millet administration for a month, though the limitation was small sample size.

Lakshmi Kumari and Sumathi (2002) also reported that malting and fermentation processes increase the carbohydrate digestibility of finger millet and attributed the higher GR of germinated finger millet dosa (fermented) and germinated finger millet *roti* compared to the normal whole finger millet *dosa* and whole finger millet *roti* possibly due to the conversion of starch to lower molecular weight dextrins and maltose during germination. The authors reported a higher GR for finger millet *dosa* compared to finger millet *roti* and attributed their results to the wet grinding and fermentation of batter prior to *dosa* preparation leading to starch gelatinization and enhanced rate of starch digestion in finger millet *dosa* compared to finger millet *roti*.

Decorticated (polished) finger millet in the grain form as a formulation with legumes gave a higher GI (93.4) as compared to wheat-based formulations with legumes (55.4) (Shobana et al., 2007). Lower GI for finger millet incorporated noodles compared to refined wheat flour-based noodles was reported by Shukla and Srivastava (2011).

Patel, Dhirawani, and Dharne (1968) did not observe any benefit in the treatment of diabetes when the diets of eight male diabetic subjects (40–80 years of age) with duration of diabetes from 1 day to 13 years were changed from rice to finger millet as the staple grain in their diets for 8–10 weeks. The recent report on the nutritional management of diabetes with finger millet is still not very conclusive, and hence studies for prolonged periods are needed to draw meaningful conclusions (Kamala et al., 2010; Pradhan, Nag, & Patil, 2010).

This drawback is not only in the case of studies on finger millet, but it also applies to the studies on GI of other millets. Mani et al. (1993) indicated that the GI of finger millet in the form of roasted bread (unleavened flat bread) (104) was higher than the GI values obtained for pressure cooked *varagu* (kodo millet) (68) and roasted breads from *bajra* (pearl millet) (55) and *jowar* (sorghum) (77). While Pathak, Srivastava, and Grover (2000) determined the GI of *dhokla* (fermented and steamed cakes), *uppma* (cooked roasted semolina seasoned with vegetables and spices), and *laddu* (an Indian sweet ball) prepared from a blend of foxtail and barnyard millet with fenugreek and legumes and reported a GI of 34.96 for *dhokla*, 23.52 for *laddu*, and 17.60 for *uppma*. Vijayakumar, Mohankumar, and Srinivasan (2010) in a recent study reported a GI of 84.8 for barnyard and kodo millet incorporated noodles compared to 94.6 for the branded noodle prepared from *maida* (refined wheat flour) in 10 normal subjects. There was no indication on the method of estimation of available carbohydrates, and the capillary blood glucose response was determined at 1-h intervals (0, 1, 2, and 3 h). The GI reported in the literature for foxtail millet incorporated biscuit was 50.8 compared to 68.0 for both barnyard millet incorporated biscuits and control refined flour wheat biscuits (Anju & Sarita, 2010). Ugare, Chimmad, Naik, Bharati, and Itagi (2011) in their study reported a GI of 50.0 and 41.7 for the dehulled and heat-treated barnyard (dehulled) millet, respectively. Inspite of several studies on the GI of millets, due to the outdated methodology

Table 1.4 A sample meal plan with "finger millet"-based preparations

Meal	Menu	Description
Breakfast	Finger millet steamed cake	Fermented steamed cake prepared from finger millet and black gram dhal
	Tomato and onion sauce	Ground paste of tomatoes and onions seasoned with spices
	Lentil sauce	Spicy lentil curry in tamarind sauce
Lunch	Finger millet balls/ unleavened flat bread	Gelatinized stiff porridge made into balls with whole finger millet flour/finger millet flour based unleavened flat bread
	Egg plant sauce	Spicy lentil curry in tamarind sauce with egg plant
Evening tea	Tea	With milk
	Finger millet crisps	Low fat extruded snack prepared from finger millet flour
Dinner	Finger millet fermented pan cake	Fermented pancake made with ground batter of finger millet and black gram dhal
	Vegetable stew	Vegetable stew with spices

adopted in these studies, it is very difficult to draw meaningful interpretations on the GI of other millets too.

However, it is a general belief that lower glucose responses are obtained with unrefined finger millet-based products and health professionals tend to advice finger millet preparations for treatment of both obesity and diabetes. There are many traditional (Fig. 1.1) and contemporary foods that could be prepared with whole finger millet meal. These foods could be used in place of staple foods such as rice and wheat. Table 1.4 lists such a sample meal plan using finger millet-based preparations. However the GI testing of the individual preparations should be carried out before recommending these preparations for population with diabetes. Judicious selection of accompaniments should also be made for these preparations to lower the overall meal glycemic response.

11. GAPS IN THE KNOWLEDGE AND FUTURE DIRECTIONS FOR RESEARCH

Though finger millet inherently possess components that are likely to lower GI, various methodologies and nonstandard protocols adopted for the determination of GI in most of the studies resulted in GI values ranging from low to high GI categories. Moreover, the available carbohydrate (glycemic carbohydrates, carbohydrates available for metabolism) content of the foods was not estimated by direct measurement and most of the values were calculated from food composition data that give carbohydrate values "*by difference*" method (Gopalan et al., 2009). The updated GI methodology published elsewhere (Brouns et al., 2005; FAO/WHO, 1998; Wolever, Jenkins, Jenkins, & Joss, 1991) recommends volunteers aged between 18 and 45 years and inclusion of at least 10 subjects for the determination of GI of a food. Capillary blood glucose is preferred over venous sample to give the greatest sensitivity to the food's GI, whereas most of the studies cited mostly used venous samples. In addition, the current GI methodology guidelines strongly recommend direct measurement (by enzymatic procedure) of available carbohydrates from foods. Imprecise estimation of the available carbohydrate content of foods can lead to over or underestimation of GI values of the food (Brouns et al., 2005).

The method of processing, DG, particle size, food ingredients, accompaniments, and the form in which the food is consumed are known to affect GI (Brand Miller, Wolever, Foster-Powell, & Colagiuri, 2007). Hence, the glycemic response to finger millet-based preparations should be determined in isolation and also along with usual accompaniments using validated protocol to understand its glycemic properties.

12. CONCLUSION

Whole-grain consumption is associated with reduced risk of CVD and type 2 diabetes; hence, consumption of whole meal-based finger millet products may be desirable due to the protective role of SCM that could contribute varied health benefits. Finger millet products processed suitably to lower their GI in synergy with accompaniments rich in vegetables and pulses may help in prevention or control of chronic diseases in general and diabetes in particular. The published literature shows a wide range of GI values for foods from finger millet (45–104), despite methodological limitations and due to processing attributes like particle size, germination, hydrothermal processing, decortication, roasting, cooking in the form of dumpling, etc. The presence of higher levels of dietary fiber and other protective healthy nutrients in the whole meal-based finger millet preparations may still help in the nutritional management of diabetes. Hence to enjoy the benefit of the functional constituents, it is imperative to identify judicious processing methods for finger millet preparations to obtain maximum health benefits from the millet through appropriate research. GI testing of finger millet preparations as well as short- and long-term intervention trials using judiciously processed finger millet may be helpful in understanding the health benefits of finger millet before appropriate recommendations could be made for prevention and management of chronic diseases such as diabetes. Studies in this direction are already in progress at Madras Diabetes Research Foundation, Chennai, India.

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