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GRAIN QUALITY OF SORGHUM, PEARL MILLET, MAIZE AND MINOR MILLETS*

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ABSTRACT

Maize, sorghum, pearl millet, and other minor millets are important staple cereals in many tropical countries including India and supply the essential calories, proteins, minerals and vitamins. Grain mass and composition show considerable variation in these cereals and therefore give rise to a variety of food products. Maize and pearl millet are valuable for their oil content and finger millet is considered as a nutritious food grain due to its very high calcium content. Maize and sorghum are inferior in amino acid composition. Cereal grains are generally processed by dehulling, wet milling, dry milling, popping, roasting, malting or fermentation. Traditional foods like roti, and thick and thin porridges are commonly prepared from these cereals. The role of a few physicochemical characteristics of the grain and their influence on processing and food quality are discussed.

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Sorghum, pearl millet, maize, and finger millet are considered as coarse or minor cereals as compared to major cereals, rice, and wheat. Besides these, foxtail millet, proso millet, little millet, barnyard millet and kodo millet are also included under minor millets (Table 1). In India, sorghum, maize, and millets are extensively cultivated next only to rice and wheat. Among the minor cereals, maize and finger millet are gardenland crops while all the others are generally grown under rainfed conditions. Some of these crops possess adaptation like tolerance to drought, high temperature and low soil fertility conditions. Sorghum, pearl millet, finger millet and other millets are extensively cultivated for traditional food uses. Maize in addition to traditional food uses, has received attention for industrial uses. More information on food and nutritional quality is available on sorghum and maize, and to a lesser extent in pearl millet, than on other minor millets. Nutritional and food quality including processing quality of sorghum, maize and millets are described in this report. Since information on nutritional and food quality is not adequate for minor millets, most of the citation have been based on sorghum, pearl millet, and maize. However, attempt has been made to bring out the available information on minor millets also. The objective of this report is to provide information on the present status of nutritional and food quality attributes of these crops in India. Attempt has been made to bring out the relationship of grain factors to processing and food quality.

Physical characters of the grain

The color of sorghum and millet grains may be white, yellow, red, brown, grey white and yellow while in maize it is white, yellow or orange. Grain color vary in minor millets. Grains are generally varying in shape and consists of pericarp, germ and endosperm. The pericarp has three layers, the epicarp, the mesocarp and endocarp. Various grain sizes are encountered for the minor cereals (Table 2) The size (weight) and shape of grains impart influence on processing characters of these grains. Foxtail millet and little millet are among the lowest in their grain size. Maize has the largest grain size among the cereals.

The endosperm generally consists of floury and corneous portions and these are distributed in various proportions in cereal grains. Though the nature of endosperm in sorghum and maize is well documented, the information on other minor cereals are scanty. The floury endopserm with its large intercellular air spaces, differs structurally from compact hard corneous endosperm. In the floury type, the spherical starch granules have small particles of protein adhering to their surfaces and are loosely associated with protein.

Chemical composition of grains

Carbohydrates: The starch account for 57.6 to 76.3% of these cereal grains (Table 3). Studies on amylose content of minor cereals are scanty. However, high amylose corn has been reported previously[1]. Amylose content varied from 21.1 to 30.2% in non-waxy sorghums[2]. In pearl millet amylose content varied from 23.6 to 28.8 and in finger millet from 15.8 to 17.5%[3,4]. The gelatinization temperature of starch is affected by the proportion of amylose to amylopectin in starch[5]. The gelatinization temperature of starch of 12 sorghum genotypes varied from 66.0 to 70.5°C[2] and from 67.0 to 69.0°C for pearl millet genotypes. The swelling capacity and solubility of starch at different temperatures also showed wide variation for the genotypes studied. Relatively little data are available on the nature and amount of free sugars. In minor cereals, sugars play an important role in malting and also impart characteristic tastes to the food product. Maize contains large quantities of sugar; particularly in sweet corn, the major carbohydrate is low molecular weight dextrins[1]. Total soluble sugars ranged from 0.7 to 4.2% in sorghum[6] and from 1.4 to 2.6% in pearl millet[7]. Stachyose, raffinose, sucrose, glucose and fructose are found in sorghum and pearl millet[6,7].

Lipids: The lipid content of sorghum varies from 2.3 to 4.7%, and in maize and pearl millet from 4.0 to 6.0%; foxtail, proso, little, barnyard and kodo millet have from 3.0 to 5.0% (Table 3). Finger millet has the lowest lipid content of all the cereals. When grains are milled to flour, lipids are liable to undergo deterioration by the action of lipioxidase. Normally the enzymes and the lipids do not come into contact in the intact grain. Milling may bring the lipid and enzyme together, thereby promoting deterioration, giving rise to unpleasant flavors, instability, and rancidity of flour.

Minerals, crude fiber, and vitamins : Nutritional studies in semi-arid tropics show evidence for deficiency in calcium, iron, and zinc. Minor cereals are one of the major source of minerals for people who consume them. Proso and barnyard millet had high quantities of ash (Table 3). Finger millet contains high quantities of calcium (up to 350 $mg.100\ g^{-1}$) and is also rich in potassium (Table 4). Pearl, barnyard, and kodo millets contain high quantities of iron. Except sorghum, maize, pearl millet, and finger millet all the minor cereals contain large quantities of crude fiber (Table 3). Variations for vitamin content were observed for the various cereals (Table 5). Sorghum contains more niacin. Foxtail millet contain large quantities of thiamine[1].

Proteins : Cereals are the major source of proteins and calories in many parts of Asia, the Near East, Africa and Latin America[8]. The grain protein content of sorghum varies from 4.4 to 21.1% with a mean of 11.4%. Pearl millet protein content ranges from 5.8 to 20.9% with a mean of 10.6% (Table 3). The protein content of maize is about 9.0% and of finger millet is about 8.3%. Other minor cereals contain generally more than 10% protein. Proso millet has higher protein content (14.3%). Frey[9] reported a negative correlation between yield and grain protein content in several cereal species.

The quality of grain proteins depends on its amino acid composition (Table 6). In general, sorghum has higher levels of glutamic acid, leucine, alanine, proline and aspartic acid than other amino acids. Lysine and methionine and cystine contents of finger millet are higher than other cereals. The leucine to isoleucine ratio is higher in sorghum and maize, while it is low in other cereals. Tryptophan content is low in maize and sorghum[1]. Lysine, threonine and sulphur containing amino acids, methionine and cystine are the limiting amino acids in cereals. Attempts to increase lysine content in sorghum and maize have been made[10,11]. However, increase in lysine changed the kernel characters[12].

Protein quality is associated with the amount and distributions of various protein fractions in the grain. Sorghum and finger millet contains nearly similar quantities of albumin and globulin (17%). Albumin and globulin content in pearl millet was up to 25% of total protein. Proso, little, and foxtail millet contains lower quantities of this fraction (9-10%), (Table 7). The protein quality of cereals in general, are inversely related to their prolamin contents[6]. The prolamins are low in lysine and other nutritionally important amino acids. Maize contains larger quantities of prolamine (up to 55% of total protein). Prolamine accounts for 26% in sorghum and 31% in pearl millet. Minor millets generally contain lower amount of prolamines. Sorghum, maize, foxtail and finger millets contain more quantities of cross-linked prolamins. Finger millet had high quantities of cross-linked prolamines. However, this class of protein is considerably low in pearl millet, proso millet and little millet. Glutelin is higher in sorghum, proso and little millets, as compared to other cereals (Table 7).

Food quality and utilization

Minor cereals are used as human foods in several regions of India and African countries[13,14,15]. Maize is used for traditional food as well as in the starch industry. A detailed survey on traditional methods of food preparation of sorghum and pearl millet grains was undertaken in seven states of India[14]. For making acceptable foods, these grains are processed by dry milling, wet milling, fermentation, roasting and puffing[14]. Though several food products are prepared from sorghum and pearl millet in India, roti is the major food. Thick and thin porridges, boiled grains are other products of importance[14]. Maize is used for the preparation of thick roti, porridges, roasted or boiled ears and as pop corn[16]. Several other minor foods are also prepared using these grains. The traditional foods made from sorghum and pearl millet, in India can be grouped into seven basic types[14].

1. Unleavened bread - roti
2. Porridge - muddhae, sankati, kali

3. Gruel - _ganji_, _kuzh_

4. Boiled product - _soru_,

5. Steamed products - _kadabu_

6. Fried products - _papad_, _puda_

7. Snacks - _hurda_, _halwa_, _sukhadi_

Grain processing

Grains are processed in various ways such as dehulling, dry milling of whole grain or dehulled grain to flour and grits, soaking and fermentation of grain and flour[17]. Dehulling is commonly done to remove the large amounts of fiber in these grains. Dehulling is done by the traditional method of pounding the grains using mortar and pestle with little addition of water (2.5%) until the outer layers are separated from the endosoperm. The endosperm is then separated from the hulls by winnowing. The dehulled grain is further pounded to grits or flour. The traditional dehulling process is cumbersome and time-consuming. For dehulling of sorghum and millet grains, vertical rice cone polisher can be effectively used[17,18]. However, for minor millets, only little information is available on dehulling. The dehulling quality is influenced by varietal differences. Murty and House[19] indicated that local cultivars of sorghum in West Africa was relatively easier to dehull by traditional methods than introduced cultivars from India and USA. Murty _et al_[20] concluded that sorghum kernels with a highly corneous endosperm and a very thick pericarp were easier to dehull by hand pounding than those with a thin pericarp and those floury endosperm. Dehulling maize, pearl millet and kodo millet improves cooking in water and makes the product acceptable[21].

Pearl millet grain is difficult to dehull as compared to other cereal grains due to its structural peculiarity, namely presence of irregular identation of the pericarp[1]. Studies indicated that varietal variation existed for dehulling by traditional methods (Table 8). However, mechanical dehulling as done in laboratory model mill showed improvement over traditional dehulling indicating the possibility of development of a suitable mill[22]. Grain with thin pericarp and corneous endosperm have proved acceptable for mechanical dehulling[23]. Bolder grains with less breaking strength yield more brokens during dehulling. A mini grain mill for dehusking and grinding cereal grains was developed[24]. This could be used for maize, sorghum, finger millet, pearl millet and wheat (Table 9). There is need to study in detail the physical characters of the grain and their role in the dehulling process. Improvement of milling methods will circumvent the undesirable features in the grain.

Milling methods influence the flour quality and thus the food products[20]. A major portion of maize for human consumption is processed by tempering-degerming system and hard textured grains are suited for this process[16]. There are variations for processing of corn of different groups namely dust corn, flint corn, sweet corn, flour corn, pop corn, waxy corn, and pod corn[16]. Wet milling is adopted to a limited extent for food products and is mostly used in starch manufacturing process[16]. The nature and extent of starch damage showed variations due to grinding, which may significantly affect the product quality[25].

Dry milling is done using disc mill or stone mill and milling products include grits, meal, and flour[14]. The different products of dry milling vary in their particle size[1]. In India maize semolina is popular among cosumers, which is prepared through dry milling[16]. Grits are used in the manufacture of corn flakes and grits from yellow maize are preferred[1]. Coarse and medium grits are used in the manufacture of cereal products and snack foods[1]. Yield of meal having particle size 250-841 which constitutes 65% of standard semolina was dependent on the hardness of the kernel[26]. Bulk density and protein content was associated with yield of milled fraction in maize[26]. Kurien and Desikachar[3] found wet milling to be superior to dry milling of finger millet for flour extraction. However, it resulted in the loss of protein, calcium, phosphorus, and thiamine. The physical structure of kernel plays an important role in the efficiency of milling in terms of flour yield, color, chemical composition and acceptability[27].

Malting, germination and fermentation

Malting of cereals in well known in India. Patwardhan and Narayana[28] reported that finger millet is superior to sorghum and maize for malting. The enzymes responsible for malting were investigated by Chandrasekhara and Swaminathan[29]. The industrial feasibility of finger millet malt has been reported[30,31]. Suitability of high yielding varieties of finger millet were studied for malting quality and variations have been observed among the cultivars[32]. Further refinement of flour from malted finger millet was attained by suitable milling techniques[33].

Germination is a vital stage for malting as enzymes, amylases, and protease develop during the process[32]. Germination also increased lysine and tryptophan in maize[34]. The suitability of malting of other cereals like sorghum[35] has been studied as early as 1918. Recently, Malleshi[36] indicated that sorghum could be malted for various preparations such as malt extract, malt sugars and weaning food formulations. Pal <u>et al</u>[37]

reported that barley and bajra malts had comparable amylolytic as well as protelytic activities and only minor differences existed. However, Singh and Tauro[38] reported that pearl millet had low amylolytic activity as compared to barley. Malt from pearl millet is bitter in taste[36]. Dhamija and Singh[39] reported sorghum at 35%, and pearl millet at 25% as malt adjuncts with barley resulted in beer comparable analytically and organoleptically to the commercial beer. Finger millet also could be used as adjunct in equal proportion with barley malt for producing beer[40]. This suggest the possibility of using these cereals for industrial uses. Fermentation is important in producing acceptable dosa from maize, sorghum and pearl millet[41]. Digestibility of sorghum food was also improved due to fermentation[42]

Traditional foods from sorghum, maize and millets

Roti or chapati is an unleavened bread, made in India from sorghum, pearl millet, maize, and finger millet flours. A good roti should be of acceptable color, sweet in taste with characteristic flavor, soft in texture and should remain soft for several hours[14]. Dough and roti quality sorghum and pearl millet genotypes have been evaluated at ICRISAT[4,43]. A broad range of variation was observed for cultivars even with visually similar and good grains[4,43].

Dough quality

The cohensiveness of dough and organoleptic qualities of roti are important criteria for evaluation of grain for roti quality. A flour that produces cohesive dough generally produces an acceptable roti[44]. Wide variation for cohesiveness has been observed for sorghum flours while much difference were not seen for pearl millet flours[4,44]. Dough cohesiveness was evaluated both subjectively, and with the Instron Food Testing instrument using a back-extrusion cell. Cohesive doughs yielded a characteristic back-extrusion profile requiring less force for deformation[44]. Dough made from pearl millet showed good cohesiveness and rolling quality. Maize flour required more water for making dough than sorghum, pearl millet and wheat flour[41] (Table 10). Relatively little work on dough quality of other millets has been reported.

Roti quality

In general, pale yellow sorghum grain with intermediate corneous endosperm, and with a thin pericarp without testa produced *roti* with acceptable quality. Panelists' scores for taste, texture, flavour, and keeping quality varied significantly for 167 sorghum genotypes with visually good grains[43]. White grains with coloured spotting or a testa and brown types produced a dark red or dark brown *roti*[43]. Waxy and floury grains produced poor quality *rotis*. Even minor infestation with grain molds resulted in poor quality *roti*. A good pearl millet *roti* is grey to greyish white in color, and smooth in appearance uniformly soft over the sufrace, slightly sweet in taste and with characteristic odor[4]. Maize *roti* was soft and chewing count was less with good keeping quality, which may be due to more water absorption of flour during dough making[41] (Table 10).

Porridge quality

Thick and thin porridges are made in some regions in India. Thick porridges are prepared either with grits or flour from sorghum, pearl millet and other millets[14]. Grits (semolina) and flours are prepared after dehulling the grains. Grits and/or flour is cooked in boiling water for thick consistency and the product is callled *kali*, *muddhae*, or *sankati*.

The cooked product should have sufficient adhesiveness, but should not be sticky[45]. Information on the quality factors of thin porridge of these grains are scanty.

Boiled sorghum and millet

Boiled sorghum or millet (soru or annam) is one of the common products prepared in India[2,14]. Dehulled grains are used to cook similar to rice. The cooked product has to be fluffy, uniform in color with a sweet taste. Subramanian et al[2] reported the variation for boiled sorghum characters among the cultivars. The cooking time was more for sorghum than pearl millet (Table 11). The volume increase for sorghum was 152 to 400 and for pearl millet 163 to 263. However, similar ranges of weight increase was observed for sorghum and pearl millet grains. Wide variation in quality scores for boiled sorghum and pearl millet as evaluated by taste panelists was also observed for the genotypes (Table 11).

Popping and roasting

Pops of maize, sorghum, and ragi are common snacks[17]. Pop maize is hard. In general, pop sorghum possessed a small grain size, medium thick pericarp, hard endosperm with a very low germ/endosperm ratio[46]. Varieties of ragi with good puffing yield gave puffed material of high specific value[47]. The earheads of maize, sorghum and ragi at the hard dough stage of grain development are roasted on coal and the grains are consumed[14,16].

Relationship between food quality and properties of the grain

Several physicochemical characteristics of sorghum and pearl millet grains which relate to roti, porridges and boiled products quality have been reported[2,41,44,46]. Maize semolina was found to have higher swelling number which is due to its relative swelling power of starch[48]. Maize semolina may have higher water absorption[26]. Fine grinding may reduce cooking time in maize and sorghum[48]. Sorghums with low genatinization temperature (GT), high peak viscosity (PV) and set back and high water uptake gave doughs with better rolling quality[45]. The relationship between the physicochemical characters and roti quality indicated that quantity of water-soluble protein, amylose and sugars jointly influence the sorghum roti quality[49] (Table 12). Physical factors like swelling capacity of flour showed significantly and positive relationship while water soluble flour fraction (WSFF) showed negative relationship with roti quality characteristics of pearl millet[4] (Table 13). Softness and keeping quality of maize roti was better which may be due to high water absorption of flours while making dough[41]. Excessive stickness is undesirable for thick porridge[45]. Varieties with high GT and low PV, and set back gave muddhae with adequate consumer acceptability (Table 14). These are the properties unsuitable for roti. Therefore, varieties unsuited for roti may be used for muddhae preparation[45]. Heat processing of sorghum increases cold slurry viscosity but decreases hot paste viscosity[45].

Maize batter offered more difficulty in dosa preparation as compared to sorghum and pearl millet[41]. Peak viscosity as well as viscosity on cooling at 50°C were lower for maize indicating poor gel setting and more flow characteristics[41]. Vermicilli made from maize and sorghum disintegrated upon cooking. However, steaming maize and sorghum vermicilli strands for 20 to 30 min prior to drying conferred sufficient strength[41].

For boiled sorghum (soru, annam) grains having low hardness produced an acceptable product[2]. Swelling power and solubility have shown a significant relationship with cooking time (Table 15). Per cent weight increase of the product was negatively associated with starch solubility at $60^{o}C$, the temperature at which most of the starch granules reaches gelatinization[2]. The gruel solids showed a positive relationship with starch content in the grain. The swelling power of starch at 60^{o} and $90^{o}C$ and solubility at 25^{o} and $50^{o}C$ showed a negative relationship with gruel solids content[2]. This may be due to the association of starch with factors like protein in the grain. In pearl millet, the swelling power of starch at $70^{o}C$ showed a negative correlation with soru quality. Gelatinization temperature, and amylose contents did not show any relationship.

Germination of finger millet brings about reduction in flour paste viscosity[32]. Weaning foods with low paste viscosity, and high calorie density are being advocated[32]. Even addition of as little as 5% malted barley flour to weaning food reduced paste viscosity. Such addition is feasible for increasing calorie density and reducing viscosity, and would enable the child to take more food. Pearl millet, sorghum, and maize could be flaked, after soaking the grits in water and steaming[50]. These cereals are comparatively hard to flake and are similar to rice in this respect. Presence of horny endosperm in peripheral layers of grain and longer size of starch granules give rise to slow hydration indicating that these need soaking in water before flaking[17].

Consumer acceptance of local and hybrid grains

During a survey on the food consumption pattern of sorghum in Maharashtra state in India[14], it was observed that the farmers and other consumers were of the opinion that bhakri (roti) made of local sorghum (Maldandi) kept them without hunger for a longer time than that prepared from hybrids. To test whether this opinion was real or psychological, a preliminary study was conducted in Rahuri area (Maharashtra) with the help of six families. Sorghum flour of a hybrid (CSH 8) and a local (M 35-1) were supplied to each of the family members for a period of four weeks and their consumption pattern was assessed. Analysis of results revealed that four of six families could not differentiate between the hybrid and local sorghum. Therefore it is necessary to carry out consumer acceptability studies on advanced breeding materials before they are considered for large-scale testing and subsequent release.

Industrial Uses

Maize has been used in starch industry in India[51]. Sorghum and millet will increasingly be used for industrial processing into flour, grits and other products which will be utilized for the production of various foods using blends of maize, wheat and other commodities[52,53]. Sorghum grains are used widely in Mexico as an adjunct in preparing European types of beer[54] and a number of food products from millet and sorghum are sold commercially in South Africa. In Sudan, industrial processing is becoming important for pearling sorghum to cook similar to rice[55]. Such possibilities would be useful in India. Malted finger millet is well accepted and has reached into markets. There is good potential for finger millet for industrial use, both for malt as well as for beers. Although the use of minor cereals in industry is secondary, the interest and ability to make commercial products are increasing. This will increase the demand for high quality grains.

Conclusions

Sorghum, maize, and millets are important food grains in several regions of the world[17]. Efforts are underway to improve and stabilize the yields of these crops in various countries. However, it is important to pay attention to the nutritional, processing and food quality attributes while developing new and improved cultivars. There is an immediate need to develop a suitable technology like processing and refined methods of milling that enhance the consumer acceptability and improved, and alternative utilization of these cereals. Good interaction among plant breeders, food technologists, biochemists, biotechnologists, socio economists and entrepreneurs would prove very beneficial in achieving rapid progress in this area.

REFERENCES

1. Kent, N.L., Technology of cereals, Pergamon Press, Oxford, 1983, 27.

2. Subramanian, V., Murty, D.S., Jambunathan, R., and House, L.R. 1982. Boiled sorghum characteristics and their relationship to starch properties. Proceedings of the International Symposium on Sorghum Grain Quality, Patancheru, A.P., October 1981, 103.

3. Kurien, P.P., and Desikachar, H.S.R., Studies on refining of millet flours I. Ragi (Eleucine coracana). Food Science, 1962, May, 136.

4. Subramanian, V., Jambunathan, R., and Ramaiah, C.D., Physical and chemical characteristics of pearl millet grains and their relationship to roti quality. J. Food Sci., 1986, 51, 1005.

5. Hoseney, R.C., Varriano-Marston, E., and Dendy, D.A.V. Sorghum and millets. In Advances in Cereal Science and Technology. (by Y. Pomeranz), American Association of Cereal Chemists, INC, St. Paul, Minnesota, 1981, Vol. IV.

6. Subramanian, V., Jambunathan, R., and Suryaprakash, S., Note on soluble sugars of sorghum. Cereal Chem., 1980, 57, 440.

7. Subramanian, V., Jambunathan, R., and Suryaprakash, S., Sugars of pearl millet (Pennisetum americanum [L.] Leeke) grains. J. Food Sci. 1981, 46, 1614.

8. Axtel, J.D., Breeding for improved nutritional quality. Proceedings of the plant Breeding Symposium, Iowa State University, March 1979, 365.

9. Frey, K.J., Protein of oats. Z. Pflanzenzuchrg, 1977, 78, 185.

10. Mertz, E.T., Bates, L.S., and Nelson, O.E., Mutant genes that changes protein composition and increase lysine content of maize endosperm. Science, 1964, 145, 279.

11. Nelson, O.E., Mertz, E.T., and Bates, L.S., Second mutant gene affecting the amino acid pattern of maize endosperm proteins. Science, 1965, 150, 1469.

12. Riley, K.W. Inheritance of lysine content, and environmental responses of high and normal lysine lines of Sorghum bicolor (L.) Moench in the semi-arid tropics of India. 1980. Ph.D., Thesis, University of Manitoba, Canada.

13. Vogel, S., and Graham, M., Sorghum and Millet: Food production and use. International Development Research Centre Publication, IDRPC-123e, 1979.

14. Subramanian, V., and Jambunathan, R., Traditional methods of processing sorghum (Sorghum bicolor) and pearl millet (Pennisetum americanum) grains in India. Reports of International Associaton of Cereal Chemistry (ICC), 1980, 10, 115.

15. Vaidehi, M.P., Vijayakumari, J., Shanthakumari, K., Pilot study on consumption pattern of ragi among selected families of different income cereals. Current Res., 1981, 10, 62.

16. Salunkhe, D.K., Charan, J.K., and Kadam, S.S., Post-harvest biotechnology of cereals, CRC Press, Inc., Boca, Raton, Florida. 1985, 93.

17. Desikachar, H.S.R., Processing of maize, sorghum and millets for food uses. J. Sci. and Ind. Res., 1975, 34, 231.

18. Viratamath, C.S., Raghavendra G., and Desikachar, H.S.R., Use of rice milling machinery for commercial pearling of grain sorghum (jowar) and culinary use for pearled sorghum products. J. Food Sci. Technol., 1971, 8, 11.

19. Murty, D.S., and House, L.R., 1980. Sorghum Food Quality: its assessment and improvement. Report submitted to the 5th Joint Meeting of the UNDP-CIMMYT-ICRISAT Policy Advisory Committee, ICRISAT, 14-18 Oct. Patancheru, A.P., India, (limited circulation).

20. Murty, D.S., Patil, H.D., House, L.R. Processing and cooking quality characters in sorghum. Nutritional and processing quality of sorghum, by D.K. Salunkhe, J.K. Chavan and S.J. Jadhav, Oxford and IBH Publishing Co., New Delhi, 1984.

21. Raghavendra Rao, S.N., and Desikachar, H.S.R., Note on the comparative swelling characteristics of polished and unpolished wheat and rice during cooking. Cereal Chem., 1964, 41, 316.

22. Annual Report. International Crops Research Institute for the Semi-Arid Tropics, (ICRISAT), Patancheru, India 1985.

23. Maxon, E.D., Fryar, W.B., Rooney, L.W., and Krishnaprasad, M.N., Milling properties of sorghum grain with different proportions of corneous to floury endosperm. Cereal Chem., 1971, 48, 478.

24. Shankara, R., Malleshi, N.G., Krishnamurthy, H., Narayana, M.N., and Desikachar, H.S.R., Development of a mini grain mill for dehusking

and grinding of cereals. J. Food Sci. and Technol., 1985, 22, 91.

25. Subramanian, V., Jambunathan R., and Prasada Rao, K.E., Dry milling characteristics of sorghum grains and their relationship to product quality. Paper presented at the National Seminar on "Technology and Application fo alternate uses of sorghum" February 1987, Marathwada Agricultural University, Parbhani, India. 1987.

26. Manohar Kumar, B., Gerstenkorn, P., Zaingelberg, H., and Boplling, H., On some corrleations between grain compsotion and physical characteristics to the milling performance in maize. J. Food Sci., Technol., 1978, 15, 1.

27. Munck, L., Bach Knudsen, K.E., and Axtell, J.D. Milling processes as related to kernel morphology. Proceedings. International Symposium on Sorghum Grain Quality, Patancheru, A.P., Oct 1981, 200.

28. Patwardhan, V.N., and Narayana, N., Amylose from ragi (Eleucine coracana). J. Indian Inst. Sci., 1930, 13, 38.

29. Chandrasekhar, M.R., and Swaminathan, M., Factors affecting the yield and quality of malt extract from Ragi (Eleucine coracana) malt. J. Sci. Industr. Res., 1953, 12 B, 610.

30. Sastri, B.N., Ragi (Eleucine coracana Gaertn.,) - A new raw material for the malting industry, Current Sci., 1939, 1, 34.

31. Kamalanathan, G., Girija, K.A., and Devadas, R.P., Possibilities of white ragi (Eleucine coracana) in human dietary. Indian. J. Nutr. Dietet., 1971, 8, 315.

32. Malleshi, N.G., and Desikachar, H.S.R., Malting quality of new varieties of ragi (Eleucine coracana). J. Food Sci. and Technol., 1979, 16, 149.

33. Malleshi, N.G., and Desikachar, H.S.R., Studies on suitability of roller flour mill, hammer mill and plate grinder for obtaining a refined flour from malted ragi. J. Food Sci. Technol., 1981, 18, 37.

34. Ram, P.C., Lodha, M.L., Srivastava, K.N., Tyagi, R.S., Singh, J., and Mehta, S.L., Improving nutritive value of maize (Zea mays L) by germination. J. Food Sci. Technol., 1979, 16, 258.

35. Vishwanath, B., Row, T.L., and Ayyangar, P.A., Cholam (A. sorghum) a substitute for barley in malting operations. Mem. Dept. Agric. Indian Chem. Sei. 1918, 5, 117.

36. Malleshi, N.G., Malting of sorghum for food uses. Paper presented at the National Seminar "Technology and alternative uses of sorghum", Marathwada Agricultural University, Parbhani, India. February 1987.

37. Pal, A., Wagle, D.S., and Sheorain, V.S., Some enzymatic studies of bajra (Pennisetum typhoides) and barley (Hordeum vulgare), during malting. J. Food Sci. Technol., 1976, 13, 75.

38. Singh, D.P., and Tauro, P., Evaluation of bajra (Pennisetum typhoides) for malting and brewing. J. Food Sci. Technol., 1977, 14, 255.

39. Dhamija, S.S., and Singh, D.P., Adjuncts in brewing I. Bajra and sorghum. J. Food Sci. Technol., 1978, 15, 197.

40. Venkatanarayana, S., Murty, V.S., and Satyanarayana Rao, B.A., The use of ragi (Eleucine coracana) in brewing. J. Food Sci. Technol., 1979, 16, 204.

41. Raghavendra Rao, S.N., Malleshi, N.G., Sreedharamurthy, S., Viratamath, C.S., and Desikachar, H.S.R., Characteristics of roti, dosa and vermicilli from maize, sorghum and bajra. J. Food Sci. Technol., 1979, 16, 21.

42. Graham, G.G., MacLean, W.C., Morales, E., Hamaker, B.R., Kirleis, A.W., Mertz,. E., and Axtell, J.D., Digestibility and utilization of protein and energy from nasha, a traditional Sudanese fermented weaning food. J. Nutrition, 1986, 116, 978

43. Murty, D.S., Patil, H.D., and House, L.R. Sorghum roti. II Genotypic and environmental variation for roti quality parameters. Proceedings, International Symposium on Sorghum Grain Quality, ICRISAT, Patancheru, Oct 1981, 79.

44. Subramanian, V., Jambunathan, R., and Sambasiva Rao, N., Textural properties of sorghum dough. J. Food Sci. 1983, 48, 1650.

45. Desikachar, H.S.R., and Chandrasekhar, A., Quality of sorghum for use in Indian foods. Proceedings of the International Symposium on Sorghum Grain Quality, Patancheru A.P., Oct. 1981, 262.

46. Murty, D.S., Patil, H.D., Prasada Rao, K.E., and House, L.R., A note on screening the Indian sorghum collection for popping quality. J. Food Sci. and Technol., 1982, 19, 79.

47. Malleshi, N.G., and Desikachar, H.S.R., Varietal differences in puffing quality of ragi (Elelucine coracana). J. Food Sci. and Technol., 1981 18, 30.

48. Raghavendra Rao, S.N., Viratamath, C.S., and Desikachar, H.S.R., Relative cooking behaviour of semolina from maize, sorghum, wheat and rice. J. Food Sci. Technol., 1976, 13, 34.

49. Subramanian V., and Jambunathan, R. Properties of sorghum grain in relationship to roti quality. Proceedings of the International Symposium on Sorghum Grain Quality, Patancheru, A.P., October 1981, 280.

50. Annual Report. Central Food Technological Research Institute (CFTRI), Mysore, Report on Project 325, 1973.

51. Manoharkumar, B., and Kempf, W., On wet milling suitability of four maize cultivars. J. Food Sci. Technol, 1978, 15, 253.

52. Rooney, L.W., Khan, M.N., and Earp, C.F. The technology of sorghum products. In cereals for food and beverages: Reecent progres in Cereal Chemistry and Technology, by Inglette, G.E. and Munck, L. Academic Press, New York, U.S.A., 1980, 513.

53. Miche, J.C., Alary, R., Jeanjean, M.P., and Abecassis, J., Potential use of sorghum grains in pasta proceesing. Proceedings of the Symposium on Sorghum and Millets for Human Food, by D.A.V. Dendy, London: Tropical Products Institute, May 1977, 27.

54. Aldape, G.A., A sorghum dry milling system. Proceedings, Sorghum Research Utilization Conference, 1981, Lubbock, Textas, USA.

55. Badi, S.M., Perten, H., and Abert, P., New food product "pearl durra". Reports of the International Association Chemistry (ICC) 1980 10, 102.

56. Rachie, K.O., The Millets - Importance, utilization and outlook, International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, 1975.

57. Jambunathan, R., Singh, U., and Subramanian, V., Grain quality of sorghum, pearl millet, pigeonpea and chickpea. Pages 47-60, Proceedings of the Workshop on Interfaces Between Agriculture, Nutrition and Food Science, 10-12 November 1981, Patancheru, A.P., 1981, 47.

58. Misra, P.S., Mertz, E.T., and Glover, D.V., Studies on corn proteins VI. Endosperm protein changes in single and double endosperm mutants of maize, Cereal Chemistry, 1975, 52, 161.

Table 1. Names of minor cereals

English name	Scientific name	Common Indian names
Sorghum	*Sorghum bicolor* (L.) Moench	Jowar, cholam
Pearl millet	*Pennisetum americanum* (L.) Leeke	Bajra, bulrush millet
Maize	*Zea mays* L.	Makki jowar, corn
Finger millet	*Eleucine coracana* (L.) Gaertn.	Ragi, Kezhvaragu
Foxtail millet	*Setaria italica* Beauv.	Italian millet, thenai
Proso millet	*Panicum miliaceum* L.	Common millet, samai
Little millet	*Panicum sumatrense* Roth ex Roem. Schult.	Panivaragu
Barnyard milet	*Echinochloa crysgalli* (L.)	Kudhiraivali
Kodo millet	*Paspalum scrobiculatum* L.	Varagu

Source: Rachie[56]

Table 2. Mass for 1000 grains of the minor cereals

Cereal	Number of cultivars	1000-grain mass (g)		SE ±
		Range	Mean	
Sorghum	100	13.0 - 57.0	28.0	0.09
Pearl millet	36	4.8 - 10.1	7.5	0.03
Maize[a]	-	150 - 600	324	-
Finger milet	5	2.85 - 3.94	3.33	0.10
Foxtail millet	5	1.16 - 2.40	1.50	0.22
Proso millet	5	4.95 - 6.88	5.92	0.34
Little millet	5	1.79 - 2.19	2.02	0.07
Barnyard millet	5	2.57 - 3.71	3.27	0.23
Kodo millet	5	4.19 - 4.83	4.48	0.13

[a]Source: Kent[1]

Table 14. Varietal differences in physical and organoleptic properties of sorghum muddhae (dumpling).

Dumpling quality[a]	Tackiness[b] With 2.5 parts water (g)	Tackiness[b] With 3.5 parts water (g)	GT (°C)	PV (BU)	Setback (BU)
Poor (4)[c]	248	279	71.4	320	628
Moderate (7)[c]	240	267	71.4	367	612
Good (4)[c]	194	241	76.1	212	365

[a]Poor: BP53, Patcha Jonna, Patancheru, P721
Moderate: GPR370, GPR148, CSH-8, M64-71, CSH-1, A-2283
Good: H2269, M3165, E-35-1, M-7777

[b]Tackiness is measured as the force required to relase a plate in contact with the dough measured.

[c]Figures in parenthesis represent the number of samples taken for tests.

BU = Brabender Units, PV = Peak Viscosity.

Source: Desikachar and Chandrasekhar[45].

Table 3. Chemical composition of minor cereals (g.100 g^{-1})

Crop	Protein	Starch	Soluble sugars	Lipids	Crude	Ash
Sorghum[a]	11.4	70.8	1.3	3.3	1.9	2.1
Pearl millet[a]	10.6	71.6	2.1	5.1	1.3	1.9
Maize[b]	9.6	72.4	1.9	4.7	3.5	1.4
Finger millet[c]	8.3	76.3	1.3	1.9	3.1	2.8
Foxtail millet[c]	13.9	60.9	1.2	4.8	9.9	3.2
Proso millet[c]	14.3	62.0	1.2	4.9	7.9	4.3
Little millet[c]	10.7	63.3	1.3	5.3	11.1	3.7
Barnyard millet[c]	11.2	60.5	1.5	5.3	10.1	5.1
Kodo millet[c]	10.6	57.6	1.1	3.4	9.8	3.0

[a]Source: Jambunathan _et al_[57]

[b]Source: Kent[1]

[c]Values based on mean of 5 cultivars.

Table 4. Mineral and trace element composition of sorghum, maize and millet grains (mg.100 g^{-1})

Elements	Sorghum[a]	Pearl millet[b]	maize[c]	Finger millet[d]	Foxtail millet[d]	Proso millet[d]	Little millet[d]	Barnyard millet[d]	Kodo millet[d]
Phosphorus	526	260	294	302	424	435	335	391	245
Magnesium	212	106	143	164	148	160	154	166	127
Potassium	537	379	342	635	432	383	322	323	301
Calcium	26	38	20	350	42	29	33	42	50
Iron	9	17	3	4	5	10	6	15	12
Copper	9	8	0.9	0.9	4	15	9	19	12
Zinc	4	4	2	2.4	6	6	4	8	6
Manganese	1.8	1.5	0.6	8	1.8	1.8	1.5	2.6	5

[a]values based on mean of 99 cultivars.

[b]values based on mean of 27 cultivars.

[c]Source: Kent[1]

[d]based on mean of 5 cultivars

Table 5. Vitamin contents of the cereal grains ($ug.g^{-1}$)

Cereal	Thiamine	Riboflavin	Niacin	Pantothenic acid
Sorghum	3.5	1.4	41	11
Maize	4.0	1.1	19	5.3
Millet:				
pearl	3.6	1.7	26	11.4
foxtail	5.9	0.8	. 7	-
proso	2.0	1.8	23	-
finger	3.6	0.8	13	-

Source: Kent[1]

able 6. Amino acid composition (g.100 g^{-1} protein) of minor cereal grains[a]

ino acid	Sorghum[b]	Pearl millet[b]	Maize[c]	Finger millet[b]	Foxtail millet[d]	Proso millet[d]	Little millet[d]	Barnyard millet[d]	Kodo millet[d]
ine	2.6	2.7	3.0	3.5	2.0	1.7	1.9	2.1	1.9
stidine	2.4	2.0	2.8	2.8	2.1	2.3	2.3	2.2	2.2
ginine	3.7	4.7	4.7	4.3	3.4	3.3	3.9	3.6	3.5
partic acid	7.0	8.1	6.4	6.5	7.0	6.0	6.0	6.0	6.3
reonine	3.1	3.3	3.6	3.9	3.3	2.9	3.5	3.3	3.4
rine	3.9	3.9	4.9	5.3	4.4	5.5	5.2	4.7	4.6
utamic acid	19.9	23.2	18.8	21.4	18.5	19.3	19.7	19.9	20.2
oline	7.5	6.2	8.8	6.5	6.8	6.4	6.2	6.6	6.8
ycine	4.0	3.7	3.9	3.9	2.6	2.3	2.5	2.9	2.6
lanine	10.4	8.5	7.7	6.2	8.5	9.7	8.3	8.5	8.8
lf cystine	0.9	1.0	1.3	1.2	0.8	0.8	0.8	0.9	0.9
line	4.8	6.1	5.2	6.3	4.9	4.8	5.6	5.3	4.9
ethionine	1.6	1.4	1.8	2.9	1.8	1.8	1.6	1.2	1.4
soleucine	3.9	4.1	4.0	4.7	4.3	4.2	4.4	4.3	3.5
eucine	12.4	11.1	12.5	9.9	11.8	11.1	10.1	9.5	8.9
Tyrosine	3.3	3.0	4.4	3.9	2.7	3.1	3.2	3.4	5.3
Phenylalanine	4.6	4.5	5.1	5.5	5.1	5.5	5.5	5.8	7.6

[a] Ion exchange chromatorgaphy.

[b] Values based on mean of 3 cultivars

[c] Source: Kent[1]

[d] Values based on mean of 5 cultivars

Table 7. Nitrogen distribution in protein fractions of sorghum, maize and millet grains[a]

Fraction	Sorghum[b]	Pearl millet[b]	Maize[c]	Finger millet[b]	Foxtail millet[b]	Proso millet[b]	Little millet[b]
	% of total nitrogen						
I (albumins and globulins)	16.1	23.6	12.4	17.3	10.8	9.0	10.2
II (prolamins)	14.2	29.4	32.1	7.2	18.7	1.8	6.9
III (cross-linked prolamins)	15.1	3.9	10.2	15.6	10.1	5.6	7.2
IV (glutelin-like)	4.2	5.0	12.4	7.5	4.4	2.4	2.3
V (glutelin)	40.4	17.4	27.4	17.1	20.8	53.6	49.6
VI (residue)	6.0	4.6	-	8.1	6.4	15.3	9.1

[a]Per cent of total nitrogen.

[b]Values based on mean of 2 cultivars

[c]In endosperm - Source: Misra et al[58]

Table 8. Dehulling quality of sorghum and pearl millet grains

Characters	Sorghum[a]			Pearl millet[b]		
	Range	Mean	SE ±	Range	Mean	SE ±
Grain mass ($g.1000^{-1}$)	19.6 - 59.8	29.0	1.60	6.63 - 13.61	9.4	0.52
Breaking strength (kg)	4.6 - 14.0	7.3	0.72	2.5 - 3.8	3.1	0.13
Endosperm recovery (%)	52.0 - 82.6	73.4	3.12	56.9 - 77.2	69.6	1.40
Brokens (% <20 mesh)	2.1 - 9.8	5.3	0.72	9.9 - 19.2	14.3	0.71

[a]Values based on mean of 11 cultivars;
[b]Values based on mean of 15 cultivars.

Dehulling was done by hand pounding using mortar and pestle.

Table 9. Comparative yield of various fractions of cereals and millets in mini grain mill

Cultivar	Bran (+16) (%)	Coarse semolina (-16+30) (%)	Fine semolina (-30+60) (%)	Flour (-60) (%)
Maize	8.1 (5.9)	24.2 (26.0)	33.0 (32.6)	34.7 (35.5)
Sorghum	11.4 (10.2)	21.0 (18.1)	32.5 (34.0)	35.1 (37.7)
Wheat	10.5 (6.7)	21.0 (24.1)	26.5 (25.0)	42.0 (44.2)
Bajra	12.4 (8.4)	14.4 (13.8)	30.2 (33.6)	43.0 (44.2)
Ragi	9.5 (7.1)		28.5 (29.3)	62.0 (63.0)

Figures in parentheses indicate yield of milled fractions without moist conditioning.

Source: Shankara et al[24]

Table 10. Characteristics of *roti* made from cereal flours

Crop	Water needed for making dough (ml.100 g^{-1})	Time of baking (sec)	Moisture in *Roti* after baking (%)	Chewing counts	
				Immediately after baking	2 h after baking
Maize	110	120	40.2	31	36
Sorghum	90	105	36.2	38	50
Pearl millet	85	105	32.2	37	40
Wheat	65	90	31.0	40	50

Source: Raghavendra Rao *et al*[41]

Table 11. Boiled sorghum and pearl millet (*soru*) quality

Characters	Sorghum[a]			Pearl millet[a]		
	Range	Mean	SE ±	Range	Mean	SE ±
Cooking time (min)[b]	33 - 42	38	0.7	19 - 24	22	1.0
Volume increase (%)	150 - 400	328	21.8	163 - 263	224	13.2
Weight increase (%)	124 - 186	162	5.7	118 - 194	164	6.4
Gruel solids (5)	-	-		7 - 9	8.4	0.70
Quality score[c]	1 - 4	2.3	0.21	1 - 4	2.3	0.41

[a]Values based on mean of 12 cultivars

[b]Time for cooking 5 g grains in 50 ml water

[c]Quality score 1 - poor; 4 - excellent

Table 12. Comparison of physicochemical characters of sorghum cultivars having poor and good *roti* qualities.

Cultivar	Grain color	Mean *roti* quality score[a]	WSFF[b] (mg/100g)	Water soluble protein in flour (%)	Total amylose in flour
Poor *roti* types					
PJ 16R	Creamy white	1.5	29.8	0.30	25.1
PJ 19R	White with brown spots	1.8	28.9	0.44	24.8
PJ 2K	White with red spots	1.9	33.9	0.34	27.1
Simila	Light brown	1.7	26.6	0.63	21.5
Manu Vani	White	1.9	35.0	0.62	22.2
Mean ± SE		1.8±0.06	30.8±1.41	0.47±0.06	24.1±0.91
Good *roti* types					
285	Creamy white	3.1	26.3	0.60	29.9
E 35-1	Creamy white	3.1	19.4	0.71	29.9
IS 12611	Dull white	3.3	24.7	0.58	28.8
Bodgawanda vani	White with brown spots	3.1	22.0	0.60	28.0
Vidisha 60 1	Dull white	3.0	29.2	0.85	28.2
M 35-1 (Check)	Creamy white	3.3	21.0	0.80	28.2
Mean ± SE		3.2±0.05	23.8±1.36	0.69±0.05	28.8±0.42

[a]Average evaluation scores of taste panel for color, appoearance, texture, taste, flavor, and acceptability, (Score 4 = good; 1 = poor)
[b]Water soluble flour fraction.

Table 13. Relationship (r) between *roti* sensory quality and physicochemical characteristics of pearl millet (n=20)

Factors	*Roti* quality				
	Color	Texture	Odor	Taste	Acceptability
Swelling capacity of flour					
V_f/V_i	0.91**	0.64**	0.83**	0.84**	0.81**
W_f/W_i	0.91**	0.58**	0.84**	0.85**	0.82**
WSFF[a]	-0.92**	-0.59**	-0.88**	-0.89**	-0.87**
Water soluble protein	0.69*	0.54*	0.68**	0.68**	0.67**
Amylose	-0.59**	-0.30	-0.64**	-0.62**	-0.61**
Fat	0.49*	0.58*	0.51*	0.56**	0.51*

*Significant at 5% level; **Significant at 1% level.

V_f, W_f: final volume and weight; V_i and W_i: initial volume and weight

[a]Water soluble flour fraction.

Table 14. Varietal differences in physical and organoleptic properties of sorghum muddhee (dumpling).

Dumpling quality[a]	Tackiness[b] With 2.5 parts water (g)	With 3.5 parts water (g)	GT (°C)	PV (BU)	Setback (BU)
Poor (4)[c]	248	279	71.4	320	628
Moderate (7)[c]	240	267	71.4	367	612
Good (4)[c]	194	241	76.1	212	365

[a]Poor: BP53, Patcha Jonna, Patancheru, P721
Moderate: GPR370, GPR148, CSH-8, M64-71, CSH-1, A-2283
Good: H2269, M3165, E-35-1, M-7777

[b]Tackiness is measured as the force required to relase a plate in contact with the dough measured.

[c]Figures in parenthesis represent the number of samples taken for tests.

BU = Brabender Units, PV = Peak Viscosity.

Source: Desikachar and Chandrasekhar[45].

Table 15. Simple correlation coefficients (r) among the starch characteristics and cooking quality of *soru* from sorghum and pearl millet[a]

Characteristics	Sorghum	Pearl millet
Soru		
Quality score - Swelling power at 60°C	0.67*	-
- Swelling power at 70°C	-	-0.83**
- Starch damage	-	-0.61*
- Gruel solids	-0.65*	-0.57*

[a]Values based on 11 cultivars of sorghum and 12 cultivars of pearl millet

*Singificant at 5% level; **Significant at 1% level.