The Pharma Innovation Journal 2023; 12(1): 1291-1297

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(1): 1291-1297
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www.thepharmajournal.com
Received: 20-11-2022
Accepted: 24-12-2022

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Nutritional qualities, processing and health benefits of finger millet (*Eleusine coracana* L.)

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Abstract
This article discusses the history, consumption, nutritional content, processing, and health advantages of one of India's first millets, finger millet, often known as ragi (2300 BC). Finger millet has the highest calcium (344 mg %) and potassium (408 mg %) content of all grains and millets. It has more dietary fibre, minerals, and amino acids including sulphur than white rice (current staple grain) of the nation. Despite the nutritional value of finger millet, urban Indians consume less of it, according to recent studies. Finger millet is processed by milling, malting, fermentation, popping, and decortication. Noodles, vermicelli, pasta, Indian sweet (halwa) papads, soups and baked items are also derived from finger millet. *In vitro* and *in vivo* (animal) experiments have demonstrated that it can aid in wound healing, lowering blood sugar and cholesterol. Regarding these health implications, however, there are no appropriate therapies or randomized clinical studies. The glycemic index (GI) of finger millet preparations ranges from low to high, however the bulk of investigations employed obsolete methodologies. Therefore, proper gastrointestinal (GI) testing of finger millet formulations as well as short- and long-term human intervention studies may be effective for establishing health benefits.

Keywords: Millets, production, utilization, nutritional properties, processing, health benefits

Introduction
Minor cereals of the Poaceae grass family include millets. Their ability to thrive in less nutritious soil distinguishes them as small-seeded, annual cereal grasses, many of which are adapted to tropical and desert conditions. Ragi also known as *Eleusine coracana* L., is a widespread millet in many parts of India. It has historically been a significant millet staple meal in portions of eastern and central Africa and is also frequently known as Koracan in Sri Lanka and by other names in Africa. To make beverages, porridge, idli (an Indian fermented steamed cake), dosa (an Indian fermented pancake) and roti. Finger millet was traditionally ground, malted, and fermented in India (unleavened flat bread).

According to research, consuming whole grains and cereal fibre is inversely related to BMI, waist circumference, total cholesterol, metabolic syndrome, cardiovascular disease mortality, insulin resistance, and type 2 diabetes incidence. The widely consumed polished white rice is nutritionally inferior to whole-grain cereals like brown rice and millets. Studies have also revealed a link between the dietary glycemic load, which measures the quality and amount of carbohydrates, and a higher intake of refined grains like white rice among South Asian Indians living in urban areas. Several studies have documented the beneficial effects of low glycemic index (GI) foods and diets in the nutritional management of diabetes and a number of other chronic diseases. GI is a measure of the quality of carbohydrates. Low GI foods typically slow down the rate of glucose absorption, which lowers insulin demand. Among addition, it was discovered that in obese South Asian Indians, a calorie-restricted diet with moderately fewer carbohydrates was effective in reducing insulin resistance and other metabolic abnormalities. by incorporating whole, ancient grains like sorghum and millets like finger millet into the diets of contemporary Asian Indians, researchers have provided techniques that are realistic for lowering the burden of chronic disease has discussed about how eating finger millet can help prevent chronic diseases as well as provide a variety of nutritional and health benefits.

Unfortunately, a large number of traditional Indian grains, especially millets, have not been properly assessed for GI. Additionally, the production and distribution of low GI foods is restricted, particularly in India's millets. Being a low-cost millet with better dietary fibre levels, several phytonutrients, and virtually no reports of any negative effects, finger millet demands consideration.

This review aims to investigate the potential health advantages of processed finger millet, paying particular attention to its dietary and glycemic characteristics. Using appropriate keywords, literature searches were carried out in the Pubmed, Science Direct, and Google databases. The studies considered in this study were written between 1939 and 2012.

History of finger millet

One of India's oldest crops, finger millet, was also referred to as "rajika" or "markataka" in ancient Indian Sanskrit literature, which means "Dancing grain." The earliest mention of finger millet dates to about 2300 BC and originates from Hallur in Karnataka, India. There is substantial controversy around the origin of finger millet. According to some ideas, the grain may have crossed the Indian Ocean in both directions or arrived by sea from South Africa or Arabia reviewed the archaeological work done in India and elsewhere on the origin of Eleusine in great detail, reports its African origin, and provides linguistic evidence for the term "ragi" from the root source term-de'gi for finger millet in a number of Bantu languages from southern Tanzania and northern Malawi and its other variants in the Indian subcontinent. Fuller reported that the grains recovered from Hallur (1000 BC), Malhar (800 BC-1600 BC), and Hulaskhera (700 BC) in India were real, notwithstanding his skepticism regarding the majority of the discoveries on finger millet (Fuller, 2003). Despite being of African descent, ragi (finger millet), jawar (sorghum), and bajra (pearl millet) have long been domesticated in India.

In many Indian states, finger millet was a well-domesticated plant known by names like "umi" in Bihar and "nachni" (which means dancer) in the state of Maharashtra. The grains were gently roasted, crushed, and sieved (sometimes after they had been sprouted and dried). When eaten as a ball or gruel, the pinkish flour (from red finger millet) was either salted or sweetened. Additionally popular as weaning foods was finger millet.

Red finger millet is referred to as "Kelvaragu" in the ancient Indian Tamil work "Kuruntogai." "Purananuru," a passage from Sangam Tamil literature (600 BC–200 AD), describes the drying, husking, and cooking of finger millet grains. In ancient India, poets were offered finger millet boiled in milk with honey (Achaya, 1992) [1]. It is still in use in Karnataka today.

Millet consumption in India

According to reports from the National Nutrition Monitoring Bureau (NNMB, 2006) [13], consumption of millets, in general, was higher in Gujarat (maize and pearl millet),

Maharashtra (sorghum) and Karnataka (finger millet) but almost nonexistent in Kerala, West Bengal, Orissa, and Tamil Nadu, where rice is the main staple food. Gujarat and Maharashtra used more millets per capita than Karnataka, Madhya Pradesh, and Andhra Pradesh (75, 32 and 16 g/CU/day, respectively; the consumption unit is a coefficient). Orissa (1 g/CU/day) and Tamil Nadu (3 g/CU/day) reported low levels of consumption.

Despite the fact that for the bulk of Indian diets, grains continue to make up the main staple and account for 70–80% of total caloric intake, finger millet (Ragi, *Eleusine coracana* L.). As shown by our recent study on the dietary profile of urban Indians (from the Chennai Urban Rural Epidemiology Study (CURES)), which found that millets contributed to only about 2% of total calories (6.7 g/d), while almost half of the daily calories were derived from refined grains like polished white rice (253.4 g/day), millets consumption is significantly lower than rice consumption.

Table 1: Millet consumption in India in different years

Crop Years	Ragi	Jowar	Bajra	Small millets	Total Nutri-cereals
2011-12	19.3	59.8	102.8	4.5	186.4
2012-13	15.7	52.8	87.4	4.4	160.3
2013-14	19.8	55.4	92.5	4.3	172.0
2014-15	20.6	54.5	91.8	3.9	170.8
2015-16	18.2	42.4	80.7	3.9	145.2
2016-17	13.9	45.7	97.3	4.4	161.2
2017-18	19.9	48.0	92.1	4.4	164.4
2018-19	12.4	34.8	86.6	3.3	137.1
2019-20	17.6	47.7	103.6	3.7	172.6
2020-21	19.6	47.8	108.6	3.5	179.6

Nutritional significance and structural features of finger millet

The three main botanical parts of a millet kernel are the seed coat, the embryo (germ), and the endosperm. There are varieties with yellow, white, tan, red, brown, and violet colors; however, only the red varieties are frequently grown around the world. The pericarp, which is the outermost layer of the seed, has minimal nutritional value. In contrast to other millet varieties including sorghum, pearl millet, proso millet, and foxtail millet, the seed coat or the testa is multilayered (five layers thick) and this can be one of the reasons why finger millet has a greater level of dietary fiber. The starchy endosperm, which is further separated into corneous and floury areas, and the aleurone layer, which lies between the seed coat and endosperm, are both securely attached to the seed coat. Starch granules are well structured in the cell walls of the corneous endosperm and are loosely packed in the cell walls of the floury endosperm.

When compared to pearl and proso millets, the diameters of the starch granules in the finger millet kernel vary substantially, ranging from 3 to 21 mm. Millets' floury endosperm often contains larger starch granules than their corneous counterparts, making it more amenable to enzymatic digestion. However, more investigation is needed to examine the properties of starch that are susceptible to enzyme (digestive enzymes) action in the corneous and floury endosperm sections of finger millet separately. Typically, finger millet is ground into flour along with the seed coat, which is high in dietary fibre and minerals, and the whole meal is used in food preparation. Finger millet contains tannins in its seed coat layers, which may help explain why its products are so astringent. There is a high concentration of polyphenols in the millet seed coat, germ, and endosperm cell walls.

Nutrient composition of finger millet

Carbohydrates

Finger millet is a rich source of carbohydrates, containing free sugars (1.04%), starch (65.5%) and non-starchy polys-accharides (11.5%) or dietary fibre. In a study on a few different types of finger millet, the percentages of starch, pentosans, cellulose, and lignins were found to be between 59.5 and 61.2%, 6.2 to 7.2% and 0.04-0.6%, respectively. Finger millet (11.5%) has a nutritional fibre content that is

significantly higher than that of brown rice, polished rice, and all other millets, including foxtail, tiny, kodo, and barnyard millet. However, finger millet has a dietary fibre level that is comparable to that of wheat and pearl millet. When compared to wheat, finger millet has a similar amount of carbohydrates, but less than polished rice.

Amylose and amylopectin are components of finger millet starch. Compared to other millets like sorghum (24.0%), pearl millet (21.0%), proso millet (28.2%), foxtail millet (17.5%), and kodo millet (24.0%), finger millet starch has a lower amylose concentration (16%). The maximum set back viscosity (560 BU) was found in the finger millet (Purna variety) starch during cooling (from 930 to 500 C), which is suggestive of its propensity to retrograde (retro gradation of starch is known to induce resistance starch formation).

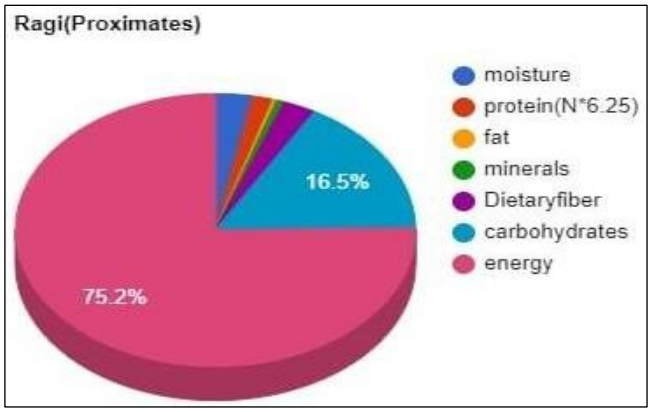


Fig 1: Ragi (Proximates)

Proteins

The protein content of finger millet varies with variety. The majority of the protein in finger millet is composed of prolamins. 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. When comparing the amount of an amino acid in a test protein to that in a reference protein, the chemical score—a metric for protein quality—is calculated as finger millet protein (percentage) is 52 compared to 37 for sorghum and 63 for pearl millet (. Compared to milled rice, finger millet has higher quantities of the sulfur containing amino acids methionine and cystine The tannin concentration of the grain has an impact on the finger millet's ability to digest proteins that a diet high in finger millet and pulses was sufficient to keep the levels of phosphorus (8.7% P), calcium (3.0% Ca), and nitrogen (10.4% N) in humans adults in a positive balance

In comparison to a control casein diet, the B-11 variant of the finger millet-based diet had a protein efficiency ratio (a measure of protein quality in terms of weight gain per amount of protein taken) of 0.95, according to their study.

Fat

Seven breeding variants of finger millet contained 1.85–2.10% of the total lipids. The lipid composition of finger millet is composed of 1012% glycolipids, 5-6% phospholipids, and 70-72% neutral lipids, primarily triglycerides and traces of sterols. The percentages of oleic acid, linoleic acid, palmitic acid, and linolenic acid in lipids range from 46 to 62, 8 to 27, and 20 to 35, respectively. In comparison to pearl millet, barnyard millet, little millet, and foxtail millet, finger millet has a lower fat content. This lower lipid content may be one of the reasons for finger millet's superior storage qualities.

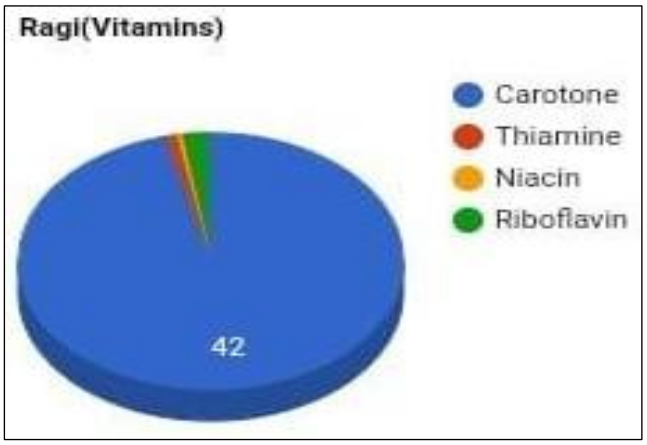


Fig 2: Ragi (Vitamins)

Micronutrients

Compared to other cereals and millets, finger millet has an outstanding amount of calcium (344 mg %), is eight times more iron- and phosphorus-rich than pearl millet (3.9 mg %), and includes a variety of trace elements and vitamins (Gopalan *et al.*, 2009) [18]. When compared to other cereals and millets, finger millet has a high (408 mg %) potassium content (Table 1). The "Hamsa" variety of finger millet was reported to have substantially greater amounts of calcium (660 mg %) than other high calcium finger millet variants. The readings for different kinds of finger millet ranged from 0.45 to 0.49 g% for phytic acid concentration, which was lower than that of common (proso) millet and foxtail millet.

The finger millet's oxalate concentration was in the 29–30 mg% range, the husk of finger millet contains almost 49% of the grain's total calcium content. According to Sri Priya, Antony and Chandra's (1997) [29] research, finger millet's germination and fermentation reduced its phytate level by 60% and increased the bioavailability of micronutrients. Enhanced bio accessibility of minerals (iron, manganese) after malting finger millet was also reported. While popping finger millet increased the bio accessibility of iron and zinc but decreased the bio accessibility of calcium, decorticating finger millet boosted the bio accessibility of calcium, iron, and zinc while decreasing the overall mineral contents. Calcium, iron, and zinc's bio accessibility was improved by malting finger millet.

In addition to maintaining a favorable nitrogen balance, a study on 9 to 10-year-old girls found that switching from rice to finger millet boosted calcium retention. Given that it contains a lot of calcium and iron and that its bioavailability may be increased with straightforward processing, including germination and fermentation, it should be regarded as an excellent supplement for kids and teenagers to boost their hemoglobin levels and bone health

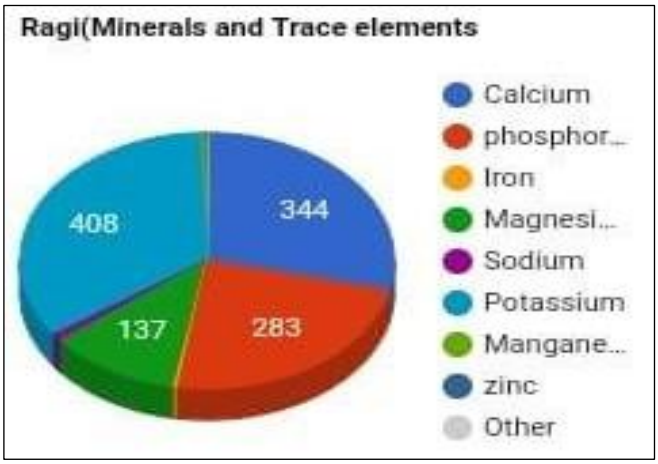


Fig 3: Ragi (Minerals and Trace elements)

Phytonutrients/ Phytochemicals

Phenolic compounds

In finger millet, the phenolic concentration varies depending on the variety. Brown variety is reported to contain more phenolic chemicals than white variant. Numerous phyto-chemicals found in finger millet, in general, and the seed coat in particular, may have positive health effects. A great source of several phenolic compounds is finger millet. In finger millet, phenolic acids have been found in both free and bound forms (Subba Rao & Muralikrishna, 2002) [30]. In a rat intravenous glucose tolerance test, caffeine is said to lower fasting glycemia and lessen the rise in plasma glucose. Additionally, it has been shown to enhance glucose absorption in mouse myoblasts and rat adipocytes.

Quercitin was discovered to decrease glucose transport in a transfected oocyte model and glucose absorption in rats, while catechin was found to enhance glucose tolerance in rats. These potentially beneficial polyphenols are present in finger millet. The effect of grain phenolics primarily depends on how bioavailable they are. There are few studies on the bioavailability of finger millet phenolics, and it is crucial to conduct human trials to learn more about the phenolic compounds found in finger millet, their nature, bioavailability, *in vivo* antioxidant activities, and long-term benefits.

Processing and Utilization of finger millet

In India, finger millet is often ground up and the entire meal is used to make traditional dishes like roti (unleavened flatbreads), kazhi (finger millet balls), and kanji (thin porridge), (Fig 1). Additionally to these conventional foods, finger millet is processed to create popped, malted, and fermented goods. Papads (rolled, dried, preserved food), noodles, soup, and other unconventional goods are made from finger millet. Decorticated finger millet was created recently. The specifics of the various processing steps are shown in (Fig. 2).

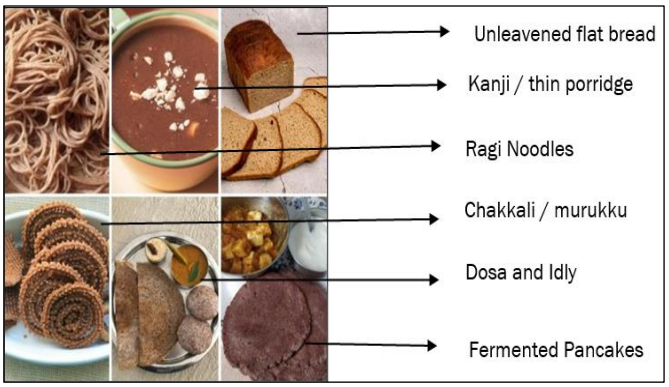
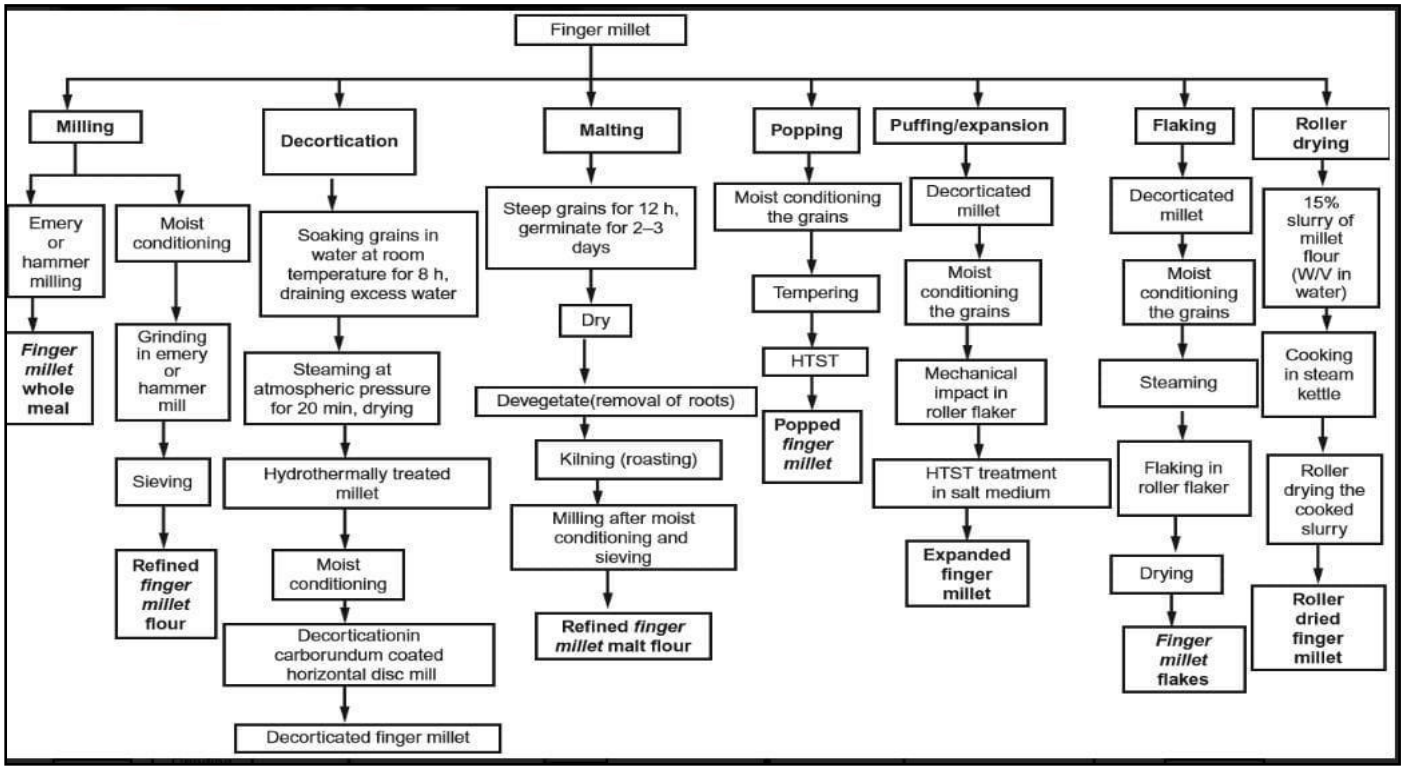


Fig 4: Prominent traditional Indian foods from Finger millet



Source: Malleshi (2007) [28], Shobana (2009) [27], Shobana and Malleshi (2007) [28]

Fig 5: Different processing techniques adopted to develop products from finger millet

Milling

Due to the fragile endosperm and unbroken seed coat of the finger millet kernel, which are distinctive characteristics, the grain cannot be polished and cooked in the grain or grit form like rice or other cereals. Therefore, in order to prepare flour, the grain must always be ground or milled. Foods made from whole meal finger millet are typically darker and less appealing (Fig. 3). An effort had been made to create refined or seed coat free flour akin to white flour or "maida" (refined wheat flour) in light of this and to address the shortcomings. The refined flour is more seed coat matter-free and noticeably whiter (SCM). However, compared to whole meal based goods, refined flour may have higher glycemic responses (GRs).

However, because to it predominate starch content and lower levels of dietary fibre, refined flour may have higher glycemic reactions (GRs) than whole meal-based goods. Because it contains more dietary fibre, vitamins, and minerals than refined wheat, whole flour is healthier for you overall (Table 2).

Decertification

This method was just recently discovered for finger millet. Due to the entire seed coat and extremely fragile endosperm, finger millet was not amenable to the debranning or decortication techniques used for most cereals. As a result, finger millet is hydrothermally processed (hydrated, steamed, and dried) to decorticate, hardening the delicate endosperm to make it survive the mechanical impact (Fig. 4). The finger millet that has been decorated can be prepared as separate grains and cooked like rice. The SCM, which is the main by-product of the decortication process, is a rich source of phenolic compounds, minerals, and dietary fibre that are good for your health. However, decorticated finger millet's glycemic characteristics (cooked in the discrete form similar to rice grains. The glycemic characteristics of decorticated finger millet, which is prepared in discrete grains comparable to rice, have not yet been determined. In food compositions, the SCM can serve as a source of fiber and minerals.

Table 1.2: Nutrient content of few of the finger millet products

Nutrients	Native millet Finger	Refined finger millet flour	Malted finger millet refined flour	Hydrothermal Processed finger millet	Decorticated Finger millet	Expanded Finger millet	Popped Finger millet	Flaked Finger millet	Finger millet toasted flakes	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
Fats (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
Calcim (mg)	321	163	350	311	185	190.0	250	272	273	270
Phosporus (mg)	201	106	190	160	111	NA	125	103	100	146

Malting

One tropical cereal that has good malting qualities is finger millet. Barley is typically the cereal of choice for both the brewing and food industries. However, attempts to research the malting qualities of finger millet were performed as early as 1939, when Sastri (1939) [31] reported the requirements for making high-quality malt. The author further claimed that finger millet's small size was useful for achieving consist ent germination and for kilning, the procedures involved in making malt. The details of the malting process are shown in Fig. 5. Malt flour is a good source of amylases and enzymes that break down proteins. "Amylase-rich food." Maltflourcan be used as a substitute for maltodextrin and combined with milk before being spray dried to make baby food (Malleshi, 2007) [28]. The malt flour has a high energy density because during germination, the amylases partially hydrolyze the starch to produce lower molecular weight carbohydrates like oligo- and disaccharides. Because of this, there is potential for using refined finger millet malt flour in newborn foods, weaning foods, and enteral foods. The malted millet additionally, cakes, confections, and milk-based beverages have all used the millet malt flour. Malted cereals may have greater GRs, contain highly digested carbs, and otherwise not be suited for various metabolic disorders.

Popping

This is one of the important processing methods that is frequently used to make ready-to eat foods. Sand is used as the heat transfer medium during the high-temperature, short time treatment (HTST) of finger millet, causing the endosperm to burst open and the starch to gelatinize. The flavor and perfume of finger millet that has been popped are very appealing. After seasoning with spices and condiments, it is eaten as a snack. In the Indian state of Karnataka, hurihittu is the name given to pop-millet flour. It is a wholegrain 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 Nowadays, finger millet is also puffed using an air popper device, which is better (in terms of quality with no sand and low salt content in the product) than the product created using sand or salt as heat transfer media. The decorticated finger millet has recently also given rise to expanded finger millet. Since expanded finger millet is made from decorticated finger millet, which lacks a seed coat, its dietary fibre level is lower than that of popped finger millet.

Health benefits of finger millet

Natural weight loss agent

Ragi contains a lot of fiber, which keeps your stomach full and prevents you from having unhealthy desires. Weight loss is aided by this. It lowers your body's blood sugar levels and converts it to insulin. The best time to eat ragi is first thing in the morning. Tryptophan is an amino acid found in ragi that

aids in weight loss. Since tryptophan decreases appetite, you don't feel hungry as frequently.

Ragi as a load of calcium

There is no cereal that has calcium levels as high as those in ragi. Human bones need calcium to grow and to avoid osteoporosis, which causes brittle and frail bones. Consequently, drinking ragi porridge is advised rather than taking calcium supplements (ragi kanji). 344 milligrams of calcium, which is a significant amount and excellent for your bones, are present in 100 grams of ragi.

Prevent diabetes

Your risk of developing diabetes can be lowered by regularly eating ragi. This is due to ragi's high concentration of dietary fibre and polyphenols. Comparing ragi to other whole wheat grains reveals how much fibre it has. Regular ragi consumption helps to stabilise your blood sugar level and reduce it. Ragi works as an absorbent; thus it absorbs starch and decreases your body's ability to digest it. Because of this, most ragi consumers rarely experience hunger.

Anti-ageing agent

Ragi is a natural anti-aging ingredient and skincare product. Ragi contains crucial amino acids like methionine and lysine that shield your skin against the hazards of rashes, wrinkles, and dullness. Ragi contains antioxidants that assist your body battle stress and delay the onset of ageing. It revitalizes skin cells, giving you a youthful, healthy appearance. Additionally, ragi has Vitamin E, which is excellent for your skin. Vitamin E helps the body heal naturally from wounds. This aid lubricates the skin and creates a shield, allowing your skin to develop.

Conclusion

Dietary fiber and polyphenols found in finger millet have been shown to have a number of health advantages for regular users, including anti-diabetic, defense against chronic diseases linked to diet, hypercholesterolemia, and antioxidant, and antibacterial activities.

Additionally, finger millet is a crucial component of dietary and nutritionally balanced diets due to its high carbohydrate, energy, and nutritional content. By preserving blood glucose homeostasis, the regular consumption of finger millet as a nutrient and its products aids in the management of several bodily illnesses. Furthermore, due to the protective properties of the seed coat matter, which have positive effects on health, whole meal-based finger millet products may be appealing.

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