



A comprehensive review on millet as the future crop, processing innovations, and Value-Added product development

Divya KM¹, Elakiya R¹, Sneha Chandran¹, Haripriya A²

¹ Department of Food Technology and Management, M.O.P. Vaishnav College for Women, Chennai, Tamil Nadu, India

² Assistant Professor, Department of Food Science, M.O.P. Vaishnav College for Women, Chennai, Tamil Nadu, India

Abstract

Millet plays a crucial role in people's diets due to its rich nutritional profile. Emerging as future crops, millets exhibit resilience and can withstand adverse growing conditions. They serve as valuable sources of carbohydrates, proteins, fats, vitamins, minerals, and antioxidants. Millets are broadly categorized into two types: Major millets (such as Sorghum and Pearl) and Minor millets (including Kodo and Foxtail). Various processing methods are applied to eliminate inedible portions, enhance nutrient bioavailability, improve digestibility, and reduce antinutritional content, thereby elevating the nutritional quality of millets. This versatile grain is utilized to produce a range of traditional and value-added products. Traditional millet-based items encompass roti, upma, idli, dosa, paniyaram, while novel products include extruded items like noodles, pasta, and breakfast cereals. This review provides insights into the types of millets, their nutritional composition, millet processing techniques, and the array of value-added products derived from them.

Keywords: Millets, millet processing, nutrient composition

Introduction

Millets are called as "nutri-cereals" as they are storehouses of nutrients. They provide nutrients for normal functioning of human body. Millets are small seeded cereals with distinct varieties, produced from annual grasses that are grown as grain crops, primarily on marginal land in dry areas of temperate subtropical and tropical regions [19]. Millets are the 6th cereal crop in terms of world's agricultural production. Millets are expected to be the 'future crops' as they are more resistant and can be grown under adverse growing conditions [2]. Millets are highly nutritious as they are a good source of carbohydrates, proteins, fats, vitamins, and minerals. They possess many health benefits against metabolic disorders. Millets are processed to remove the inedible portion, improve the nutritional and sensory properties and thereby extending the shelf life [25]. Different primary and secondary processing are done to improve the functionality of millets.

Nutrient composition

Millet stands out nutritionally when compared to wheat and rice, offering a rich array of essential nutrients. It serves as an excellent source of carbohydrates, proteins, including vital amino acids like methionine and cysteine, and essential fatty acids. Additionally, millets are abundant in dietary fiber, B vitamins (niacin, pyridoxine, folic acid), and essential minerals such as calcium, iron, phosphorus, potassium, magnesium, and zinc. Enriched with phytochemicals and other antioxidant properties, millets exhibit health-promoting benefits [25].

Millets have a low glycemic index and low glycemic load. They are gluten-free and non-acid forming, making them easily digestible. Recent studies highlight the therapeutic benefits of millets, showcasing their potential to protect against metabolic diseases. Millets can be incorporated into

diets as functional foods and nutraceuticals. Moreover, their minimal water requirements make them a sustainable choice for grain production, ensuring a reliable and eco-friendly grain supply [5, 30].

Types of millets

Millets are primarily classified into major and minor millets. Major millets include sorghum, pearl millet, finger millet and minor millets consist of proso millet, kodo millet, barnyard millet, foxtail millet, little millet [29].

Sorghum (Jowar) – *Sorghum bicolor*

Sorghum, a warm-season crop, demonstrates remarkable adaptability to climate change factors such as drought, salinity, and high temperatures. With approximately 349 kcal per serving, sorghum stands as a valuable source of energy. Its nutritional profile includes 6.7 g of fiber and 10.6 g of protein per 100 g of grain.

The dietary fiber in sorghum, attributed to the presence of resistant starch, contributes to the control of type 2 diabetes. Additionally, the lipids present in sorghum have the potential to lower cholesterol levels. Not containing gluten, sorghum is a safe dietary choice for individuals with celiac disease. Furthermore, the presence of polyphenols and tannins imbues sorghum with anti-mutagenic and anti-carcinogenic properties, enhancing its overall health benefits [8, 45].

Pearl millet (Bajra) – *Pennisetum glaucum*

This group of major millet does well in low pH, high salinity, and low soil fertility environments and has an excellent tolerance for difficult growing circumstances. Pearl millet boasts the highest protein content among various millets, with 22 g per 100 g. Its alkalinizing effect makes it advantageous for preventing and treating stomach ulcers. Additionally, the substantial magnesium content in pearl millet aids in controlling blood pressure levels and

alleviating severe respiratory problems. Because of the presence of insoluble fiber, there is a reduction in excessive bile production, thereby decreasing the chances of developing gallstones [38, 43].

Finger millet (Ragi) – *Eleusine corona*

Finger millet, a staple in numerous African and South Asian nations, emerges as a nutritional powerhouse. Having a significant calcium content of 344 mg/100 g and phosphorous at 283 mg/100 g, it plays a crucial role in fortifying bones and preventing osteoporosis. It has 44.7% of essential amino acids, including methionine. Being gluten-free, it accommodates individuals with gluten sensitivities.

In addition to its bone-strengthening properties, finger millet proves beneficial in addressing anemic conditions due to its substantial iron content (3.9 mg/100 g). Notably, its high dietary fiber content (11.5 g/100 g) contributes to lowering serum cholesterol levels and provides protection against colon-related cancer [37, 41].

Proso millet – *Panicum miliaceum*

This minor millet grows well in the dry and temperate climates such as northern India, Africa, and the Middle Eastern areas. Proso millet has a protein content of 11 g/100g and dietary fiber content of 8.8 g/100 g. Consuming this millet can prevent cardiovascular disease since it lowers the triglycerides and improves the high-density lipoproteins levels. It is a good source of tocopherols and antioxidant activity is exhibited. Niacin (4.5g/100g) found in proso millet prevents skin disorders like pellagra [17, 35].

Foxtail millet – *Setaria italica*

Foxtail millet adapts to a wide range of soils and temperature but is a poor tolerant to the water logging condition and is fairly tolerant to drought. Their magnesium concentration keeps the heart healthy and decreases blood sugar levels. It has a protein content of 12.3g/100g and phosphorus of about 290 mg/100g. This millet shows anti-hyperglycemic activity. Ferulic and p-coumaric acids are present in them. It also exhibits antioxidant activity. They also include tocopherols and carotenoids [28].

Kodo millet – *Paspalum scrobiculatum*

This is an indigenous cereal of India grown in the parts of Madhya Pradesh, Tamil Nadu, and Karnataka. The phytochemicals and fiber content (9.0 g/100 g) in kodo millet is high. Thus, they have antioxidant property and prevents the free radicals from causing any damage. It provides an energy of 346 kcal. The intake of kodo millet helps in preventing joint pain and knee pain in individuals. This millet is characterized by properties that contribute to the reduction of cholesterol and blood sugar levels. It shows a protein level of 8.3 g with glutelin as the major part [7, 12].

Barnyard millet – *Echinochloa crus-galli*

This millet is termed as a multi-purpose crop, cultivated for food and fodder. It has 4.2mg/100g of niacin and 280 mg/100 g of phosphorus. Also, the iron content of this millet is 15.6-18.6 mg/100 g making them beneficial for anemic patients. Consuming barnyard millet reduces triglyceride, blood glucose, and serum cholesterol levels. The dehulled

varieties has a glycemic index of 41.7 and therefore is beneficial for individuals with type 2 diabetes and it helps in improving the HDL levels [32].

Little millet – *Panicum sumatrense*

The seeds of proso millet are greater than those of little millet. It could withstand both waterlogging and drought conditions. It contains 67g/100g of carbohydrate, 4.7g/100g fat. It contains essential fatty acid, vitamins, and certain minerals (phosphorus, iron, calcium). They aid in the prevention of obesity due to their high fiber content [6].

Processing of millets

Processing is the technique of turning inedible cereal into edible grain and thus improving its quality. Processing cereals and millets plays an important part in their use as food. Millets can be processed into rice, flour, sprouting, roasted, popped, salted ready-to-eat cereals, porridges, and fermented goods. Because millet seeds have a hard seed coat, the first step in processing them is to remove the husk [21]. Millets need to be processed for three main reasons: i) to make them fit for consumption, ii) to extend the shelf life and iii) to increase the availability of the nutrients. Millets are well known to be a good source of calories, energy, and dietary fibers, and new research has revealed that millets are also a good source of phytochemicals³³. Germ, starchy endosperm and the protective pericarp are the three main components of millet which are partially separated or modified during processing [5].

Two types of processing are: primary and secondary processing. Primary processing involves operations like cleaning, destoning, washing, soaking, germination, decortication or dehulling. Primary process involves the separation of the inedible portion called the offal. Offal comprises of the protective pericarp and sometimes the germ. The process of removal of offal is termed as decortication or dehulling. The process of converting primary processed grist into various products such as “ready-to-eat” (RTE) or “ready-to-cook” (RTC) by performing operations such as extrusion, flaking, popping, and baking is called secondary processing [13].

Decortication/dehulling

Millets were previously decorticated at the family level by hand pounding. These are now milled in rice milling machinery with minor modifications to the procedure¹⁵. The procedure of removing the pericarp from the millet grain is known as decortication or dehulling. Sometimes these decorticators are attached with an aspirator, grader or destoner. Decorticated millets give a soft texture in five minutes when cooked as rice, which is difficult without dehulling. The extent of decortication is done in such a way that only about 12-30% of the outer surface of the grain is removed. Excessive decortication results in the loss of minerals like fats, ash, and fiber [39]. Decortication process reduces the total protein and lysine by 9% and 21% respectively but it improves the protein utilization. Consumer acceptability and biological availability of nutrients like iron & zinc and are improved due to the decortication process. Additionally, the millet grain's antinutrient content, such as phytates and polyphenols, is decreased [9].

Parboiling

Parboiling is one of the processing technologies used in paddy milling to increase milling efficiency and minimize breakage. It is a hydrothermal treatment that includes three fundamental processes: soaking to absorb water, steaming to gelatinize the starch in the endosperm, and drying before milling. As a result, the starch framework strengthens the endosperm, rendering it translucent. The hardening procedure toughens the cereals and increases their resilience to breakage during milling, increasing milling output and decreasing nutrient losses during milling and heating. Parboiling millet would result in a rise in milling millet output^[36].

Milling

The initial process in millet processing is to turn the grain into flour, which is accomplished by pulverizing or milling^[3]. Milling is done primarily to maximize the separation of endosperm, bran, and germ and to reduce the particulate size of endosperm to enable the production of fine flour. Millet can be ground using a hammer mill or a rolling grinder. Hammer mills create a flour with bigger grain size which restricts its usage for production of thin and stiff porridge of rough texture and in producing baked and steamed food products of smooth texture. However, these food items can be readily created using fine flour obtained from roller mills. The grinding action of roller mills also causes physical harm to starch granules, raising their enzymatic susceptibility^[31].

Malting

Malting is the process of preparing a brewing raw material through the controlled germination. Millet is malted before being used in brewing, distilling, or food manufacturing^[24]. The entire millet grains are steeped in four times their volume of water for 20 hours in the standardized malting procedure. After draining the water, the grains are maintained at 25-30 °C for 72 hours to facilitate germination. The sprouted seeds are then washed and sun-dried. Subsequently, the millets are gently toasted on a skillet at 80-110 °C for 15 minutes before being abraded by hand. Following this, the toasted millets are ground to a fine powder and sieved. The resulting product is stored in an airtight receptacle. Studies show that the protein content of finger millet malt rises from 14% to 17.5% as the germination time increases from 8 to 24 hrs. Protein content is greatest in malt made after 24 hours of germination^[40].

Fermentation

Fermentation, a traditional process that has been practiced for thousands of years, which is known to boost the nutritional quality, improves flavor and appeal of the food. Fermentation can be defined as a process of intentional conversion or modification of a substance to obtain a new product through microbial action^[1]. Fermentation is one of the processes that reduces antinutrient levels in food cereals while increasing *in vitro* protein digestibility (IVPD) and the nutritive value of millets. This increase in protein digestibility was ascribed to microbial enzymes degrading tannins, polyphenols, and phytic acid^[22]. This process imparts unique flavors and textures to millet-based products, contributing to their overall palatability.

Extrusion

Extrusion cooking is a thermo-mechanical process involving unit operations such as mixing, kneading, shearing, shaping, cooking, forming, and drying^[27]. Extrusion causes starch gelatinization, protein denaturation, fat degradation, and other effects. These alterations also result in the inactivation of enzymes and microorganisms in millet. When the material is discharged from the outlet, the pressure drops dramatically and the water in the material evaporates quickly, resulting in an instantaneous decline in the temperature of the material, which expands to become a loose porous structure^[42]. Extruded millet products have improved digestibility, enhanced flavor profiles, and increased nutritional value, making them a popular choice for health-conscious consumers.

Composite flour

Despite being nutritionally better to cereals, millets are not widely consumed. One method of expanding their use could be to blend them with wheat flour after appropriate processing. The inclusion of millet flour would alter the physicochemical, nutritional, and functional properties. Many researchers have tried to create composite millet flours by partially replacing conventional cereal flours in the production of traditional foods, ready-to-use or RTE food products, or pasta. One of the simple semi-finished products appropriate for making chapatti is multigrain flour, which is made by combining wheat and finger millet in a 7:3 ratio³⁴. In a research study¹⁶ composite flour surpassed wheat flour in protein (13.74 g/100 g vs. 8.55 g/100 g), fat (5.30 g/100 g vs. 1.93 g/100 g), and energy content (388 Kcal vs. 367 Kcal). Notably, composite flour exhibited higher crude fiber (3.57 g/100 g vs. 2.87 g/100 g) and superior mineral levels compared to wheat flour.

Popping

Cereal popping has been practiced for hundreds of years. It is a form of starch cooking in which grains are exposed to high temperatures for a brief period. Popping millet grains enhances their taste and flavor invariably. It is one of the most simple and cost-effective ways of preparing ready-to-eat products. Popping produces a crisp, aerated product with desirable sensory characteristics. Because the lipase enzyme is denatured during popping, popped goods have a longer shelf life than other types of millet products. The popping not only extends the shelf life but also enhances the nutritional quality in terms of nutrient bioavailability²³. When grains are exposed to high temperatures for a brief period, they undergo instantaneous gelatinization and expansion. The grain is also cooked by the abrupt expansion of the endosperm, which breaks the surface epidermis, while popping the superheated vapor created inside the grain by instantaneous heating. Season, varietal difference, grain features, moisture content, constituents of grain, physical appearance, type of endosperm, temperature, time, and popping technique are all factors that influence popping. Various techniques of popping or puffing have been used for many years. The traditional techniques, such as puffing with sand or salt, popping in heated oil, gun puffing, hot air popping, and microwave heating are all options. Sand popping is an ancient method in which sand is placed in a pan and heated to a higher temperature. Sand is heated to approximately 250 °C, and grains are combined with hot sand using a spatula⁴. Gun Puffing- After preheating the

milled grains, they are inserted into the gun or high-pressure chamber, and then superheated steam is introduced into the closed rotating chamber. Other process techniques used for millet popping includes microwave popping, HTST fluidized bed popping [26].

Millet- based Products

Millets are used to prepare both traditional and contemporary food products in place of rice and wheat. The traditional food items made from different types of millet include idli, dosa, idiyappam, rotti, upma, porridge, halwa, paniyaram, vadai, pakoda, murukku, thattuvadai, adhirasam etc., and the modern food products include extruded products, breakfast cereals - flakes, bakery products – muffins, buns, cakes, noodle, pasta, ready to eat – instant foods, beverages, papads etc. These foods are diabetic-friendly due to their high levels of protein, dietary fiber, minerals (calcium, phosphorus), and gluten-free millet-only goods [18].

“Eatrite” is a brand that is owned and promoted by ICAR – Indian Institute of Millet Research (ICAR-IIMR). Several millet-based items are available under this name, including jowar atta, multigrain atta, ragi atta, jowar idli rava, instant jowar pongal mix, jowar pasta, jowar vermicelli, ragi vermicelli, jowar puffs, bajra puffs, barnyard sweet puffs, millet laddu, instant millet idli mix, jowar murukku. Several biofortified and value-added sorghum products, such as sorghum bran fryums, sorghum-based energy bars, and jowar vermicelli, pasta, and biscuits (which are high in iron and zinc respectively) are still waiting to be commercialized [11].

The Central Food Technology Research Institute (CFTRI) created a new process to create shelf-stable jowar flour with a storage period of 6 to 8 months, shelf-stable bajra flour with a storage period of 3 to 4 months, expanded ragi that can be used in health bars, ragi snacks, expanded bajra, cookies (ragi and bajra), and muffins (ragi and bajra). They even launched a separate application named Milletpro for android phones that was funded by DSIR, Ministry of science and technology. This application provides information on the technology employed in the millet processing sector and the goods generated by it.

Millets: Future India

The UN (United Nations) general assembly has announced 2023 as the International Year of Millets. Hence, the Indian government has decided to celebrate 2023 as IYoM. It was established to create awareness among people and increase the production and consumption of millets [14].

Educating people about the nutritional quality and health benefits of millets is crucial to increase the consumption and utilization of millet-based products, thereby protecting individuals from malnutrition and other metabolic-related diseases. To revive our traditional diet, a holistic approach is needed, encompassing studies from various perspectives such as sustainable agriculture, environmental impact, health benefits, marketing strategies, and consumer acceptance [29].

Government institutions such as IIMR (Indian Institute of Millets Research) and ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) are collaborating to boost millet productivity. Their joint efforts involve the development of various technologies to assist farmers and initiatives to encourage millet consumption

among the public. Notable schemes include the All India Coordinated Research Project on Small Millets (AICRP), the Initiative for Nutritional Security through Intensive Millet Promotion (INSIMP), and the National Food Security Mission (NFSM) [44]. The incorporation of millets into midday meal programs is crucial for addressing hidden hunger and the government should proactively introduce millets into the Public Distribution System. Incentives and support for new start-ups in the production of millet-based value-added products should be provided to encourage the growth of this nutritious food source [20].

Conclusion

Millet, rich in nutrients compared to other cereals such as rice and wheat, offers diverse health benefits. Various types of millets contribute to managing diabetes, promoting gut health, controlling blood pressure levels, and lowering cholesterol. The application of different processing techniques enhances nutrient bioavailability, improves digestibility, and reduces anti-nutrient content. These processing methods enable the creation of a variety of value-added millet products.

However, further advancements and additional studies are required to optimize millet processing and minimize nutritional losses. Creating awareness about the health benefits of millets is crucial to increasing consumption. Including millets in our daily diets can help combat metabolic diseases and promote overall health, encouraging people to adopt a healthier lifestyle.

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