Review

Processing of minor millets: a review

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ABSTRACT

Minor millets such as kodo millet (*Paspalum scrobiculatum* L) and little millet (*Panicum sumatrense*) are small-seeded grasses that grow well in dry zones as rainfed crops under marginal conditions of soil fertility and moisture. These crops are cultivated with lesser inputs and are unique due to their short growing season. Millet grains are nutritious with good quality protein and are rich in minerals, dietary fiber, phyto-chemicals and vitamins. Millets occupy an important place in the diet of people in many regions of the world. Although these are nutritionally superior to cereals their utilization as food is still mostly confined to the traditional consumers and population of lower economic strata. The statistical documentation on various aspects of processing and utilization of minor millets is generally poor and mostly fragmented compared to major cereal grains such as rice and wheat. The climate change, water scarcity, population growth, inadequate access to enough food and absence of local agro-food systems present, there is a challenge to scientists and nutritionists to investigate the possibilities of producing, processing and utilizing the potential of minor millets as nutri-cereals. The husk on the minor millets is tightly attached with the endosperm thereby making its removal difficult during de-husking operation. Very small size of grains is another challenge in the husk removal process. One of the barriers to increase millet processing and its value-added products in our country is unavailability of efficient de-huskers. However the special features of the millets, their beneficial uses and health consciousness of the consumer have made food scientists and engineers to develop various food products and mechanize the processes. The present paper reviews the essential engineering properties such as physical and frictional properties, nutritional content, traditional and modern de-husking practices and value-added food products developed from millets.

Keywords: Minor millets; processing; value addition

INTRODUCTION

Millet is a cereal crop belonging to the grass family Poaceae (Graminae). Minor millets include barnyard millet (*Echinochloa esculenta*), finger millet (*Eleusine coracana*), foxtail millet (*Sestaria italica*), kodo millet (*Paspalum scrobiculatum* L), little millet (*Panicum sumatrense*) and poroso millet (*P miliaceum*). Millets are classified as coarse grains and cultivated mostly in India, China, Japan and Africa (Malleshi and Desikachar 985). In the year 2013 global millet production was 29870058 MT and India produced 10910000 MT of millets (https://en.wikipedia.org/wiki/Millet). Minor millets are grown in almost every state of India under rainfed conditions. In India important minor millet growing states are Madhya Pradesh, Andhra Pradesh, Chhattisgarh, Tamil Nadu, Gujarat, Maharashtra and Karnataka. In Madhya Pradesh these are mainly grown in Mandla, Chindwara, Shahdol, Sidhi, Betul, Rewa, Jabalpur and Satna districts. Millets are water saving, drought tolerant (need no irrigation), pest resistant crops that can be adopted through a wide range of ecological conditions.

Kodo and little millet (Kutki) (Plate 1) are mainly grown in Asian and African countries under various kinds of soils and adverse agro-ecological situations. These are extremely important crops largely cultivated by tribal for their sustenance. In India, Madhya Pradesh

Plate 1. Kodo millet and little millet (Insat: grains)

Table 1. State-wise area, production and yield of small millets (average of 2007-08 to 2011-12)

State	Area ('000 ha)	Production ('000 tons)	Yield (kg/ha)
Andhra Pradesh	30.8 (3.36)	19.4 (4.22)	630
Arunachal Pradesh	21.9 (2.39)	19.6 (4.26)	897
Assam	6.2 (0.68)	3.3 (0.72)	531
Bihar	5.5 (0.60)	4.2 (0.91)	758
Chhattisgarh	178.5 (19.47)	38.8 (8.44)	218
Gujarat	48.8 (5.32)	49.8 (10.83)	1020
Himachal Pradesh	6.3 (0.69)	4.0 (0.87)	636
Jammu and Kashmir	8.9 (0.97)	4.5 (0.98)	510
Jharkhand	25.0 (2.73)	12.0 (2.61)	480
Karnataka	32.0 (3.49)	15.3 (3.33)	477
Madhya Pradesh	297.1 (32.40)	85.6 (18.62)	288
Maharashtra	71.4 (7.79)	34.5 (7.50)	483
Nagaland	16.3 (1.78)	12.0 (2.61)	737
Odisha	18.1 (1.97)	8.9 (1.94)	489
Rajasthan	16.2 (1.77)	5.7 (1.24)	354
Tamil Nadu	36.1 (3.94)	38.5 (8.37)	1067
Uttar Pradesh	13.2 (1.44)	9.1 (1.98)	695
Uttarakhand	73.4 (8.00)	85.6 (18.62)	1166
Others	11.4 (1.24)	9.0 (1.96)	791
All India	917.0	459.8	501

Source: Anon (2014)

occupies highest area under small millets (32.4%)followed by Chhattisgarh (19.5%), Uttarakhand (8%), Maharashtra (7.8%), Gujarat (5.3%), Tamil Nadu (3.9%), Karnataka, Andhra Pradesh, Jharkhand, Arunachal Pradesh, Odisha, Nagaland, Rajasthan and Uttar Pradesh. Uttrakhand has highest productivity of 1166 kg/ha followed by Tamil Nadu (1067 kg/ha) and Gujarat (1020 kg/ha) (Anon 2014) as depicted in Table 1.

Engineering properties of minor millets

Sahay and Singh (1994) mentioned that the physical properties are essential for the design of equipment for handling, processing and storage of the grains. They affect the conveying characteristics of solid material by air or water and cooling and heating loads of food material.

Mandhyan et al (1987) studied physical properties of kodo, kutki and sawan and reported that the average geometric mean diameter of kodo (1.82 mm) was higher than that of sawan (1.59 mm) and kutki (1.07 mm). The sphericity of kutki (0.93) is observed to be highest among the three minor millets and kodo has the least sphericity value. The length-breadth ratio is highest in sawan (1.07) indicating that sawan grain is the most slender of all. Thousand-grain mass is the highest in kodo (4.89 g) followed by sawan (4.03 g) and kutki (2.00 g) but specific gravity is highest in kutki (1.35). The bulk density of kutki (0.72 g/ml) is highest followed by kodo (0.57 g/ml). The angle of repose of kodo (28° 50') has been observed to be the highest followed by sawan (24° 25') and kutki (20° 21'). The physical properties of millets have been evaluated by Baryeh (2002) as a function of grain moisture content varying from 5 to 22.5 per cent (db). In this moisture range grain length, width, thickness and geometric diameter increased from 3.522 to 4.163 mm, 2.75 to 3.211 mm, 2.180 to 2.788 mm and 2.759 to 3.340 mm respectively; the grain surface area, volume and sphericity increased from 23.91 to 35.05 mm^2, 8.2 to 14 .65 mm^3 and 0.783 to 0.803 respectively; the 1000-seed mass, true density, angle of repose and terminal velocity increased from 14 to 44 g, 1550 to 1712 kg/m^3, 34.5^o to 48.1^o and 2.75 to 4.63 m/sec respectively.

The bulk density, coefficient of static friction and coefficient of internal friction were determined by Subramanian and Viswanathan (2007) for the grains and flours of barnyard, finger, foxtail, kodo, little and poroso millets at the moisture contents of 8.7, 11.1, 16.3, 22 and 28.2 per cent (db) for the grains and 11.1, 17.6, 25, 33.3 and 42.8 per cent (db) for the flours respectively. The bulk density of the millet grains in this moisture range decreased linearly from 888.7-750.1, 794.9-740.3, 746.7-626.3, 810.1- 681.3, 748.1-570.3 and 820.9-762.1 kg/m^3 for the barnyard, finger, foxtail, kodo, little and poroso millets respectively. The coefficient of static friction increased in the range of 0.26-0.62 for the grains and 0.62-1.13 for the flours with increase in moisture content. For both grains and flours mild steel surface offered the maximum friction followed by galvanized steel, aluminium and stainless steel. The coefficient of internal friction ranged between 0.59-1.25 and 0.73-1.16 for the grains and flours respectively in the moisture content range of 11.11-42.86 per cent (db). Both the values of coefficient of static friction and coefficient of internal friction exhibited a linear relationship with moisture content with higher coefficient of fit.

Shirsat and Patel (2008) studied the effect of moisture content on physical and engineering properties of a local variety of kodo and found that with the increase in moisture content of kodo grains from 13.47 to 50.60 per cent (db) theere was increase in the 1000-grain mass from 5.55 to 7.32 g, sphericity from 0.75 to 0.81, length-breadth ratio from 1.30 to 1.18 and the equivalent diameter between 2.15 to 2.31 mm. It was further observed that the bulk density, true density and specific gravity varied from 0.76 to 0.64 g/ml, 1.22 to 1.24 g/ml and 1.057 to 1.075 respectively. The angle of repose and porosity increased linearly from 25° 34' to 33° 47' and 37.7 to 48.39 respectively.

Balasubramanian and Viswanathan (2010) studied the physical properties including 1000-kernel weight, bulk density, true density, porosity, angle of repose, coefficient of static friction, coefficient of internal friction and grain hardness for foxtail, little, kodo, common, barnyard and finger millets in the moisture content range of 11.1 to 25 per cent (db). Thousand-kernel weight increased from 2.3 to 6.1 g and angle of repose from 25°.0' to 38°.20'. Bulk density decreased from 868.1 to 477.1 kg/m^3 and true density from 1988.7 to 884.4 kg/m^3 for all minor millets when observed in the moisture range of 11.1 to 25 per cent (db). Porosity decreased from 63.7 to 32.5 per cent. Coefficient of static friction of minor millets against mild steel surface increased from 0.253 to 0.728 and coefficient of internal friction was in the range of 1.217 and 1.964 in the moisture range studied. Grain hardness decreased from 30.7 to 12.4 for all minor millets when moisture content was increased from 11.1 to 25 per cent (db).

Kumar et al (2016) did studies on engineering properties of variety Indira Kodo-I in moisture range from 8.19 to 12.71 per cent (db). It was found that the length, width and thickness ranged from 2.61 to 2.74 mm, 1.96 to 2.23 mm and 1.33 to 1.45 mm respectively. The length-breadth ratio ranged from 1.33 to 1.23, the size from 1.90 to 2.07 mm and the sphericity from 0.73 to 0.76. Surface area and volume ranged from 9.06 to 11.53 m^2 and 2.59 to 3.46 m^3 respectively. It was further observed that the bulk density of kodo decreased from 0.67 to 0.62 g/ml, true density increased from 1.20 to 1.24 g/ml, porosity ranged from 43.99 to 50.27 per cent and the angle of repose increased from 25°28' to 26°05'.

Nutritional value

Millets are good source of energy. They provide protein, fatty acids, minerals, vitamins, dietary fibre and polyphenols. Typical millet protein contains high quantity of essential amino acids especially the sulphur containing amino acids (methionine and cysteine). They are also a good source of antioxidants such as phenolic acids and glycated flavonoids. Processing millet by milling removes the bran and germ layers that are rich in fibre and phytochemicals causing significant nutritional loss (Amadou et al 2013).

According to Deshpande et al (2015) kodo millet is rich in dietary fiber and minerals like iron, antioxidant etc. The phosphorus content in kodo millet is lower than any other millet and its antioxidant potential is much higher than any other millet and major cereals. Processing like parboiling and debranning affects the mineral content and fibre however it reduces anti-nutritional factors like phytate. Several traditional Indian food items have been prepared solely from kodo or blended with other cereal and legume flours to enhance the nutritional value, palatability and functionality.

Chandel et al (2014) reported that kodo millet contains 66.6 g of carbohydrates and 353 kcal per 100 g of grain comparable to other millets. It also contains 1.4 per cent fat and 2.6 per cent minerals. The iron content in kodo millet ranges from 25.86 to 39.60 ppm. Among the millets it has the least amount of phosphorus content.

Kodo millet flour has a gelatinization temperature range of 13°C (76.6-90°C) which is less resistant to gelatinization (Subramanian et al 2006) and can be incorporated for baking of bread and cakes, extrusion of cereal-based products, gravy, soup, heat set gel, porridge, instant powders and modified flour and starches for specialty foods.

Millets are rich sources of insoluble (IDF) and soluble (SDF) dietary fibre and has comparable or even higher total dietary fibre (TDF) than other cereals. Decorticating significantly decreases millet TDF. Studies on barnyard, kodo, foxtail and little millets have reported the IDF as 18-30 per cent and SDF as 0.6-2 per cent in whole form and decortication decreased the amount of IDF to 1.5-3 per cent and SDF to 0.3-0.9 per cent (Geervani and Eggum 1989).

Apart from being a rich source of nutrients kodo millets also contain high amounts of polyphenols, antioxidants, tanins, phosphorus and phytic acids. These anti-nutrients form complexes with micronutrients such as iron, calcium and zinc and reduce their solubility and bioavailability. Tannin also adversely affects utilization of proteins and carbohydrates by forming complexes thus resulting in reduced growth, feeding efficiency, metabolizable energy and bioavailability of amino acids (Balasubramanian 2013a).

Little millet has reasonably good levels of protein but very poor amino acid values. In general minor millets are considered to be more nutritious than rice both in terms of macro and some micronutrients. For example samai is minor millet consumed occasionally by villagers and it was once one of their staple foods and crops. One hundred grams of the edible portion of the millet contains 7.7 grams of protein, 4.7 grams of fat, 7.6 grams of fibre and 67 grams of carbohydrate. It also has 17 mg of calcium, 220 mg of phosphorus and 9.3 mg of iron (Kumaran et al 1998).

Balasubramanian (2013a) in a study emphasized on the importance of dehulling the millet grains prior to consumption as the phytate content of common millet varieties ranged from 170 to 470 mg per 100 g whole grain and dehulling resulted in a 27 to 53 per cent reduction in phytate content. On dehulling, phytin phosphorus decreased by 25 per cent in kodo millet.

A study by Chandrasekara and Shahidi (2012) revealed that the phenolic content after digestion and colonic fermentation by gut microflora of cooked kodo millet had the lowest insoluble residue which mainly consisted of insoluble fibre (81mg/g of cooked grain) as compared to finger millet (179 mg/g of cooked grain), pearl millet (132 mg/g of cooked grain), foxtail (157 mg/g of cooked grain) and proso millet (210 mg/g of cooked grain).

Amadou et al (2013) in their report emphasized the importance of millets in providing sulphur containing essential amino acids like methionine and cysteine and the loss of germ, antioxidant containing bran and other minerals on debranning.

Millets with dark brown pigmented testa and pericarp (kodo, finger) possess a higher phenolic content than those with white or yellow testa and pericarp (pearl, proso, foxtail, little millets). Highest phenolic content is reported for kodo (368 mg/g) followed by finger (brown variety), little, foxtail and barnyard millets (Hegde and Chandra 2005).

Pretreatment

The main purpose of fermentation and germination is to reduce anti-nutrients in millet and improve nutrient bio-availability. Fermentation can synthesize certain amino acids and increase availability of vitamins (Chavan et al 1989). It also sets optimum pH conditions for enzymatic degradation of phytate which is present in millets as complexes with polyvalent cations such as iron, zinc, calcium, magnesium and proteins. The reduction in phytate may increase the amount of soluble iron, zinc and calcium manifold (Mahajan and Chauhan 1988, Khetarpaul and Chauhan 1989, Kouakou et al 2008). Improvement of starch and protein digestibility and sensory properties of food products from fermented and germinated flour has also been reported (Khetarpaul and Chauhan 1989, Inyang and Zakari 2008).

Hydrothermal treatment or parboiling process basically involves steeping the grains for bringing them to equilibrium moisture content, steaming or boiling to gelatinize the starch and finally dehydrate the grains to bring the moisture to a safe storage level (Clegg 1991). This entire process brings about various changes in the physico-chemical properties which leads to an increase in yield of decorticated millet and nutritional value of the grains (Young et al 1990). Parboiling method used for pearl and proso millets increased the yield of decorticated millets by 28-35 per cent. Parboiling significantly altered the nutrient composition and in vitro digestibility of millet products. Porridge and steam-cooked couscous prepared from parboiled millets showed lower in vitro starch and protein digestibility when compared to native millet products. Significant increases in the resistant starch and phenolic acids were also observed in the millet products from parboiled grains. The study demonstrated that parboiling may be an effective way of improving decortication yield without deteriorating nutritional quality of millets.

Pawar and Machewad (2006) soaked foxtail millet grains in distilled water (1:5, w/v) for 12 h at room temperature and de-hulled; de-hulled and soaked; de-hulled, soaked and cooked in distilled water (1:3, w/v) and the effects of removal of polyphenols and phytate on the in vitro protein digestibility (IVPD) and availability of iron and zinc were measured. The results showed that polyphenols and phytate were decreased significantly up to 50.92 and 49.89 per cent respectively. The IVPD however increased up to 38.71 per cent. The iron and zinc contents decreased up to 18.79 and 18.61 per cent respectively but the ionizable iron and zinc were increased up to 55.45 and 80.18 per cent respectively. This indicated the suitability of simple processing techniques for improvement of availability of nutrients from foxtail millet.

Vijaykumar et al (2013) subjected the kodo millet to heat treatments such as boiling for 25 minutes at 95-100°C, steaming at 80-90°C and pressure-cooking at 9.8 x 104 Pa for 20 minutes. Boiling reduced the starch yield and exhibited greater porosity and water absorption capacity. Pressure-cooked samples had greater oil absorption capacity and swelling power, reduced the peak and final viscosity which indicated large starch damage due to greater alpha-amylase activity. The resistant starch content was higher in pressure-cooked flour resulting in low starch digestibility index. They concluded that since the pressure-cooked flour is less viscous, high dense and rich in resistant starch, it is more suitable food in the diet for degenerative disorders.

Shirsat et al (2009) studied the hydration characteristics of kodo millet and reported that rate of water absorption increased with increase in soaking temperature. The rate of water absorption was more appreciated at temperature 50^{o}C and above whereas at lower temperatures (below 50^{o}C) the absorption rate was comparatively slow. The rate of moisture absorption decreased with the increase in soaking time up to 70^{o}C and below but at 80^{o}C it tended to increase after 120 min of soaking which was due to bursting and partial cooking of kodo grains.

Pradhan et al (2010) reported that parboiling helps in de-husking of kodo millet and to eliminate the stickiness in cooked finger millet. The basic problem of kodo millet is the milling for the grains, milling drudgery associated with upper husk sticking endosperm tightly that reduces the efficiency of grain recovery from each spikelet. Indigenous mill Jatta is made out of well mixture of soil and straw that helps it to check deflocculating while working which is used by turning the upper plate. Time of milling for the whole process required nearly half day to mill 20-30 kg of kodo millet seed with grain recovery of 40 ± 5 per cent.

Traditional milling practices

The particle size of the endosperm fraction can be reduced by crushing or grinding to produce coarse grits or fine flour. This unpleasantly hard work is almost always done by women. Traditional grinding stones used to grind whole or decorticated grain to flour usually consist of a small stone which is held in the hand and a larger flat stone which is placed on the ground (Subramanian and Jambunathan 1980, Vogel and Graham 1979).

Grain which should be fairly dry is crushed and pulverized by the backward and forward movement of the hand-held stone on the lower stone. The work is very laborious and it is hard work for anyone to grind more than 2 kg of flour in an hour. In a traditional process used in many countries of Africa and Asia decorticated grain is crushed to a coarse flour either with a pestle and mortar or between stones. Grain is also ground to coarse or fine flour in mechanized disk mills now located in many villages. Dry, moistened or wet grain is normally pounded with a wooden pestle in a wooden or stone mortar. Moistening the grain by adding about 10 per cent water facilitates not only the removal of the fibrous bran but also separation of the germ and the endosperm if desired. Although this practice produces a slightly moist flour many people temper the grain in this way before they pound it. Pounding moist or dry grain by hand is very laborious, time consuming and inefficient. A woman working hard with a pestle and mortar can at best only decorticate 1.5 kg per hour (Perten 1983). Pounding gives a non-uniform product that has poor keeping qualities.

Minor millet de-huskers

Ravindra et al (2008) studied postharvest processing methods for little millet using rubber roll sheller cum abrasive grain polisher and provender mill. De-husking efficiency was obtained higher for millets heated with boiling water for 20 minutes and then sun-drying. Head rice yield ranged from 67.0 to 73.0 and 48.7 to 67.9 per cent in case of millets milled with rubber roll sheller cum grain polisher and provender mill. The mean milling efficiency varied from 44.8 to 57.8 per cent for both methods.

For pearling of millet Vivek thresher cum pearler was designed and developed by PHET, VAPKAS, Almora, Uttarakhand centre with capacity of 60 kg/h. It was found suitable for hilly region as the machine is light-weighted and can be operated with engine as well as electric motor (1 hp) (Dixit et al 2011).

Central Institute of Agricultural Engineering (CIAE), Bhopal, Madhya Pradesh has developed a machine for millet de-husking. This machine has a de-husking capacity of 100 kg/hour for millets with 10-12 per cent moisture content. It operates with one horse power single phase electric motor. The separation of the husk is simultaneous with a suction arrangement and cyclone separator attached to the machine. It is suitable for de-hulling foxtail, little, kodo, proso and barnyard millets. It is provided with provisions to adjust gap between the de-husking surfaces to suit the different sizes of minor grains. The de-hulling efficiency of the machine is about 95 per cent (Balasubramanian 2013b).

A multigrain centrifugal de-huller with 100 kg/h capacity was developed by Tamil Nadu Agricultural University. It can be operated continuously and is powered by 3 hp three phase motor. The machine operates on the principle of centrifugal and impact force. The machine de-hulling efficiency is 95 per cent (www.dhan.org).

Value-added products from minor millets

Small millets are traditionally used for preparation of Roti, Khichdi, Pulao, Dokla etc. Several literatures reported the use of kodo flour to the extent of 30-100 per cent for development of traditional as well as novel food products like Idli, Dosa, chapatti, Pongal, Puttu, Idiyappam, Kozhukattai, Boli, soup, Adai, Payasam, cutlet, biscuits, bread, cookies and Laddoo to name a few (Kalpana and Koushikha 2013, Senthamarai et al 2013, Padma and Rajendren 2013, Chakraborty and Kotwaliwale 2016).

Papad is prepared by mixing kodo millet flour and blackgram flour in equal quantities with addition of cumin seeds, salt and sodium bicarbonate for improving taste and getting good texture. The stiff dough is made to roll out in circular shape and dried. The flour is mixed with chilli powder, salt and cumin seeds and thick batter is formed by adding water. This batter is then dropped on greased plates for sun-drying.

Thatuvadai is prepared using kodo millet flour and small quantity of roasted Bengal gram dal. Thick dough is prepared to which salt, chilli powder, curry leaves and butter are added. Small portion of the dough is rolled out on polythene sheet and deep-fried in hot oil. Muruku is a popular snack food which is known as Chakli in other regions. Kodo millet flour is added with chilli powder, sesame seeds, cumin seeds, asafoetida, butter and salt to taste. Mixture of all is turned into thick dough using required quantity of water, textruded through hand extruder and deep-fried in hot oil till it turns golden brown.

Hot Kolukattai is prepared from kodo millet flour by mixing it with water to make paste. Paste is seasoned using chopped onion, chopped green chillies, coriander leaves, asafoetida, mustard seeds and black gram dal and boiled with continuous stirring to make dough of thick consistency. Dough is turned into oval shape and steamed using Idli cooker.

Pakoda and Vadai which are very common in all parts could be prepared using kodo millet flour with other ingredients such as chopped onion, green chillies, spices and deep-fried in hot oil. Addition of Bengal gram dal to the kodo millet rice gives the shape to the product. For preparing Halwa the coarse kodo flour and wheat flour (2:1) are roasted with ghee and added to boiling milk while stirring to avoid lumps. On solidification sugar and ghee are added to obtain required consistency which is then seasoned with dry fruits (Malathi et al 2012).

Sudhadevi et al (2014) prepared pasta by using kodo flour and refine wheat flour of different proportions. Ranganna et al (2014) also prepared cold extruded vermicelli and pasta using kodo flour, refined wheat flour and soy flour having a ratio of 50:40:10. Using a twin screw extruder Geetha et al (2014) prepared extruded product of kodo (70%) and chick pea flour (30%). Addition of hydrocolloids with gluten kodo flour can be used for the preparation of leavened breads (Chakraborty and Kotwaliwale 2016). To increase the protein content of the biscuit prepared soy flour can be added with 70 per cent kodo (Kumar et al 2010). Vijayakumar and Mohankumar (2009) prepared biscuits using composite flour (kodo, barnyard millet, whole wheat flour and defatted soy flour).

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