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Sorghum Utilization as Food

Ratnavathi CV* and Patil JV

Directorate of Sorghum Research, (Formerly National Research Centre for Sorghum), Rajendranagar, Hyderabad-500 030, Andhra Pradesh, India

Abstract

Sorghum is an important crop for food and fodder in the semi-arid tropics of the world. Sorghum is a staple food in African and Asian subcontinents. Most of the grain produced in these countries is utilised for human consumption. Though sorghum is known for its nutritional quality, the consumption of this cereal is decreasing due to easy availability of rice and wheat through public distribution system and easy methods of processing and cooking of fine cereals (such as rice). The various foods that are made in different parts of the world especially in Indian and African sub continent are described in this review. The objective of this review is to explore the global utilization of sorghum as a food.

The requirement of special skill in preparing sorghum *roti*s and non-availability of ready-made sorghum flour and suji in the market are deterrents for wider use of sorghum as food. The grain sorghum is utilised in preparation of many traditional foods and in bakery preparations like bread, cakes and biscuits. Dough prepared with cold water has poor adhesiveness and is difficult to roll thin. Higher water uptake, low gelatinization temperature, high peak paste viscosity and high setback are the starch properties that have been shown to be associated with good quality of *roti*, the unleavened bread that is the most common form in which sorghum consumed on the Indian subcontinent. Technologies for production of shelf-stable refined flour, grits and semolina from sorghum and millet have been developed and laboratory studies have demonstrated their successful utilization and incorporation into various traditional foods (idli, dosa, chakli, papad, etc.) and newer convenience health products (vermicelli, noodles, plain and ready-to-eat flakes, extruded products, weaning and supplementary foods, and bakery products). Efforts are being made for popularization and wider adoption of the successful technologies to promote sorghum for diversification of their utilization among the non-traditional urban population.

Keywords: Sorghum; Food; Nutrition; Traditional; Semiprocessed; Flakes

Introduction

Sorghum is a staple food in African and Asian subcontinents. Most of the grain produced in these countries is utilised for human consumption. The grain sorghum is utilised in preparation of many traditional foods and in bakery preparations like bread, cakes and biscuits. Sorghum is an important crop for food and fodder in the semi-arid tropical India. It is mainly grown in *kharif* (rainy) and *rabi* (post-rainy) seasons. Sorghum is a staple food in the states of Maharashtra and parts of Karnataka, Madhya Pradesh, Tamilnadu, Gujarat and Andhra Pradesh. Though sorghum is known for its nutritional quality (Table 1), the consumption of this cereal is decreasing due to easy availability of rice and wheat through public distribution system and easy methods of processing and cooking of fine cereals (such as rice). The requirement of special skill in preparing sorghum *rotis* and non-availability of ready-made sorghum flour and *suji* in the market are deterrents for wider use of sorghum as food. On the other hand, the sorghum that is harvested in the post-rainy season is of superior quality and used only for food. At present most of the sorghum produced in India is consumed in the form of *roti* or *chapatti* (unleavened flat bread). Kharif sorghum grain can be polished with pearling machine and used for other food products like snack foods and baked foods.

Nutritional Value of Sorghum

The proximate composition and nutritional aspects of grain sorghum have been extensively reviewed by Hulse et al. [1] Subramanian and Jambunathan [2]. They found that grain sorghum protein varies from 4.4 to 21.1% with a mean value of 11.4%. Sorghum grain is known for its hardness compared to other food grains. The hardness of the grain is due to higher content of protein prolamin. Prolamin content varies from 3.6 to 5.1%. The Lysine content ranges from 1.06 to 3.64%. The

Constituent	Range
Protein (%)	4.40 - 21.10
Water Soluble Protein (%)	0.30 – 0.90
Lysine (%)	1.06 – 3.64
Starch (%)	55.60 – 75.20
Amylose (%)	21.20 – 30.20
Soluble Sugars (%)	0.70 – 4.20
Reducing Sugars (%)	0.05 – 0.53
Crude Fibre (%)	1.00 – 3.40
Fat (%)	2.10 – 7.60
Ash (%)	1.30 – 3.30
Minerals (mg/100g):	
a. Calcium	11.00 – 586.00
b. Phosphorous	167.00 – 751.00
c. Iron	0.90 – 20.0
Vitamins (mg/100g):	
Thaimine	0.24 – 0.54
Naicin	2.90 – 6.40
Riboflavin	0.10 – 0.20
Anti-nutritional factors:	
Tannin (%)	0.1 – 7.22
Phytic acid (mg/100g) as Phytin Phosphate	875 - 2211.9

Source : Hulse et al., (1980); Subramanian and Jambunathan (1984), Makokha et al, 2002

Table 1: Nutrient Composition of Sorghum Grain.

***Corresponding authors:** Ratnavathi CV, Directorate of Sorghum Research, (Formerly National Research Centre for Sorghum), Rajendranagar, Hyderabad-500 030, Andhra Pradesh, India, Tel: +91 40 24015349; Fax: +91 40 24016378; E-mail: ratnavathi@sorghum.res.in

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protein fractionation studies in sorghum indicated that the distribution of albumin-globulin, prolamin and glutelin is about 15, 26 and 44% respectively of total nitrogen. Starch is the major constituent of grain accounting for 56-75% of the total dry matter in the grain. The total content of soluble sugars of sorghum grain ranged from 0.7 to 4.2% and the reducing sugars from 0.05 to 0.53%. Fat content in sorghum grain varies from 2.1 to 7.6%, crude fibre from 1.0 to 3.4% and ash from 1.3 to 3.3%. Another study on the physic chemical characterization of sorghum accessions showed a wide variation in protein (7.99 to 17.8%), lipids (2.52 to 4.76%), starch (51.88 to 85%), and amylose (12.30 to 28.38%) content. Linoleic acid (18:2) and oleic acid (18:1) were the major fatty acid constituents of sorghum lipids [3]. The wide range in composition of mineral and trace elements indicated that sorghum is a good source of minerals. The mineral composition however is influenced by the environmental conditions [4].

Anti-nutritional Factors and Mycotoxins in Sorghum

The anti-nutritional factors present in sorghum grain are polyphenols and phytic acid. Polyphenols are the secondary metabolites produced and they inhibit the digestibility of proteins as they bind the proteins present in grain and make them unavailable for the intestinal absorption. Sorghum grain contains polyphenols and phenolic acids which are generally associated with grain pigmentation. Polyphenols (tannins) also interfere with bio-availability of other major nutrients [6]. The tannin content of the grain ranges from 0.10 to 7.22%. In white sorghum, flavan 3-ols or flavan 4-ols (monomers of polyphenols) are present in very low quantity. Apart from flavan 4-ols, phytic acid is also present in sorghum in the form of 6-inositol phosphate. Phytic acid usually forms insoluble compounds with minerals like calcium, iron, magnesium and zinc thus making them unavailable. In sorghum, as in other cereals and oil seeds, phytic acid is the major storage from of phosphorous. Phytic acid ranged from 875.1 to 2211.9 mg/100 g in sorghum. The important nutritional implication of phytic acid is that it chelates di and trivalent cations particularly Fe, Ca, Na, Mg and Zn and decreases their bioavailability. Phytic acid forms insoluble compounds with mineral elements including Ca, Fe, Mg and S. Fermentation resulted in a mean decrease of phytic acid of 64.8% after 96 hours and 39.0% after 72 hours in sorghum grain. Malting also resulted in a mean decrease of 23.9 and 45.3% after 72 and 96 hours, respectively [5]. Phytic acid occurs primarily in the seed coats (brain) and germ of plant seeds. Genetic variation for low phytic acid is available in rice mutants [7].

Presently the new research investigations on polyphenols and phytic acid consider these compounds as health factors and consumption of these factors increases immunity in animal and human systems against several diseases. Sorghum along with six other millets was screened for their free radical quenching of 1, 1, Diphenyl-2-picrylhydrazyl (DPPH). Methanol extracts of the millet flours showed 15-70% DPPH quenching. The white varieties of sorghum (great millet), ragi (finger millet) and foxtail millet showed lower quenching than their coloured counterparts, indicating that phenolics in the seed coat could be responsible for the antioxidant activities [8]. Due to grain mould the kharif grain gets severely affected by *Fusarium* and *Aspergillus* fungi which produce harmful toxins. These mycotoxins namely aflatoxins and fumonisins cause deleterious effects to human and animal health. Hence the grain that is used for food preparation and consumption should be free of these toxins. However these toxins have a safety limit beyond which they cause ill health. The safety limit for aflatoxins is 20 ppb and for fumonisins it is 200 ppb as per the CODEX committee. Aflatoxin contamination was relatively less compared to Fumonisin contamination in sorghum.

Sorghum Food Quality

Starch quality

The average starch content in sorghum varies from 56-73 percent of which 70-80 % is amylopectin and the remaining 20-30 percent is amylose. Waxy sorghums or glutenous sorghum varieties contain very low or no amylose and the starch is 100 % amylopectin [9]. In sugary sorghums, the amylose content of starch is about 5-15% higher than in normal sorghums and they contain exceptionally high levels of water soluble polysaccharides i.e. 29.1% [10]. The digestibility of isolated starch of sorghum cultivars ranged from 33 to 48 percent as against 53 to 58 percent for corn starches [11]. The grain endosperm texture, the particle size of the flour and starch digestibility was found to be strongly correlated with each other. Starch in floury sorghum was found to be more digestible than that in corneous sorghum. Particles of ground floury sorghum were smaller than those of similarly ground corneous sorghum. Pedersen and Kofoid [12] found significant variation in sorghum for IVDMD, chemical and physical grain quality parameters. They also reported that digestibility was correlated with crude protein and grain hardness. Hicks et al. [13] found crude protein has correlated to seed weight and IVDMD to fat content of seed in sorghum. The smaller particle size and correspondingly greater surface area facilitate the enzyme action and thus improve starch digestibility. The starch digestibility was reported to be higher in low-amylose, i.e. waxy sorghum than in normal sorghum, corn and pearl millet grains [14]. Feeding trials in rats [15] and other animal species [16,17] have confirmed the superiority of waxy sorghum over normal grain types in terms of dry matter and gross energy digestibility. Groth et al. [18] developed high starch digestible lines by mutagenesis in maize. The gelatinization temperature of isolated sorghum starch and that of finely ground flour of the corresponding endosperm has been reported to be the same. On the other hand the pasting temperature, i.e. the temperature at which starch *atta*ins peak viscosity when heated with water to form a paste, was found to be about 10°C higher for the sorghum flour than for the isolated starch.

The quality of cooked sorghum has been strongly associated with the total and soluble amylose content of the grain and also the soluble protein content [19]. The swelling power of starch and its solubility significantly influenced the cooking quality of sorghum [20]. Plasticity of sorghum flour dough mostly arises from the gelatinization of starch when the dough is prepared in hot or boiling water. The stickiness of the cooked flour is a function of the starch gelatinization. Porridge prepared from hard endosperm of sorghum is less sticky than that prepared from grains with a larger proportion of floury endosperm [21].

Dough prepared with cold water has poor adhesiveness and is difficult to roll thin. Thus heat modification of the starch when the dough is prepared with hot water determines its rolling properties [22]. Higher water uptake, low gelatinization temperature, high peak paste viscosity and high setback are the starch properties that have been shown to be associated with good quality of *roti*, the unleavened bread that is the most common form in which sorghum and pearl millet are consumed in the Indian subcontinent On the other hand, for stiff porridges such as Indian mudde or sankhati and African tô, the desirable characteristics of the grain starch are high gelatinization temperature, low peak paste viscosity and low retro-gradation tendency. Thus sorghum genotype that is not suitable for *roti* may be suitable for porridge.

Protein quality

The second major component of sorghum and millet grains is protein. In sorghum the variability is large, probably because the crop is grown under diverse agroclimatic conditions which affect the grain composition [23]. The quality of a protein depends primarily on its essential amino acid composition. Lysine is the limiting essential amino acid in sorghum. Grain proteins are broadly classified into four fractions according to their solubility characteristics: albumin (water soluble), globulin (soluble in dilute salt solution), prolamin (soluble in alcohol) and glutelin (extractable in dilute alkali or acid solutions). Grain sorghum proteins consist of albumin and globulin together (15%), prolamin (26%) and glutelin (44%). The amounts of the cross-linked prolamin, ß-prolamin were higher in sorghum compared to albumin and globulin fractions. The prolamin fraction was extremely poor in lysine, arginine, histidine and tryptophan and contained high amounts of proline, glutamic acid and leucine.

Both in vitro and in vivo studies have demonstrated wide variability in protein digestibility of sorghum varieties [24]. Values ranging from 49.5 to 70 percent [25] and from 30 to 70 percent [26] have been reported. The protein digestibility in Indian sorghum genotypes varied from 39-72% [27]. The protein digestibility of sorghum grain was thus found to be extremely poor as compared to that previously observed for wheat (81 percent), maize (73 percent) and rice (66 percent). Contrary to this, digestibility of protein in decorticated and extruded sorghum product [28] is 81 percent, which was much higher than for the whole grain (46 %).

Semi - Processed Products of Sorghum

The traditionally consumed foods of sorghum in India were discussed earlier. Absence of appropriate primary processing technologies to yield shelf-stable flour/products has been the major limiting factor in their utilization for diversified food uses and development of value-added products. Some recent works have shown this possibility. Technologies for production of shelf-stable refined flour, grits and semolina from sorghum and millet have been developed and laboratory studies have demonstrated their successful utilization and incorporation into various traditional foods (idli, dosa, chakli, papad, etc.) and newer convenience health products (vermicelli, noodles, plain and ready-to-eat flakes, extruded products, weaning and supplementary foods, and bakery products). Efforts are needed for popularization and wider adoption of the successful technologies to promote these grains for diversification of their utilization among the non-traditional urban population [29].

However, sorghum can be replaced with rice or wheat in many household food dishes that are commonly made. Sorghum grains are polished with a pearling machine and processed in to flour as well as semolina (*suji*) of different particle size (coarse *rawa,* medium *rawa* and fine *rawa)*. Pearling/polishing reduces the coarseness of the product and also removes the bitterness that is associated with the pericarp of the grain. Sorghum does not have gluten and therefore becomes a very good ideal gluten free energy source for the people suffering from wheat or gluten allergies.

The milled products that are commonly made from wheat can be made from sorghum also. *Rawa* types of different particle sizes (coarse *rawa*, medium *rawa* and fine *rawa*) can be prepared to suit the special food product that is made. For preparation of bakery products, sorghum grain has to be polished and made into very fine flour. Recovery of the different grades of *rawa* was compared among elite genotypes of sorghum and cultivars with corneous endosperm are more suitable for semolina/*rawa* processing. The recovery of *rawa* (coarse one) would be 60-70% where as medium one would be approximately 40-45%. However the quality of *rawa* made from corneous grain of sorghum would be hard in texture unlike wheat *rawa*. The cooking quality of sorghum *rawa* is very much different from that of wheat *rawa*. Unlike wheat *rawa* sorghum *rawa* becomes harder after roasting before it is processed into a food product [27].

With regard to shelf- life of these products, coarse *rawa* has a good shelf-life up to 45 days (6 weeks). The medium and fine *rawa* were having shelf life for a period of 30 days when tightly packed in polythene bags. These *rawa*s have a shelf life for a week when kept open in polythene bags without sealing. A study on the percent recovery of these products was compared in 20 elite genotypes. Among released genotypes, C-43, CSV 14R, CSV 216 R, M 35-1 were having percent recovery as 48%. Among advanced rabi hybrids, SPH 1581, SPH 1582, SPV 1709, SPV 1758, SPV 1760, SPV 1762 and SPV 1768 were having recovery of 49%. These products were also tested for their suitability to make different sweet recipes like kesari, laddu and appam etc.

Some of the processed products like parboiled *rawa*, flakes, extruded products, and pops were also prepared from sorghum at laboratory scale at NRCS. Further, the commercial production and suitability of wheat or rice machinery for production of these products from sorghum are being studied.

Traditional foods in India

The various traditional food preparations in India encompass the following:

1. *Roti*
2. *Annam*
3. *Sankati*
4. *Kanji*

Roti

The most preferred form of sorghum used traditionally is *roti* or *bhakri* (unleavened pan cake). *Roti* is consumed along with different kinds of dishes depending on the socio economic status of the consumer [2]. The consumption of sorghum *roti* is a traditional practice in Maharashtra, Karnataka and Andhra Pradesh. There is a decline in the consumption pattern of sorghum mainly due to the urbanization and easy availability of fine cereals like rice through public distribution system. Further special skill is required to make sorghum *roti*.

But recently (for the past 1-2 years), there is a growing awareness among the urban population that sorghum is a health food for diabetics. This is due to the higher dietary fibre and prolonged release of energy leading to a low pressure on insulin. There is an increase in the consumption of sorghum and now sorghum *roti* has become popular health food in Andhra Pradesh. The consumption of sorghum as a staple diet in Africa proven that the risk of cancer and arthritis are very low among the African population (Tariq M. Sawandi) and the presence of nitrilosides in sorghum is the basis for this. The flour from sorghum is gluten free and therefore is a safe energy source for people allergic to gluten.

Sorghum flour can be made using a grinding mill and sieving the flour to make it fine and used in *roti* making. Since sorghum does not contain gluten and the dough does not have stickiness, it is difficult to roll with the chapatti roller. Rolling *roti* with sorghum dough needs special skill. Traditionally it is done by hand tapping on a flat stone. The *roti* rolling is not only time consuming, but the *roti*s will also be thick and unpalatable for some.

To overcome this, a machine is developed to facilitate rolling wet *roti*s on a commercial scale. The electric machine consists of a revolving rotary circular flat plate with an upper rolling pin. A foot operated lever applies pressure gradually on the rotating dough, flattening it uniformly. A thin *roti* is formed between two plastic sheets which is removed carefully and baked on a hot pan. Using this machine, 40-45 *roti*s can be made in one hour. Thirty thin *roti*s each weighing 25-30 gm can be made per Kg. flour using the machine. Polishing of the grains in a pearling machine prior to milling will remove the bitterness associated with pericarp and reduces insoluble fibre and thereby increases digestibility. However the shelf life of the polished grains is lower than that of whole grain [30].

A comparison of four independent studies made on the dough and *roti* quality analysis of sorghum genotypes was done using M 35-1 as control. For the preparation of *roti*, the quality of the dough is very important. The dough quality is assessed by following parameters: a) water requirement, b) kneading quality c) time required for baking, d) rolling quality (diameter of the *roti* that is expanded with an equal amount of flour), e) diameter of the *roti* after baking and f) percent moisture retained in the *roti*. The kneading quality was scored in a scale of 1-3 (1= poor, 2= medium to good and 3= very good). *Roti* quality was assessed for the taste and sensory properties which were measured on a hedonic scale. The properties used for sensory evaluation were a) *roti* colour and appearance, b) *roti* texture, c) *roti* flavour, d) grade and e) acceptability of the *roti*. This comparative study based on four independent analyses showed that more than 20 improved breeding lines out of 77 genotypes (genotypes pooled from elite breeding lines and also released genotypes) tested were superior to M 35-1 for *roti* quality [30].

Annam

In India, particularly in southern regions, boiled sorghum (rice-like) called *annam* or *soru* is one of the common items cooked, and it accounts for about 10% of the total sorghum grain produced. The freshly made product is consumed with *dhal, sambar,* buttermilk with pickles, or onion and green chillies for lunch or supper. Sometimes, it is stored overnight by adding water and consumed the next morning with buttermilk.

Sorghum is traditionally used as boiled sorghum after dehulling the grains. The dehulled grain is cooked in water in the proportion of 1:3. Sometimes the grains are also soaked overnight in water and cooked next day morning. The cooking is preferably done in an earthen pot, which is heated using firewood. The grains are cooked to softness and the excess water is drained off. The cooked product has to be fluffy, uniform yellow or creamy white in colour with a sweet taste.

Sankati

Sorghum *sankati* is a type of thick porridge consumed in South India. It is called by different names in various regional languages, e.g., *mudda* (Telugu), *mudde* (Kannada), and *kali* (Tamil). Sorghum *sankati* is consumed in the Rayalaseema tracts of Andhra Pradesh, the southern tracts of Karnataka, and all over Tamil Nadu. About 60-70% of sorghum consumed is eaten in the form of *sankati* in Tamilnadu., 50% in Andhra Pradesh and 30% in Karnataka. It is usually consumed with a range of side dishes such as *sauce, dhal* from *pulses, pickles, chutneys, buttermilk,* curd *curries,* etc.

Sorghum grits/flour and water in a ratio of 1:3 are used for preparing *sankati*. Water is allowed to boil in a vessel and grits are added to boiling water coupled with stirring. After 10 min, fines are added followed by stirring and this is continued for 3 min. The vessel is removed from fire and poured on to a moist plate and made into balls of 10 cm diameter by hand. *Sankati* is eaten fresh or stored overnight in water or buttermilk.

Kanji

Kanji is a thin porridge, mostly consumed in the southern parts of India, Africa and Central America. However, the local names are different. This is also called as *ambali* and is prepared from flour. Ambali is consumed after fermentation [29].

Upma

Upma is a very important South Indian breakfast food or snack food item that can be prepared in a very short time. This is usually prepared with wheat or rice semolina. Semolina should not contain flour and it can be either coarse or be fine like wheat semolina. This is usually eaten hot with either sauce or chutney made with coconut and chana dal (chick pea) or groundnut. *Upma* is made with semolina that is prepared with polished sorghum grain. A little oil is taken on a sauce pan and seasoning is done with grains like chick pea and black gram along with mustard and cumin seeds. Also curry leaves and green chillies are added for taste. Then water is added (one and half times to the quantity of semolina) and allowed to boil before the addition of semolina. Then it is cooked under reduced heat till it becomes solid.

Dosa and *Idli* are fermented breakfast foods mainly consumed in South India. *Idli* is made in moulds and a steam cooked food while *dosa* is a thin oily pan cake made with black gram dal and rice. However in place of rice, sorghum grain can be used.

Sweets that are prepared commonly from wheat semolina can also be prepared from sorghum semolina. *Rawa* laddu, *rawa* kesari and appam are the sweet dishes that can be prepared from sorghum. *Rawa laddu* is prepared with roasted semolina, sugar and ghee. Nuts and grated and de-oiled coconut are added for taste. This mixture is made into *laddus* with ghee and milk. *Rawa* kesari is prepared by cooking roasted semolina and sugar with little ghee and nuts. *Appam* is made by making small portions of kesari into round and thin shaped biscuit like products and are fried in oil.

Snack foods like *muruku, chakkalu* and *namak* para can be made from sorghum flour by blending with chick pea flour. These are fried items containing high amount of fat. However, they have commercial value and potential to compete with other snack foods made from rice and wheat.

Foods in Africa

The various food preparations of sorghum in various parts of Africa include a) *To* b) *Bogobe* c) *Ugali,* d) *Ogi* e) *Injera* f) *Kisra* g) *Tortilla* and h) *Couscous.*

To is a staple food in most parts of Africa, south of the Sahara. The decorticated grain is ground into flour by additional hand pounding in the mortar with a pestle. The flour is cooked in water that is acidified by adding extracts of tamarind or juices of lemons. The flour to water ratio varies but is usually about 1:4. The *to* is allowed to cool for about 1 hr after cooking before it is consumed with a sauce composed of numerous ingredients including *tomatoes, okra or chillies, cow pea leaves, cow peas* and *Amaranthus* [31].

Bogobe of sorghum is consumed as porridge with vegetables or meat, usually made either fermented or unfermented. Fermented *bogobe*, a soft porridge is known as *motogo wa ting* or *ting* fermented for 24 hrs. This fermented porridge requires a starter that is made by fermenting a small quantity of sorghum meal in water for 48 hr. A firm non-fermented *bogobe* is called *mosokwane*. Ting is usually eaten in the evening and morning and *mosokwane* eaten for lunch. A variation of *mosokwane* exists in which a small amount of wheat flour and sugar is added to sorghum meal before boiling into porridge. This porridge is called *mageu*. It is prepared by mixing meal and boiling water, stirring it frequently and cooking it for 20-30 min [32].

Ugali is a cooked stiff porridge usually made with white seeded, highly corneous grains of sorghum. In Uganda, Rwanda, and parts of Western Tanzania, the brown-seeded high tannin sorghum grain types are most common and are used for *ugali* preparation [33].

Ogi is the most common thick porridge eaten by Nigerians from the coast to the extreme northern boundaries of the country. The flour from dehulled or whole sorghum is mixed with water and cooked into a thick stiff porridge that is eaten with a soup (sauce) composed of vegetables, meat and other items depending upon the availability of the ingredients. *Tuwo* is usually a thin porridge, processed from dry-milled non fermented whole grain flour [34].

Injera is a leavened, flat and round, Ethiopian traditional bread made from cereals. The best quality sorghum *injera* is made from the dehulled grain. For injera preparation well kneaded dough is fermented for 48 hrs. and baked for 2-3 min. The dough is made with boiling water [35].

Kisra is a thin pan cake like leavened bread made from whole sorghum flour and it is a staple diet in Sudan. A thick paste, *ajin*, is prepared by mixing on an air-dry basis, 60% flour and 40% water [36]. The *ajin* is left to stand fermenting for approx. 12-24 hr, by which time it develops a sour taste. The batter is spread on a greased tawa like the south Indian dish, dosa [37].

Tortillas made from mixtures of maize and sorghum are considered to be the most promising form in which sorghum will be accepted in the Mexican diet. Sorghum performs very similar to maize during lime cooking (treatment of grains with calcium oxide), also called nixtamalization, both with reference to the rheological properties of the dough and the quality of the *tortilla*. The darker colour produced by the tannins and phenols is frequently present in sorghum *tortilla*. After lime treatment, the wet kernels are ground very fine into dough (masa). Using a round press with a diameter of 15cm, place about 30g dough in the shape of a round ball in the middle of the press between two pieces of nylon plastic and press very gently to form the round *tortilla*. Then the *tortilla* is baked like the traditional *roti* on a heated pan for complete cooking [38].

Couscous is a steamed granulated product made from cereal flour; in Sahel it is exclusively prepared from sorghum. It can be steamed, sun dried, stored indefinitely, and is reconstituted in milk, or again steamed and served with a sauce. The flour with 1 mm particle size, made from whole or dehulled grains is wetted with cool water and agglomerated into small particles with the fingers. Those flour aggregates are forced through a sieve with 1.5 mm mesh openings. The wet aggregates are steamed in a covered perforated pot, which is placed directly over another pot containing boiling water. The juncture between the two pots is sealed with a damp cloth to force the steam through the perforations and into the flour aggregates. The wet cloth is wiped with okra powder to assure a tight seal. After about 15 min steaming, the aggregates form a large single chunk, which is taken out of the bowl, broken up into aggregates and again steamed for an additional 15 min. The aggregates are again broken up into singular units and sifted through a 2.5mm sieve. At that point, the steamed aggregates can be dried and stored for future use. If couscous is to be consumed immediately, the aggregates are sprinkled with cool water and mixed thoroughly with the fingers. *Baobab (Adansonia digitata)* leaf powder is mixed with the particles. This powder serves as a lubricant, which prevents desiccation and stickiness, and improves palatability. Okra powder can be used as substitute for this. After mixing, the aggregates are again placed in the perforated bowl and steamed for about 15 min. The couscous is allowed to cool slowly and then served with sauce [39].

Bakery Products

Substitution of wheat with local cereals like maize and sorghum in biscuit production was studied to improve the nutritional quality of biscuits. At NRCS, efforts were made to prepare common bakery products like bread, cakes and biscuits. Fine sorghum flour made out of kharif grain (pearled) equal to the consistency of *maida* (refined wheat flour) is used in combination with *Maida* for the preparation of various bakery products like bread (whole sorghum), mixed bread (bread made from sorghum, ragi and bajra in 2:1:1 ratio), plum cake and biscuits. The method of preparation of these products is just similar to that of the one used for wheat flour [40].

Bread

Bread can be made with sorghum flour by blending with maida up to 40-60%. Bread can be made using the modified starches like carboxymethyl. Very fine flour of sorghum mixed with salt, sugar, fat and bread improvers and is made into dough. Baker's yeast is added to the dough and allowed for fermentation for longer period compared to the normal wheat bread and after the fermentation the dough is ready for baking. The dough is then kept in the mould and baked for one hour. To improve the leavening and softness comparable to wheat bread, more yeast and external gluten are added. 30- 40% of maida along with sorghum may result in a tasty product. Studies on the shelf life are very important, as it is a key factor that is directly related to economy of bakery industry. Bread can be made using the modified starches like carboxy methyl starch. The shelf life varies from 24 to 72 hrs (Figure 1).

Bread made with a composite flour containing sorghum is nutritionally valuable. However, sorghum alone lacks the functional proteins for bread making. Carson and Sun [41] investigated the rheological properties and bread baking potential of a sorghum-based composite flour system containing various amounts of vital wheat gluten (exogenous gluten protein). Mixograph and Kieffer test results showed that exogenous gluten protein significantly enhanced the composite dough's strength. At fixed gluten protein levels, as sorghum flour increased, water absorption decreased slightly, dough strength and extensibility decreased, and mixing time increased significantly. Exogenous gluten proteins when added in the form of vital wheat

Figure 1: Bread.

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gluten into the composite flour without wheat flour could not form an appropriate gluten network for bread making. The interaction between exogenous and endogenous proteins in wheat flour and in the composite flour contributed greatly to the rheological properties of the sorghum composite dough and bread volume.

Organoleptic tests of the composite bread showed that 70% of the taste panelists rated the overall quality of 70 (wheat): 30 (sorghum) composite bread as good. Proximate composition of the composite bread showed that it contained much lower protein, and higher crude fibre contents than 100% wheat bread. The shelf life of composite bread at room temperature was lower than that of 100% wheat bread. It was found that addition of 2-4% pentosans to composite flour (up to 50% substitution level) improved the quality of the bread. Pre fermentation of the sorghum flour up to 20 hours was found to have positive effects on the baking quality of the wheat and sorghum composite flour. Experience showed that composite flour required additional quantities of sugar, yeast, and water than 100% wheat, to make the bread tasty. Baking of composite dough required higher temperatures and the texture of composite bread was less acceptable. One of the major problems facing bakers is the smaller volume of composite bread as compared to 100% wheat bread from similar quantities of composite flours and wheat flours.

Cake

Preparation of cakes is similar to that of cakes prepared from wheat maida. Fine sorghum grain flour is used for the preparation of cakes. Sorghum flour is comparatively superior to the wheat flour for cake preparation. Fine sorghum grain flour is mixed with required quantities of sugar, egg, emulsifiers and fat. The dough is made little soft and nuts are decorated on the top and kept in oven for baking after keeping the dough in a mould (Figure 2).

Biscuits

Biscuits are prepared from fine sorghum flour in combination with maida to an extent of 15%. Biscuits are prepared as follows. Sorghum flour is mixed with *maida*, vegetable fat, sugar, baking powder (15%) and essences required. The mixed dough is then compressed in a mould and baked at the required temperature. Studies on the parameters like compressibility, breaking strength etc. showed that sorghum biscuits are having lesser breaking strength. Biscuits are good in taste and taste panel acceptability score is high for cakes and biscuits at NRCS, pilot studies are in progress in collaboration with a food Industry in Hyderabad. It is possible to produce biscuits of acceptable quality using 50:50 wheat and sorghum composite flour (Figure 3).

Substitution of 25% of wheat flour with sorghum flour in production of short and hard dough biscuits and wafers was cost effective without affecting quality, breakages, and plant efficiency. It was suggested that improved milling techniques to produce sorghum flour with particle size comparable to that of wheat flour can increase the possibility of higher substitution [42]. The special taste property of sorghum bakery products is its non-stickiness to the mouth. Sorghum-soy flour blends recorded the highest peak viscosities compared to other blends. Each flour blend showed a decline in its cooking properties, as the level of soy was increased from 20 to 30% while the biscuits from sorghum-soy blends were brown in colour with a slight spread [43].

Figure 2: Cake.

Noodles and pasta

Noodles of acceptable quality could be made from hard endosperm sorghums while pasta could be made from sorghum and wheat composite flours. Sorghums with soft texture, yellow endosperm, and white pericarpand without pigmented testa produce best pasta products [44]. The technology for making noodles and pasta from sorghum makes the product cheaper and healthier as sorghum products are known for high B vitamin and dietary fibre.

Extruded products

Extruded products are very important nutritional snack food items which have a very high commercial value. The extrusion properties of sorghum are excellent and equal to maize and rice. Though the machinery and other infra structure costs are very high, the major advantage of extruded products is the larger output of the final product from the raw flour. Low amylose content yielded brittle extruded products and digestibility of extruded products for high amylopectin starch increased [45]. High amylopectin (Waxy) lines are suitable for production snacks, dry breakfast cereals and beverages [46] (Figure 4).

Nutritional enrichment of sorghum with other cereal/pulse grain

Since the need for nutritive food at low cost is in demand, and majority of the population cannot afford to buy variety of food grains

Figure 3: Biscuits.

Figure 4: Extruded products made from sorghum.

	Sweet sorghum syrup	Honey
Calorific value, Cal/g	2.60	3.26
Total soluble solids, % wt	77.00	81.00
Proteins (N X 6.25), % wt	1.65	-
Ash, % wt	3.69	0.59
mg/100 g		
Calcium	160.00	5.00
Phosphorous	11.00	4.10
Riboflavin (Vitamin B2)	10.00	0.06
Vitamin C	11.50	5.00
Nicotinic acid	153.00	32.00
Iron	0.86	0.59
Sodium	86.00	4.70
Potassium	1810.00	90.00
Sulphur	Not detected	8.00
Benzoic acid	Not detected	
Added colouring matter	None	
Pesticide residues	Not detected	

Source: Final report, NATP RNPS 24 project

Table 2: Chemical composition of sweet sorghum syrup compared with honey.

S.No	Genotype	Polyphenol (mg/100g)	Iron (mg/100g)	Calcium (mg/100g)	Phosphorous (mg/100g)
1	RSSV 9	157.9	18.3	18.60	159.4
2	RSSV 47	153.6	15.6	16.77	148.1
3	NSSH 104	175.4	17.0	16.86	114.4
4	Wray	146.6	14.9	17.70	137.3
5	Kellar	163.3	18.1	18.17	160.1
6	SSV 84	192.4	17.0	18.93	115.6

Table 3: Chemical Composition of Syrup in different Genotypes.

for their bread and *roti* preparation, there is a great necessity to make a readymade *atta* with all the possible ingredients in a desired combination. The concept of multi-grain flour is ideal not only for nutritional and cost benefits but also to improve the texture and shelf-life of the flour. At NRCS, efforts were made to make composite flour with sorghum, wheat, maize, ragi (finger millet), bajra (pearl millet) and soybean keeping up to 50-60% sorghum. The kneading quality of the composite flour was very good. Also the *roti* made of the composite flours was very soft and good in taste. The dough has good viscosity and the mean diameter of the *roti* made from composite flours was 24.2 cm as compared to that from sorghum grain flour which was 22.4 cm. The composite flour is ideal for making *roti*s using big *roti* machines. It is also ideal for making different snack foods that are usually made with rice and wheat and for children with malnutrition. It is also ideal to be included in the mid day meal programme (free lunch supply programme of state government for school children) as the school children need complete balanced diet.

Natural Syrup from sweet sorghum juice

The juicy stalk of sweet sorghum, which is similar to sugarcane, can be utilised for preparation of syrup and jaggery. Cultivation of sweet sorghum is economical in rainfed areas where growing sugarcane is not economical. Sweet sorghum has the ability to yield 40-45 t/ha green cane and 1-1.5 t/ha of grain and an average brix of 18.4%. It consistently produces a minimum of 12% sucrose and alteast 15% total fermentables, at 50-60% recovery.

A protocol was developed for the production of natural, chemical-free, quality syrup from the juice of sweet sorghum hybrid "Madhura". A bottling machine has been used successfully to package the syrup so that its shelf-life is increased. The nutritional quality of syrup was also found to be excellent. Extensive screening of a large number of sweet sorghum genotypes showed that the entries RSSV-9, RSSV-24, RSSV-45, NSS-221, NSS-104 and SSV-84 gave good quality syrup. Also the hybrids developed at NARI such as Madhura, NARI-SSH-3, NARI-SSH-15, NARI-SSH-40 and NARI-SSH-21 produced good quality syrup [47].

The concentrated and sterilized juice to make natural syrup can be used in the dairy and confectionery industry for its use as a sweetener. This syrup can be used in place of honey and can be served also along with breakfast foods. This syrup in the name of "sorghum honey" has the immediate marketability potential. The chemical composition of sweet sorghum syrup is similar to honey (Table 2). Natural syrup obtained from sweet sorghum juice is rich in minerals like Iron, Calcium and Zinc with a recovery of 35%. The syrup of six promising genotypes were analysed for polyphenols, calcium, iron and phosphorus (Table 3). Lowest polyphenol content was recorded in Wray. RSSV 9 recorded highest iron content, calcium content was reported to be highest in SSV 84. RSSV 9 and Keller also recorded highest phosphorus content.

Conclusion

This review describes the utilization of sorghum as a food in different countries, India and Africa and its nutritional value and health benefits obtained from sorghum. The various foods prepared from sorghum are given in the review. The nutritional enhancement of the sorghum with other cereals also is given. Preparation of sweet sorghum syrup and its nutritive value is explained.

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