NUTRITION, FOOD QUALITY AND ALTERNATE USES OF SORGHUM

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Nutrition, Food Quality and Alternate uses of Sorghum[1]

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Sorghum is grown in India and Africa primarily for human consumption and is the staple food for millions of farmers. It is considered to be a coarse and less prestigeous grain for which reason the processing and utilization technology have remained stagnant and traditional. Excellent reviews of literature have been recently made by several authorities on the grain quality and utilization of sorghum (Hulse et al. 1980; Proceedings of the International Symposium on Sorghum Grain Quality - ICRISAT, 1982; Sorghum in the Eightees: Proceedings of the International Symposium on Sorghum ICRISAT, 1982; Salunkhe et al. 1984). The objective of this paper is to briefly review the status of research on the nutrition and utilization of sorghum and suggest some priorities for future research with particular reference to the Indian situation. It is hoped that the points that would be brought out will initiate a discussion that could lead to

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useful guidelines for sorghum research in the seventh five year plan.

1.NUTRITIONAL QUALITY

The sorghum grain is composed of three main parts: pericarp (7.9%), embryo (9.8%) and endosperm (82.3%, Table 1). A study of the chemical composition of sorghum grain (Table 2) shows that, like other cereals, it is nutritionally poor in terms of essential amino acid content, particularly that of lysine, and their balance. The problem is further complicated by the poor digestibility of sorghum protein, which leads to reduced nitrogen retention. Nutritional inhibitors like tannins and phytate P present in the grain are known to result in reduced bio-availability of protein and minerals.

1.1 Essential Amino Acids

Although considerable variation exists among sorghum cultivars in their amino acid composition, none of them fulfil the provisional pattern of essential amino acids of the FAO/WHO (1975, Silano et al. 1982) (Table 3). Lysine is the first limiting amino acid and is far below the recommended level essential to support normal human growth requirements. The second limiting amino acid is threonine followed by methionine. Hulse et al. (1980) estimated that at 50% digestibility and 10% protein level, it would be necessary for a child of 5 years to consume 1 kg and a lactating woman 3.3 kg of sorghum daily to satisfy their protein requirements. It is generally admitted that few survive solely on a sorghum diet. Nevertheless, these estimates bring out the marked nutritional inferiority of sorghum that one frequently overlooks. The amino acid leucine has been found to be far in excess of the desired level leading to reduced availability of isoleucine and affecting tryptophan-niacin metabolism (Gopalan and Srikantia, 1960; Belavadi et al. 1967). Protein fractionation studies have shown that sorghum grains contain a high proportion of kafirin (prolamin) and kafirin like protein components relative to others (Table 4). The kafirin protein fraction is very low in lysine and other basic amino acids and relatively high in glutamic acid and leucine. As percent protein and percent lysine (g/100 g protein) are negatively related, improved agronomic practices that lead to increased protein content result in a poor quality protein. The increase in protein is off set by increased kafirin component (Waggle et al. 1967). Therefore, it was recommended that breeders should seek for increased concentration of lysine at a safe level of 10% protein. Although considerable efforts were made to achieve this objective, significant progress could not be made till recently, due to narrow genetic variation for amino acid content and high genotype x environment interactions.

A systematic screening of sorghum germplasm at the Purdue University led to the discovery of two high lysine cultivars originating from Ethiopia, IS 11758 and IS 11167 (Rameshwar Singh and Axtell, 1973). These two cultivars are photosensitive and have a floury and shrivelled endosperm. The grains contained 15 to 17% protein and about 3.1% lysine (expressed as percent of protein). It was also established that the concentration of alcohol soluble kafirins is significantly reduced in these high lysine sorghums relative to that of normal sorghums (Table 4). The shrivelled grains of these photosensitive Ethiopian high lysine sorghums precluded their direct use. Efforts to transfer the high lysine (hl) gene from these sorghums to normal plump grain types have not met with much success. A second high lysine source, mutant P 721 was discovered by Mohan (1975). This mutant P 721 is in a photoinsensitive 3 gene dwarf back-ground and has normal seeds with a floury and opaque endosperm. The grains contained about 2.8% (percent of protein) and 12.6% lysine and protein respectively and weighed about 2.2 g/100. Currently progress is being made at Purdue University in transferring the high lysine content from P 721 opaque to normal high yielding types with corneous grains (Axtell et al 1982).

At ICRISAT, Riley (1980) observed that under low soil N conditions, the lysine level of P 721 was no higher than in the normal sorghum. The nutritional advantage of P 721 became more pronounced in higher fertility environments. In contrast, the Ethiopian hl mutant 11758 which possessed higher protein and lysine levels than did P 721, maintained its nutritional superiority over environments. Although kernel weight of both the mutants remained low in all environments, IS 11758 was able to compensate with very high numbers of kernels per head in the better environments. Progeny from crosses with P 721 resembled P 721 in producing floury endosperm, light kernels and low grain yields.

Jayamohan Rao et al. (1984) discussed in detail the efforts made in the All India Coordinated Sorghum Improvement Project (AICSIP) to utilize the high lysine sources and improve lysine content in a normal plump grain type. Segregating generations of crosses between shrivelled hl and normal plump parents showed that the shrivelled progenies were consistently high in lysine content, while the plump progenies exhibited only marginal superiority over their normal plump parents. Opaque type of endosperm was also found to be associated with high lysine. The mutant P 721 was observed to be a good combiner for high lysine. The use of P 721 as a male parent enhanced the chances of recovery of plants with lysine at high protein levels. Improved sources of high lysine and high protein with shrivelled seeds (N 82) were also recovered (Table 5). They concluded that recombination procedures would be the best choice for further improvement of protein quality in sorghum.

Deosthale (1984) summarized the earlier work on pellagra in relation to sorghum consumption and mentioned four sorghum varieties, IS 182, IS 199, IS 576 and IS 4642 showing consistently low and safe levels of leucine. He recommended that they could be exploited in pellagra endemic areas. There are no reports of specific breeding experiments directed towards reduced leucine/isoleucine ratio.

1.2 Inhibitors

No discussion on sorghum nutritional quality is complete without a mention of tannins which are known to reduce the availability of proteins (Hulse et al. 1980, Butler 1982). Chavan and Salunkhe (1984) discussed the role of sorghum tannins in human sorghum nutrition with particular reference to the Indian situation and concluded that the level of tannins required to possess antinutritional effects seems to be higher than the amount of tannins usually present in the white and yellow grain cultivars grown in India for human consumption. Tannins are known to be significantly high in those grains with a subcoat or testa. The presence of testa and a brown pericarp are governed by major genes and tannin content in the grain is dependent on these genetic factors (Rooney and Miller, 1982, Polyphenols present in the pericarp at low levels influence the color and acceptability of the food. Selection of tan colored plants and grains with white/

colorless pericarp and no testa should help develop low tannin in the grain. Quick progress could be made by breeders as these characters are governed by major genes.

Other solutions to improve the nutritional value of high tannin sorghums include alkali treatment and decortication. Since tannins are located in the pericarp and testa, decortication is probably the most convenient method if the endosperm is hard enough to withstand mechanical processing.

Hulse et al. (1980) opined that phytate phosphorous may be of greater nutritional significance to those who subsist on sorghum and millets than is generally realized. The importance of phytic acid in nutrition lies in its property of forming insoluble or nearly insoluble compounds with mineral elements including Ca, Fe, Mg and Zn, the resultant phytates being excreted in the faeces. Among thirty cultivars of sorghum, levels of phytate-P ranged from 0.17 to 0.38%, accounting for 80-87% of the total P present in the kernel (Doherty et al. 1982). The level of phytate-P in sorghum was similar to that of other cereals.. Doherty et al. (1982) observed that varietal effects were the most critical factor in selecting a sorghum variety for human consumption that would contain optimum available phosphorous. Extent of milling and type of processing would be of a lesser concern since they do not selectively lower the nondigestible phytate-p levels although dehulling as such reduces phytate-P level in the processed grain.

1.3 Protein Digestibility:

Eggum (1977) pointed out that increasing the proportion of essential nutrients is not a sufficient answer to improved nutritional quality unless these nutrients are readily available to the biological system. Therefore, factors affecting the availability of the nutrients must receive due attention. In an experiment with rats, Eggum (1977) measured true digestibility (TD) of protein in eight different cereal grains and found that the difference between total and digestible protein in sorghum was about 15%. Similarly differences for total and true digestibilities for lysine and glutamic acid were 27.3% and 9.98% respectively. He felt that biological experiments with laboratory animals are extremely useful to evaluate the nutritional quality of improved varieties.

Hulse et al. (1980) reviewed experiments on nutritional quality of sorghum in rats, poultry, swine and ruminants. Among both monogastric and ruminant farm animals total digestibility and protein digestibility vary significantly among sorghums. The yellow floury endosperms showed greater calorie and protein digestibility than did cultivars having white floury, white corneous, or yellow corneous endosperms (Noland et al. 1977). Lichtenwalner et al. (1978) reported that ruminal digestibility was increased by increasing doses of the waxy gene. Tanksley (1975) observed in experiments with swine that nonyellow and yellow sorghums exhibited a small but consistent advantage over hetero-yellow sorghums. Hulse et al. (1980) opined that it is probable that many of the observed cultivar differences, though in part attributed to differences in nutrient content among the sorghums used, resulted from the widely different proportions and compositions of other ingredients in the diets compared. In general, response of swine, poultry and rats indicated that unprocessed low tannin sorghum is about equally or slightly less efficient than maize (Axtell et al. 1982). A definite positive effect of feed efficiency was observed in ruminants by feeding processed sorghum.

Information on protein digestibility of sorghum in humans is limited. Kurien et al. (1960) observed that progressive substitution of sorghum for rice in the predominantly vegetarian diets of 12-14 year boys was associated with progressive decrease in apparent nitrogen absorption and retention. True digestibility improved when sorghum diet was supplemented with lysine and threonine and fed to 11 to 12 year old girls (Daniel et al. 1966). Experiments in Peru with preschool children (6-27 mo) using sorghum gruel as a diet indicated that whole sorghum grain is markedly inferior to wheat, rice, potato and maize as a source of dietary protein and energy (MacLean et al. 1982). However, Axtell et al. (1982) opined that the difficulties encountered in sorghum utilization have been counteracted by traditionally developed food preparation practices like decortication, fermentation and supplementation with other plant products. It was also found that *in vitro* pepsin digestibility of fermented food products of Sudan (kisra and Abrey) were 50% more than that of unfermented cooked gruel (Axtell et al. 1981). It also recognized that sole sorghum diets are detrimental to normal growth and health and need supplementation with adequate protein sources such as legumes. Adsule et al. (1982) reviewed experimental evidence on the beneficial effects of nutrition from sorghum + legume diets in animals. Pushpamma et al. (1979) observed a great improvement in protein digestibility and nitrogen retention of young children when they were fed with sorghum/legume diets. Additional information on sorghum protein and starch digestibility in humans would be desirable, particularly with reference to traditional methods of consumption with or without supplementation.

Several *in vitro* procedures have been used to measure sorghum protein digestibility using single or multiple enzyme systems (Lamar 1973, Axtell et al. 1981, Hahn et al. 1982, Birthe and Eggum 1982). Since bioassays with animals, microorganisms and humans are time consuming and expensive, *in vitro* procedures offer simple, rapid and inexpensive techniques for nutritional evaluation, provided they are highly correlated with results from *in vitro* experiments.

2. FOOD QUALITY

In India, sorghum grain is consumed mostly in rural and semi-urban areas, especially by poor people. Unlike rice and wheat, all the sorghum consumed is processed by traditional methods. Several food products and snacks are prepared from sorghum (Ayyer, 1944; Rachie, 1963; Subramanian and Jambunathan, 1980 and Jadhav and Joglekar 1984). Most of the sorghum is consumed in the form of roti (bhakri), sankati (mudde) and soru (annam). Roti, an unleavened bread made from whole grain flour, is popular in Maharashtra, Karnataka, parts of Andhra Pradesh, Madhya Pradesh, Gujarat and Rajasthan. Traditionally, sankati is a thick porridge made with grits/coarse flour of dehulled grains and soru is a boiled rice like product made from dehulled grains/brokens. Recently, however, the traditional dehulling process has been generally given up because it is laborious and time consuming. Whole milled grits/brokens/coarse flour devoid of bran are being used. Sankati and soru are popular in the southern districts of Andhra Pradesh, parts of Karnataka and Tamil Nadu. Considerable variation exists between regions in the exact techniques used to prepare these basic food products. Generally, the differences observed in the actual preparation from one area to another and among households do not affect the quality of the grain preferred.

Product evaluation studies have frequently indicated the inferior consumer quality of high yielding cultivars in contrast to preferred local cultivars (Rao et al. 1964; Madhava Rao, 1965; Anantharaman, 1968; Viraktamath et al. 1972 and Desikachar, 1977). Such observations have encouraged breeders to interact with food technologists and cereal chemists to evolve optimum screening and evaluation procedures that can be applied in breeding programs.

2.1 Roti

Extensive studies were carried out at ICRISAT on the quality of roti produced from a wide array of germplasm and breeding material using standard procedures (Murty and Subramanian 1982 and Murty et al. 1982b). The range of variation in roti quality parameters was significant even among pearly white grains which are visually good (Table 6). Pericarp color, endosperm type and endosperm texture had significant effects on roti quality. Significant effects for season, year and genotype x year interaction were recorded for grain, dough and roti quality parameters. Considerable effect of drought stress on dough characters was noticed while that of nitrogen fertilization level was insignificant. Wet weather leading to grain deterioration caused the most significant effect on roti quality. In general grains with a colorless thin pericarp and 60 to 70% corneous endosperm produced the most acceptable rotis. Presence of a tough, leathery pericarp produced rotis with inferior texture and flavor. Floury grains produced a poor quality dough while waxy grains produced a sticky dough and gummy rotis.

The physical and chemical properties of sorghum that significantly affect roti quality.are not fully understood (Murty et al. 1982b). Chemical components like water soluble protein and amylose were found to influence roti quality (Subramanian and Jambunathan, 1982). Sorghum varieties with a low gelatinisation temperature of starch, high peak viscosity and set back and high water uptake gave doughs with better rolling qauality. Water absorption properties, extent of starch damage, particle size and milling methods influenced dough quality of flour (Chandrasekhar and Desikachar, 1984, Murty et al. 1984b). Percent starch damage, water absorption, dough rolling quality and roti quality are positively correlated.

2.2 Sankati

Traditional methods of sankati preparation and consumption have been described (Murty et al. 1982a). Thrity sorghum cultivars were evaluated for sankati quality at two locations. Grain with intermediate and hard endosperm texture and a white/creamy pericarp produced sankati with preferred qualities. There were marginal differences in the level of softness of the product preferred at the two locations (Table 7). In general good porridges of neutral pH can be produced by hard endosperm types which produce thick gels (Rooney and Murty, 1982a). Sorghum varieties with high gelatinization temperature of starch, low paste viscosity and low set back were found to produce good mudde (sankati) (Desikachar and Chandrasekhar, 1982).

2.3 Soru

The cooking quality of boiled sorghum (Soru) prepared from dehulled grain of 25 cultivars was evaluated using laboratory procedures and taste panels (Subramanian et al 1982)(Table 8). The percent increase in volume and weight of grains due to cooking, time required for cooking, texture of the cooked grain, and overall acceptability of the cooked product varied among genotypes. The increase in cooked grain volume was positively related to grain desnity. Inspite of a poor color appeal, soru from local red pericarp sorghum was acceptable. In general, a sorghum that cooks, looks and tastes like rice is preferred. Murty et al (1984a) studied the cooking properties of 112 cultivars of sorghum. It was noted that cooking time of dehulled grain was reduced by half that of the whole grain while the increase in volume and weight of the cooked product was about 80 percent. In general kernels with a white pericarp and intermediate endosperm texture combined good cooking quality characters, namely, less cooking time, increased volume of the product and a soft texture.

2.4 Snack Foods

Prasada Rao and Murty (1982) reviewed the literature on special purpose sorghums traditionally grown in India: vani, basmati and pop sorghums. Murty et al (1982d) identified superior pop sorghums after screening Indian germplasm and found that pop sorghums generally possess a small grain size, thick pericarp, hard endosperm and a low germ/endosperm ratio.

2.5 Traditional Dehulling

Traditionally, sorghum has been dehulled by hand pounding with a pestle moist grain contained in a mortar. Grain samples from 55 cultivars exhibiting diversity in kernel size, shape, weight, endosperm texture and pericarp thickness were studied for their traditional dehulling quality (Murty et al. 1984a). Kernels with a highly corneous endosperm and a thick pericarp were found to be suitable to dehull by hand pounding and gave relatively cleaner and more pearled endosperm and less brokens. Grain types with a floury endosperm and/or a testa were the least suitable. Turtle beaked or caudatum type of grains posed problems in pericarp removal at the hylar region. Round or oval grain types with a hard endosperm and thick pericarp would be ideal for traditional dehulling.

2.6 Effects of grain molds and weathering on

The most important factor affecting food qauality of the grain is wet and humid weather. A major portion of sorghum produced in India is harvested at the end of kharif season. Early maturing and high yielding cultivars suffer from grain deterioration when crop maturity coincides with wet and humid weather. The grains maturing in wet weather could be affected by one or more of the following factors: molds, weathering, discoloration, and sprouting. Pathogenic fungi infecting the grain before maturity cause grain molds while saprophytic fungi lead to post maturity deterioration or weathering (Castor and Frederiksen, 1982). Grain molds and weathering lead to substantial loss in the quantity and quality of grain yield. During wet weather purple or red colored blotches appear on the grain due to leaching of phenolic compounds present in the glumes and pericarp. Tan colored plants do not have such red and purple pigments and therefore their grains do not exhibit such discoloration although very light yellow staining may be observed in some cultivars. Even slight discoloration of grain leads to intense discoloration of the food as the color pigments are water soluble.

Studies in Texas A & M University showed that there are no significant losses of nutrients due to grain weathering (Anonymous, 1978). Grains from rainy season harvest frequently showed reduced grain weight breaking strength, increased percent of water absorption by grain and relatively poor food quality properties (Murty et al.

1982b). Rolling quality of roti dough and gel viscosity of porridge were also relatively poor for kharif harvested grains. Reduced hardness of the endosperm results in poor dehulling quality. The grain density is also reduced due to molds and weathering. Sprout damage leads to partial degradation of starch as a result of amylase activity. The food quality of sprout damaged grain could be seriously affected depending upon the proportion of sprouted grains in the harvest. Murty et al. (1984c) observed that sprout damage in kharif harvested grain is associated with increased amylase activity and could be quantified through enzyme assay.

2.7 Tests to Predict Food Quality

It would be useful to identify some physicochemical tests that could predict the quality of sorghum varieties for various end uses. For instance gel spread tests were found to be useful to predict porridge quality (Murty et al. 1982c). A significant association of swelling power and solubility of starch with qualities of boiled sorghum was observed (Subramanian et al.1982). Flour particle size analyses, estimates of starch damage and water retention capacity of flour could also be potential indicators of roti dough quality (Rooney and Murty, 1982a; Murty et al. 1984b). Percent water absorption of grain was found to be negatively correlated with roti quality (Murty et al. 1982).

The proportion of floury versus corneous endosperm in the kernel is called endosperm texture or hardness. Although visual scores of grain texture on a scale of 1 to 5 can be done, environmental effects, and subjectivity of the scores suggest adoption of objective tests. Grain texture or hardness can be assessed by flour particle size analyses, pearling tests, milling energy evaluation or floatation tests (Kirleis and Crosby, 1982, Hallgren and Murty 1983, Table 9). The percent of grains floating in a solution of NaNO (1.3 sg) is highly correlated with hardness of grain and this parameter can be used routinely to screen breeding lines. Breaking strength measurements made with Kiya Rice Hardness Tester are frequently affected by the shape of the kernel and could be erroneous. Laboratory pearling machines can evaluate hardness of grains and only small samples are required (Shepherd, 1979 and Oomah et al. 1981).

Vogel and Graham (1979) have outlined procedures useful for evaluation of food acceptability. Rooney and Murty (1982a) suggested the use of Munsell color charts (Anonymous, 1975) for the evaluation and comparison of color of flour and food products. The most critical aspect of the food acceptability is texture. Simple objective tests are needed to evaluate texture of sorghum food products. Chandrasekhar and Desikachar (1984) suggested that tackiness of sorghum foods could be assessed by tachymeter devised at CFTRI for rice. A penetrometer could also be used for testing stickness of porridges (Da et al. 1982).

Subramanian et al (1983) used an Instron Food Tester for measuring dough quality but such instruments are too sophisticated and may not be useful for routine screening.

3. ALTERNATIVE USES

Two important reasons for the poor acceptance of sorghum as a food among urban areas and rich communities are the low social status or prestige attached to the grain and the less attractive food quality attributes of sorghum like poor color, coarseness, high fibre content, grittiness, more cooking time and supposedly poor digestibility (Pushpamma and Vogel 1982). People who consume sorghum have to go through a laborious and time consuming process to prepare refined or even acceptable products. Unlike rice and wheat, sorghum flour and products are not available in the markets. This situation is not conducive for an optimum demand for sorghum grain when production trends are showing an increase. Therefore, one has to adopt alternative methods of processing and maximise the utilization of sorghum which is probably the most efficient and dependable crop for the dryland farmer.

3.1 Processing Technology

During the last two decades, mechanical methods of dehulling sorghum were the most widely investigated subject. Several types of mills have been proposed in India and elsewhere (Raghavendra Rao and Desikachar, 1964; Normand et al., 1965; Viraktamath et al 1971; Perten, 1977, Miche, 1980, Rasper, 1977, Munck et al. 1982). Richert (1982) reviewed the various dehulling techniques that were or could be applied to sorghum. These milling systems mainly fall into 4 categories: a) roller milling equipment and peeling rolls b) rice dehulling equipment c) abrasive type dehullers and d) attrition type dehullers. The last two systems were developed specifically for sorghum.

Several pilot scale mills have been erected in African countries like Sudan, Senegal, Nigeria and Botswana. It is difficult to recommend a suitable milling system for the Indian situation without actual data on its relative merits in milling and consumer acceptability of products. One has to consider several factors like capacity/hour, power consumption, maintenance requirements, cost, efficiency of pericarp removal, flour color, reduction of fat and ash and the extent of nutrient losses. It has been felt that mills of an industrial scale are required in urban areas while mini batch dehullers may be useful for villages. How much of the pericarp and germ should be removed is a matter of debate and has to be carefully considered. The germ has to be removed for decreasing rancidity of flour and increasing its shelf life, but this has an adverse effect on the nutritional composition of the product. In case the flour from dehulled grains is intended for immediate use, degermination may not be useful and can have negative nutritional effects. On the other hand bioavailability of the nutrients in the dehulled grain might increase due to the removal of inhibitors like phytic acid. Therefore desirable quality criteria of the flour must be accurately defined so that millers can modify or operate their equipment with definite objectives.

Desikachar (1982) described a modified plate grinding mill to which a set of sieves have been fitted. Tempered grain (3% moisture, 5 min) is ground as per normal procedures and is sifted through a set of three sieves of different pore sizes which give four flour fractions of different particle size. The PRL batch dehuller which uses an abrasive mechanisam is simple and is also suitable for use in small villages.

Reichert and Youngs (1976) compared three types of mills - an attrition, an abrasive and a barley pearler - for dehulling sorghum and millet. They concluded that the abrasive mill was the most suitable. They also showed that all mechanical mills tested were much more effective in removing the grain's outer layers and its various nutrients than was the traditional method.

The Food Research Center (FRC), Khartoum, Sudan is running a pilot dehulling plant in cooperation with the FAO. Precleaned sorghum is passed through a vertical Schule milling machine. After separation, the unbroken pearled sorghum is packaged for use in soups and as a rice substitute or is mixed with brokens and milled to flour for use in composite flour bread.

High protein fractions can be obtained by using abrasive dehulling techniques (Normand et al. 1965, Rooney et al. 1972).

Corneous and hard grains with a thin pericarp are suited for mechanical dehulling (Rooney and Murty, 1982). Soft endosperm types and brown grains break down during the mechanical process and give poor recoveries of clean endosperm (Table 10).

The introduction of suitable dehulling mechines has the following benefits (Pushpamma, 1982): a) it reduces the drudgery of women in the sorghum eating areas b) it converts sorghum as a convenient grain c) it improves the quality of sorghum products d) it checks the tendency of shifting from sorghum to other grains e) it is an essential step to develop composite flours and to commercialise sorghum products.

In addition to dehulling, other processing methods that can improve sorghum include fine grinding, rolling, steam rolling, pressure cooking and flaking, popping, extruding, micronizing, reconstituting, etc. (Rooney et al.1980). Stringfellow and Peplinski (1966) and Wall and Bietz (1980) used airclassification techniques to obtain high protein flour fractions.

3.2 Novel Foods of Sorghum

The use of composite flours for bread making has received considerable research interest, particularly in Africa. The FRC of Khartoum is producing a good quality bread using 75% wheat and 25% dehulled sorghum flour (Badi et al. 1978). Hart et al (1970) and Bijttebier (1980) used certain gums produce bread from sorghum flour. Use of sorghum in producing cakes, pasta products and cookies, has been demonstrated (Badi and Hoseney, 1976, Miche et al. 1977, Viraktamath et al. 1971, Rooney et al. 1980). A range of attractive products that can be made from pearled sorghum like semolina, vermicilli and flakes, are on display at CFTRI Mysore. Dehulled sorghum can be cooked like rice. FRC, Khartoum, is marketing dehulled sorghum grain with the name 'pearl dura' (Badi et al. 1981).

Sorghum grain is also being used for alcohol production (Rooney et al 80, Anonymous, 1981). The whole grain is ground to produce a coarse meal and cooked. The mash thus produced is hydrolyzed followed by cooling and inoculation with yiest. After fermentation the alcohol is recovered by distillation. Sorghum has also been used to produce lactic acid, riboflavin, microbial polysaccharides, antibiotics and citric acid. Use of sorghum as a substrate depends on its price and availability relative to other grains Sorghum grits are being used in Mexico as an adjunct in brewing European types of beer and were used for several years in the USA (Aldape, 1981). A sizable amount of sorghum produced in Africa is consumed as beer (Novellie, 1982). In South Africa, the small scale village process has been scaled up to modern industrial level. Highly alcoholic whiskies are produced in China using sorghum (Lee House, personal communication).

The potential of sorghum for use in malted foods is receiving greater attention (Desikachar, 1976). Germinated sorghum has increased nutritive value and can possibly be used in manufacturing wealing foods (Adsule et al. 1984).

Axtell et al (1982) proposed the utilizastion of Ethiopian high lysine sorghums for producing special baby and weanling food. Another possible way to use them is to can their grains at hard dough stage just before the grains start shrivelling. Moderately high yielding, low tannin and high lysine (shrivelled) types are available.

3.3 Sorghums for Food, Feed, Fuel and Fiber

Sweet sorghums have been widely used in the USA for syrup production by extracting juice from the stalks. Coleman (1970) described good quality sorghum syrup as mild and sweet with a distinctive sorghum flavor. A syrup with light amber color, high viscosity and little or no crystallization are preferred. Bapat et al. (1984) have recently advocated the use of sweet sorghum and its production in India. Sweet sorghum can also be used for the production of crystalline sugar provided the juice contains very little invert sugars and a higher concentration of sucrose. A pilot plant in Weslaco, Texas, USA, has been used to produce sugar from sweet sorghum (Smith, et al.1973). Starch is an undesirable component because it interferes with juice concentration. Aconitic acid content should be low to prevent interference with sucrose crystallization. The biggest potential use for producing sugar from sweet sorghum is that of a supplementary sugar source to sugarcane. However, the economics of crystalline sugar production from sorghum does not seem to be encouraging unless suitable sweet sorghum genotypes are identified and improved techniques of sugar extraction are found.

Schaffert and Gourley (1982) described stalk quality characters of some currently used syrup and sugar varieties of sorghum. Both syrup and sugar varieties can be used for alcohol production as both sucrose and invert sugars are directly fermentable. Several countries like USA, Brazil, Newzealand, Austria, Australia, South Africa, Phillippines, Kenya, Sudan and Thailand are developing alcohol fuel programs based on crop production. On the basis of alcohol production experience in Brazil, Schaffert and Gourley (1982) strongly suggested the use of sorghum as a source of energy.

Sorghums that have desirable yields of grain, sugar in the sap and useful type of fiber have been referred to as high energy sorghums (HES)(Creelman et al. 1981). These sorghums were characterised as about 1.5 to 2.5 m tall, yielding 5000 kg/ha of high quality grain which is suitable for human consumption, fermentation, or livestock feed, and stalks with high carbohydrate levels suitable for multiple uses (Tables 11 and 12). After grain harvest, stalks can be harvested, crushed and extracted, fed to livestock, used in direct combustion or as fibers for pressed wood, paper, chemicals for industry, etc.

Sweet sorghum, grain sorghum and high energy sorghums represent a wide range of variability in the species, *Sorghum bicolor* L. Moench. Sorghum is the most efficient crop in terms of biomass production per day, surpassed only by napier grass (Loomis and Williams, 1963). It is also widely adapted to a range of adverse climatic conditions. The broad range of genetic variability in sorghum could enable breeders to 'custom build' a sorghum to fit the need of industry and develop cultivars valued not only for high yield but also carbohydrate components easily extracted and converted into convenient energy forms.

4.FUTURE RESEARCH PRIORITIES

Given the inferior nutritional quality of sorghum and the dependence of poor people upon it as a staple diet, it is important that breeders give some attention to nutritional qauality in addition to grain yield and its stability. Two important criteria were established in the sixtees for nutritional improvement of sorghum: higher concentration of lysine and lower concentration of leucine (Ganda Prasada Rao, 1972; Deosthale, 1972). Inspite of significant progress in breeding research current status of research achievements in improving protein quality would essentially recommend the same criteria for the future. The prospects of breeding improved levels of lysine with an average protein content (10%) appear to be brighter in view of the identification of sources of high lysine and an understanding of their breeding behavior. Experience indicates that benefits from recombination breeding procedures could be substantial. However, identification of newer sources of high lysine, possibly through increased mutation breeding efforts, would be useful.

High lysine cultivars with shrivelled grains could be utilized as such for cultivation. Some improved cultivars with significantly higher concentration of lysine, but with shrivelled grains are available. These are photoinsensitive, white grain types suitable for cultivation in India. These could be extended to the farmers as special purpose sorghums like *vani*, *basmati* and pop sorghums. Public agencies should make efforts to market them as special weanling and nutritious foods. Food technologists should research into methods for canning high lysine types at hard dough stage. Early maturing and higher yielding genotypes with shrivelled grains could be bred with relative ease provided there is a demand.

High yielding varieties and hybrids under test at All India level should be comparatively evaluated (using grain harvested from trials) for their nutritional characters at a central laboratory. Such a procedure would help in the identification of stable cultivars for nutritional characters.

There is an increasing concern about the poor digestibility of sorghum in humans, although animal feeding experinments indicate sorghum to be as efficient as maize, except that slightly more quantity of sorghum has to be fed. More inormation is required from nutritional experiments on humans using sorghum as a staple diet supplemented with different legumes. The most nutritious sorghum + legume combinations have to be identified. Nutritional value of different sorghum products and processing methods have to be found out. The use of *in vitro* digestibility tests in predicting the nutritional value of breeding lines should be investigated.

Basic information on major sorghum food products consumed in India and their distinguishing features are available. Sorghum grains with a thin colorless/white pericarp, intermediate to hard endosperm and an oval or round shape would be suitable for various processing and food quality characters. Breeders should use objective tests for grain hardness and pearling quality routinely even in early segregating generations. They should evaluate the [illegible]on harvest from elite cultivars (from yield trials) for food product quality, consumer acceptance and market value. In this context, a central laboratory to evaluate consumer and nutritional value of grain from All India Trials would be desirable. Efforts to breed for increased levels of grain mold resistance should continue without detriment to desirable food quality. Objective methods to evaluate the rain affected Kharif harvest for moldiness and food quality characters are required.

Objective criteria to help fixation of quality linked market prices should be developed. Frequently, produce from hybrids is not fetching a reasonable price.

Identification and extension of suitable mechanical dehullers would go a long way in alleviating processing problems of consumers. Public and private agencies should be involved in the promotion of mechanised processing of sorghum This would remove the 'coarseness' and low prestige of the grain and improvoe its acceptance and utilization.

Increased production of sorghum, particularly from the Kharif season would soon lead to a glut in sorghum marketing unless it is completely utilized. The visually poor kharif harvest discourages traditional modes of consumption. On the other hand currently no industrial use of sorghum is being made. Several alternative methods of utilizing sorghum grain are available. Mechanized dehulling and industrial processing would open new avenues for sorghum consumption and demand. Pilot scale plants are operating in some African countries. Sorghum grain can be used in producing good quality bread, cakes, flakes, popped products, vermicilli, semolina and instant mix recipes that are currently made from other cereals. Success of these products in the market would depend on the relative price of sorghum in relaltion to other cereals. Therefore, a team of experts comprising food technologists, industrialists, breeders, nutritionists and government representatives should study the case for promotion of mechanized processing and industrial use of sorghum grain.

Sorghum grain can be used not only as an animal feed but also as an adjunct in beer production. This is already underway in some countries. Similarly, there is a strong case for using sorghum grain for alcohol production. The spent grain left over contains 25 to 30% protein and is an excellent source of animal feed.

The concept of high energy sorghums (HES) is gaining momentum in several countries. This idea of total plant utilization - grain for food, stalk for feed, fuel and fiber is worthy of consideration (Creelman et al 1981). The economics and feasibility of 'gasohol' production from sorghum is an important topic for another team study and follow up action. Breeders could select for increased biomass production while maintaining the high yield of currently popular hybrids.

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Table 1. Composition of Sorghum Fractions and Whole Grain[a/]

Fraction	Percent of whole kernel	Ash (%)	Protein (%)	Oil (%)	Starch (%)
Whole grain	100.0	1.65	12.3	3.9	73.8
Endosperm	82.3	0.37	12.3	0.6	82.5
Germ	9.8	10.36	18.9	28.1	13.4
Bran	7.9	2.02	6.7	4.9	34.6

a/ Adapted from Hubbard et al, 195[illegible]

Table 2. Nutritional Composition of Sorghum[a/]

Component	Range
Proximate analyses (%)	
Protein (N x 5.7)	7.1-14.2
Lipid	2.4- 6.5
Carbohydrate	70-90
Fibre	1.2- 3.5
Amino acids (mg/g N)	
Lys	71-212
Lys amino acid score	21- 62
Ile/Leu	1.9- 5.0
Minerals (mg/100g)	
Calcium	11-586
Phosphorus	167-751
Iron	0.9-20.0
Vitamins (mg/100g)	
Thiamine	0.24-0.54
Niacin	2.9- 6.4
Riboflavin	0.1- 0.2

Adapted from Hulse et al 1980

a/ Ranges of means from several investigations

Table 3. Essential Amino Acid Chemical Score for Nine Sorghum Cultivars[a/]

Amino acid	FAO/WHO pattern (g/16g N)	M 35-1	CSH 8	IS 11758	SPV 351	SPV 387	GG 1483	M 36357	SPV 393	SPV 396	Mean score
Lysine	5.5	47	48	60	45	38	46	42	38	48	46
Threonine	4.0	75	80	84	74	76	84	77	78	87	79
Methionine + Cystine	3.5	67	70	63	76	74	69	66	72	70	70
Leucine	7.0	175	180	173	170	182	187	186	180	179	179
Isoleucine	4.0	96	95	108	90	100	96	100	95	93	97
Valine	5.0	88	107	109	88	92	95	96	89	93	95
Phenylalanine + Tyrosine	6.0	130	140	138	126	132	136	143	135	137	135

a/ Comparison was made by keeping 100 as the unit for FAO/WHO pattern of each of the amino acids

Adapted from Subramanian and Jambunathan (1984

Table 4. N distribution (% of total N) in the solubility fractions of whole kernels of normal (NL) and high Lys (hl) sorghums a/

Fraction	Redlan (NL)	Redlan x IS 11758 b/ F_2 kernels (NL)	Redlan x IS 11758 b/ F_2 kernels (HL)	IS 11758 (HL)	IS 11167 (HL)
I Saline (Albumin, globulin, free amino acids)	10.0	15.3	22.4	26.0	25.3
II Isopropanol (Kafirin)	15.7	26.4	13.7	10.3	15.2
III Isopropanol + 2-mercaptoethanol (alcohol-soluble glutelin)	31.3	26.5	20.2	19.6	19.3
IV Borate buffer + 2-mercaptoethanol	4.5	4.3	4.3	6.5	4.5
V Borate buffer + 2-mercaptoethanol + Sodium lauryl sulphate	29.3	22.5	33.5	27.2	29.5
Total N extracted (%)	90.8	95.0	94.1	89.6	93.3
Protein (%)	13.53	13.0	15.6	18.5	16.3
Lys (g/100g protein)	1.56	1.85	3.10	3.27	3.10
(mg/g total N)	97	116	194	204	194

a/ Jambunathan et al. (1975)

b/ Av. values of kernels from five different heads (55073-55077)

Table 5. Attributes of some derived lines from Ethiopian crosses

Selection	Seed type	Protein (g)		Lysine (g/100g protein)		Leucine (g/100 g protein)		Days to flowering	Plant ht. (cm)	Yield/plant (g)		No. of plants studied
		Mean	Range	Mean	Range	Mean	Range			Mean	Range	
N 49	Plump	10.40	7.20-13.46	2.44	1.75-3.71	10.78	7.14-14.88	67	115	57	26-97	22
N 55	Plump	10.45	7.10-11.95	2.19	1.57-3.29	10.55	9.13-12.12	68	155	73	38-133	25
N 59	Plump	9.16	7.00-12.32	2.23	1.86-2.52	12.14	11.31-12.97	68	150	84	70-94	8
N 82	Shrivelled	13.51	10.40-15.62	2.99	2.50-3.66	10.16	8.43-12.02	78	113	48	26-59	19
N 93	Shrivelled	13.73	10.15-16.27	2.66	1.99-3.74	11.43	7.51-12.88	66	158	48	31-75	29
N 94	Shrivelled	13.57	9.38-15.92	2.53	1.98-3.97	11.44	9.10-13.82	68	171	59	26-77	27
P 721	Plump	12.33	8.40-15.40	2.59	2.50-2.81	12.12	11.11-13.67	58	103	35	22-43	11

Pedigree: N 49, N 55, N 59, N 93, N 94 derivatives of CSV 5 x IS 11167 cross;
N 82 derivative of IS 11758 x CSV 3 cross

Adapted from Jaya Mohan Rao et al. 1984

Table 6. Roti quality characters of sorghum cultivars with pearly white grains with 40-60% corneous endosperm

Genotype	Rolling quality [a/]	Color [c/]	Roti [b/] Taste	Texture	Aroma	Keeping quality
M 35-1 (Check P.S. Mohol)	22.3	144	1.3	1.4	1.1	2.0
CSH 8	23.0	118	2.0	2.0	1.8	2.2
Local Market (Maldandi	23.2	144	1.3	1.3	1.0	1.8
SPV 101	23.2	144	2.1	2.4	1.5	2.0
SC 423	22.9	144	2.6	2.7	1.7	3.5
SC 110-114	22.8	118	2.9	3.3	2.1	3.0
8272-1	22.9	144	2.3	2.7	1.8	2.3
M 36116	22.2	143	1.3	1.4	1.0	2.3
M 36270	21.6	143	2.0	2.2	1.0	3.0
52-1	22.5	144	1.3	1.6	1.0	1.5
285 (R. Nagar)	22.3	144	1.3	1.6	1.0	1.5
SEM	±0.1	±0.1	0.04	0.04	0.03	0.04

a/ Evaluated by measuring the diameter of the roti obtained by continuous rolling of dough from 30g flour with a pin until the roti breaks

b/ Based on the scores of a trained panel of five members on rotis made from grain samples of the postrainy season harvests grown at ICRISAT Center, 1978. Taste, texture, and keeping quality were scored on a scale of 1 to 5 (1=good) while aroma was scored on a scale of 1 to 3 (1=good).

c/ All color codes refer to white or pale yellow grades of Munsell's Soil Color Charts (Anonymous, 1975)

Table 7. Sankati quality characteristics of sorghums with visually similar grain properties a/

Genotype	Color	Taste	Texture	Keeping Quality
M 35-1	1.9	1.8	2.5	2.5
CSH 5	1.3	1.3	1.7	1.9
M 50009	1.4	1.7	2.0	3.0
M 50013	1.5	1.8	1.5	1.7
M 35052	1.3	1.8	2.5	2.3
M 50297	1.6	1.7	1.8	1.8

a/ Average scores given by five and six farm workers at two locations, Bhavanisagar and Anantapur (S. India), respectively (replicated twice) on a scale of 1 to 5 (1=good).

Adapted from Murty et al. 1982a.

Table 8. Quality parameters of soru from cultivars with visually similar characteristics a/

Genotype	Color	Taste	Texture	Keeping quality
M 35-1	1.7	1.2	.1	1.6
M 50009	1.5	1.5	.8	1.7
M 50013	1.3	1.5	2.0	2.1
M 50297	1.5	1.8	2.0	1.3
S 29	1.1	1.2	1.2	1.2
CS 3541	1.1	1.7	1.8	1.9
Market 1	1.5	2.0	2.0	1.8

a/ Soru samples were evaluated by six farm workers at Bhavanisagar (S.India) on a scale of 1 to 3 (1=good).

Adapted from Subramanian et al. 1982

Table 9. Mean properties for some grain, flour, and dough quality attributes of 15 sorghum genotypes

Genotypes	Endosperm[a/] texture (%)	PF[b/] in $NaNO_3$ (%)	Grinding work c/: Brabender 10 g grain (J)	Grinding work c/: Alpine 5 g grain (arbitrary units)	Kernel breaking strength (kg) d/	Flour Particle size e/ (% < 125 um)	Dough rolling quality d/ (cm)	Gel d/ spread (mm)
2219B	78	5	70.0	27.5	6.5	14.0	22.4	55
E 35-1	74	17	75.6	24.1	11.0	19.5	22.3	56
CSH 6	66	2	64.4	21.4	6.1	16.5	23.1	57
IS 5604	66	23	67.0	24.5	5.0	18.0	23.1	59
S 29	65	87	68.0	21.7	7.2	20.0	22.0	60
SPV 351	58	32	65.4	21.4	8.1	19.5	21.0	58
296 B	48	57	56.8	18.0	6.3	26.5	21.0	62
SPV 422	48	69	59.9	18.1	7.9	25.5	18.5	61
CSH 8	47	45	59.9	18.6	5.8	25.0	22.4	59
SPV 393	45	63	62.9	20.1	6.8	22.0	22.0	62
M 35-1	38	67	56.8	14.9	5.7	28.5	22.5	60
2077B	36	70	50.7	15.9	4.1	29.0	23.0	58
IS 9985	31	98	51.2	13.2	6.1	37.5	19.3	67
IS 1401	24	97	40.6	12.1	4.3	33.0	18.1	67
P 721 Opaque	17	99	43.8	9.4	5.2	29.5	14.5	67
Mean	52.6	55.4	59.5	18.7	6.5	24.3	21.0	60.6
Standard deviation	5.1	4.5	0.80	0.88	0.51	-	0.59	1.33
Coefficient of variation	9.6	8.1	1.34	4.71	7.9	-	2.8	2.2

a/ Means of 50 kernels
b/ PF=Percentage of kernels floating in $NaNO_3$ solution. Means of triplicate determinations.
c/ Means of duplicate determinations
d/ Means of nine determinations
e/ Single determinations

Adapted from Hallgren and Murty, 1983

Table 10. 'arietal differences in breakage of sorghum samples milled in a McGill mill [a/]

Variety	Hardness of the grain (breaking strength in Kiya units)		Milling Quality		
	Unpolished	Polished	Total yield (%)	Decorticated whole grains (%)	Brokens (%)
BP 53	6.54	2,08	82.5	67.5	15.0
H 2259	7.16	2.26	84.5	68.0	16.5
Patcha Jonna	5.10	1.86	82.0	68.5	13.5
My-316-5	7.20	1.78	88.5	83.5	5.0
GPR 370	5.34	2.24	83.5	70.5	13.0
E 35-1	10.80	6.94	82.0	73.0	9.0
M 35-1	7.12	4.94	85.0	80.0	4.7
Pattancheru	5.66	1.90	83.5	71.5	12.0
GPR 148	5.82	2.30	86.0	80.5	5.5
M 7777	6.20	4.00	88.0	82.2	6.0
P 721	5.88	1.86	82.0	68.5	13.5
CSH	6.56	1.90	82.5	68.5	14.0
M 6477	6.64	1.86	80.2	77.2	3.0
CSH 1	6.56	2.06	86.5	79.0	7.5
CSH 6	6.44	2.16	87.0	79.5	7.5
A 2283	3.00	0.90	87.2	64.7	22.5

a/ These samples were grown at ICRISAT in the postrainy season of 1978. All samples were grown in the same nursery

Adapted from Desikachar, 1982

Table 11. Grain, sugars, stem starch, dry biomass and alcohol (estimated) yields from selected 'High Energy Sorghums'

Cultivar	Grain	Total Sugars	Starch	Total Carbohydrates kg/ha	Stem T/ha	Estimated Alcohol a/ l/ha	Estimated Alcohol a/ gal/ac
High Energy Sorghum							
A5930 x RTx430	8550	1517	130	10197	6.30	4997	534
ATx623 x 77CS1	7730	1480	73	9283	5.72	4558	488
ATx623 x Rio	5889	2567	464	8920	9.54	4618	494
Grain Sorghum							
RS671	4708	382	26	5116	3.72	2442	261
RS610	4006	103	25	4134	3.30	1942	208
Sweet Sorghum							
Atlas	2067	254	68	2389	5.95	1161	124
Rio	1397	4373	319	6089	7.32	3559	280

a/ Estimated at .62 l/kg of carbohydrate (1 gal/13.5 lbs carbohydrate) (75% starch from the grain yield used plus total stem carbohydrate yield).

Adapted from Creelman et al. (1981)

Table 12. Quantity of glucose, fructose, sucrose and starch in juice of 'High Energy Sorghums' at harvest (kg/ha)

Sorghum Type	Glucose	Fructose	Sucrose	Starch
High Energy Sorghum				
A5930 x RTx430	136.52	169.79	1211.12	130.40
ATx623 x 77CS1	158.70	191.21	1129.67	72.66
ATx623 x Rio	216.83	174.77	2175.20	463.46
Grain Sorghum				
RS671	55.07	37.86	288.73	26.39
RS610	29.06	24.47	49.33	24.48
Sweet Sorghum				
Atlas	85.28	87.19	81.07	68.07
Rio	172.85	136.52	3617.69	319.32

Adapted from Creelman et al. (1981)