The Breeder's Role in Crop Utilization: A Perspective

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Abstract

Research advances during the last 10 years in sorghum utilization and food quality evaluation are briefly reviewed. Grain quality criteria useful in breeding for traditional processing and food quality are summarized. Selection of important plant and grain attributes related to utilization is illustrated. Endosperm texture, i.e., proportion of hard and soft endosperm, can be evaluated to reliably predict the potential use of sorghum grain in products. The need for overall improvement of sorghum grain for much wider domestic and industrial use is emphasized. The concepts of breeding for specific end-uses and total plant utilization for food, feed, fiber, and fuel are discussed. An integrated breeding scheme, aimed at improved utilization of sorghum, is presented. Finally, the need for collaborative and cooperative efforts between breeders, chemists, food technologists, engineers, and industrialists is emphasized.

Introduction

Sorghum is used as a staple food in Asia and Africa and as animal feed in the developed world. Sorghum grain is processed and consumed domestically following diverse traditional techniques. Unlike crops like wheat, industrial utilization of sorghum is limited. Therefore, crop quality standards have been either vague or absent. Plant breeding programs were concerned mostly with selection for higher yield. Selection and crossing within native collections of germplasm posed few problems related to consumer acceptance of the breeding products. However, increased use of temperate sorghums in the tropics and selection for early-maturing varieties and hybrids with improved harvest index brought forth the importance of quality in breeding programs.

During the last two decades, a great deal of progress has been made in the understanding of the genetics, structure, and physicochemical properties of sorghum grain (Hulse et al. 1980, Hoseney et al. 1981, and Rooney and Miller 1982). Collaborative efforts between scientists in national programs and the international programs of ICRISAT, IDRC, INTSORMIL, and other institutes have resulted in evolving a tentative list of major sorghum food categories and grain quality attributes associated with the respective categories (Rooney and Murty 1982a, 1982b). Research advances in sorghum utilization and nutrition have opened up wide avenues for sorghum breeders to interact with scientists of other disciplines and broaden their breeding perspectives. Apparently, the concept of breeding sorghums for specific end uses has just been established.

An attempt is made here to briefly review the research advances in sorghum food quality evaluation and to suggest broad approaches to breeding with specific reference to various end-uses of the crop.

Grain Quality Attributes Suitable for Traditional Foods

Processing quality

Eight major categories of traditional sorghum foods are recognized (Rooney and Murty 1982b).

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1. Unfermented breads
2. Fermented breads
3. Stiff porridges
4. Steam-cooked products
5. Boiled products
6. Snacks
7. Alcoholic beverages
8. Nonalcoholic beverages.

Rooney et al. (1986) summarized the traditional processing and cooking procedures used in their production. Several of these traditional foods are prepared from sorghum grain after hand decortication with a mortar and pestle, which reduces the coarseness and grittiness of the product. In Africa, mortar and pestle dehulling is a regular domestic feature and mechanical dehulling has been introduced into urban areas in only a few countries. High-yielding cultivars are therefore acceptable to the farmers only if their grain can be processed effectively by hand-decortication. Studies in Burkina Faso on grain samples from on-farm trails indicated that under low productivity conditions, an yield advantage of 25% over the local variety can be offset by 20% less endosperm recovery from the improved cultivar by traditional processing (ICRISAT West African Programs 1987).

It has been established that oval or round kernels with thick pericarp and highly corneous endosperm are ideal for traditional dehulling (Murty et al. 1984). Corneous grains give higher pearled endosperm recovery and produce fewer losses due to broken chunks. Soft endosperm types and those with testae exhibit the poorest dehulling quality. Turtle-shaped grains (caudatum race), even when they are corneous, pose problems in pericarp removal at the hylar region. Currently, sorghum breeders frequently use caudatum types in their crossing programs. Since turtle-shaped grain is governed by dominant genes (Schertz and Stephens 1966), appropriate selection pressure should be exercised in segregating populations in favor of symmetrical grains. Grain damage caused by molds, weathering, and headbugs significantly reduce dehulling quality (ICRISAT 1986, 1987). Selection for increased grain hardness and a symmetrical shape would greatly improve processing and storage quality. Breeders should evaluate traditional quality, storage quality, and traditional dehulling quality of the grain samples of their elite varieties harvested in the crop season under local conditions.

Food quality

With the exception of beverages, there is universal preference for white- and cream-colored products (Rooney and Murty 1982a). Although red- and brown-colored foods are acceptable in some regions for various reasons, white products are invariably preferred. In view of the deleterious nutritional effects of tannins, breeders should select for a colorless pericarp. If red and brown grains or products are desired, red grains free from testae should be selected. Decortication of grains with a thin red pericarp and intermediate endosperm texture results in attractive white products. Therefore, such grains can be used for food as well as beverages. White grains from tan-colored plants are known to produce few off-colors in the product. Color should preferably be evaluated by objective tests (Rooney and Murty 1982b).

Experience with several taste panels on various traditional foods has shown that the taste parameter is extremely difficult to establish with consistent results. There are no objective tests to measure taste. Frequently, taste responses are associated with responses for texture. Taste preferences were either in favor of or against products made from grains with testae (Rooney and Murty 1982a). When white grain types were tested, taste preferences were inconsistent or neutral. The conclusion is that if white grain types free from polyphenols are selected, consumer resistance is not expected.

Texture and storage quality

Texture and storage quality are the most critical food attributes. In general, response of taste panels and consumers is distinct and consistent for these two traits. Characteristics such as the tackiness of thick porridges and boiled products, the doughy quality and rolling quality of *roti* and *injera*, or gel consistency can be evaluated objectively, although standard tests are still under development and need to be improved.

Endosperm texture

Rooney et al. (1986) summarized the most desirable kernel characteristics of sorghum for use in various traditional foods. In general, the property of sorghum grain affecting quality of the food product most consistently is endosperm texture (proportion of hard to soft endosperm). Three classes of endosperm texture were identified: hard, intermediate, and soft. Hard endosperm texture is suitable for porridges, while intermediate texture is suitable for unfermented breads, boiled rice-like products, and beverages. Soft grains are best for fermented breads.

A considerable degree of genotype/environmental interaction affects endosperm texture (Murty et al. 1982a, ICRISAT 1985). It was also found that hardness is governed by partially dominant genes. Grain texture can be determined by a variety of simple techniques (Kirleis and Crosby 1982, Hallgren and Murty 1983).

Attributes of Industrial Use

Malting quality

Novelle (1985) discussed various quality attributes of grains that affect sorghum beer production. Grains possessing a bright red color (i.e., free from testae and tannins) are sold at premium prices. High diastase grain activity is the most desirable and important character for beer production. In view of the bright prospects for increased use of sorghum in the brewing industry, breeders should evaluate a wider range of germplasm and breeding lines for malting quality and examine the possibilities for genetic improvement.

Milling quality

Several novel food products can be made from sorghum by using decorticated sorghum grains. It is expected that mechanical dehulling will soon be popular. Therefore, milling quality (i.e., mechanical decortication and flourmaking) is an important grain quality attribute. Most of the comments made under traditional dehulling quality also apply to mechanical dehulling quality, except for pericarp thickness which may be either thin or thick. In this context, laboratory dehulling machines are very useful for evaluation of small quantities of breeders' samples (Reichert 1982). In general, in spite of differences due to the relative efficiency of milling techniques, hard grain with a symmetrical shape is the most desirable.

Reference has been made to the effects of molds and weathering on sorghum grain quality. Grain weathering damage is frequently restricted to the pericarp, and mechanical dehulling of such grain can still produce flour nearly as attractive as produced from normal grains. Grain hardness is associated with grain mold and weathering resistance (ICRISAT 1986, 1987). Therefore, breeders should consider evaluation for grain hardness and mechanical dehulling quality on a routine basis using laboratory machines.

Energy and biomass

Sweet sorghum syrup has been produced in the USA since colonial days (Freeman and Broadhead 1986). Schaffert and Gourley (1982) described stalk quality characters of several currently used syrup and sugar varieties of sorghum in Brazil and suggested the use of sorghum for alcohol (energy) production. Sorghums with desirable grain yield, sugar in the sap, and useful fiber are referred to as high-energy sorghums (Creelman et al. 1982). These sorghums are 1.5-2.5 m tall and yield about 5 t ha^{-1} of high quality grain suitable for human consumption, fermentation, or livestock feed. Their stalks have high carbohydrate levels and are suitable for multiple uses (food, feed, fiber, and fuel). Thus, sweet sorghum, grain sorghum, and high-energy sorghum represent a range of variability within the species *Sorghum bicolor* [L.] Moench. Sorghum is also recognized as the most efficient crop in terms of biomass production per day, surpassed only by napier grass (Loomis and Williams 1983). It was estimated in Texas, USA, that fresh biomass yields in excess of 60 t ha^{-1} and ethanol yields in excess of 5-6000 L ha^{-1} are possible with improved cultivars (Miller 1986). Therefore, the broad range of genetic variability available in sorghum should be exploited by breeders to customize sorghum varieties to suit the needs of industry.

At ICRISAT Center, several germplasm accessions were identified possessing sweet stalks (Prasada Rao and Murty 1982, Seetharama et al. 1987). Fifty early-maturing selections exhibiting more than 16 brix degrees were derived from crosses with selected germplasm accessions (e.g., IS 990 and IS 19674). Since sweet sorghum production is affected by the same biotic and abiotic factors that affect grain sorghum, it is important to evaluate such selections in the regions proposed for their cultivation.

Nutritional Factors

Protein quality

Although considerable variation exists among sorghum cultivars in amino acid composition, lysine and threonine are recognized as the most limiting essential amino acids (Hulse et al. 1980). The amino acid leucine has been found to be far in excess of the desired level. In view of the identification of sources of high lysine and an understanding of their breeding behavior, the prospects of breeding improved levels of lysine with an average protein content (10%) appear to be brighter (Axtell et al. 1982). However, it is recognized that genetic improvement of endosperm protein quality of sorghum is still a plant breeding research objective and not a routine plant breeding objective. Plant breeders should no doubt continue to select for an optimum grain protein content of 10%.

Inhibitors

The antinutritional effects of polyphenols (tannins) are well known. Because production of these inhibitors in sorghum grains is governed by the major genes B1, B2, and S, breeders can use this information to make quick progress in selecting for tannin-free grains (Rooney and Miller 1982).

Hulse et al. (1980) reported that phytate P in the grain may be another important antinutritional factor. Doherty et al. (1982) observed that varietal effects were the most critical in selecting a sorghum variety for human consumption containing optimum available phosphorous. However, more information is needed for breeders to follow up on this aspect.

Breeding Scheme

Plant breeders need to play a crucial role in creating and improving plant types for novel uses. It is necessary to accumulate genes from the best- known sources of the desired plant characters in the crossing block to enhance the chances of recombination of multiple traits. Widely divergent crosses may not yield the desired recombinants in a good agronomic background in the first attempt. In a conventional breeding program, in order to make desired level of progress, it might be necessary to recycle selected advanced generation progenies. Fortunately, in sorghum, plant color, pericarp color, presence of tannins, glume color, plant height, and maturity are all governed by major genes. Grain size, grain hardness, and juiciness of stalk are more heritable than characters like yield. Although precise physicochemical tests to predict sorghum food quality in early segregating generations are lacking, considerable progress can be made by selecting for appropriate endosperm texture, which is highly associated with the quality of specific food categories (Rooney et al. 1986).

In general, within each endosperm class (hard, intermediate, and soft), the preferred sorghum should have a white pericarp, tan plant color, straw-colored glumes, and no testae (except where a red pericarp is desirable, such as for traditional beer). An outline of a general breeding scheme aimed at improving multiple uses of sorghum is presented in Table 1.

Table 1. A general breeding scheme for improving multiple uses of sorghum.

Crossing block with sources of good grain quality, mold and weathering resistance, high stalk sugar, and other yield-limiting factors

	F_1	Hybrids (single, three-way, and double crosses).
Crop season	F_2	Select for optimum grain size, absence of testae, colorless pericarp, round shape, appropriate endosperm texture, tan plant color, straw glume color, mold and weathering resistance, juicy stalks, and other agronomic characters in the field.
Crop season	F_3	Select for the desired grain characters, appropriate maturity, grain mold resistance, lodging resistance, high biomass, high brix value, high grain yield, and other agronomic characters in the field. Confirm grain texture and light color reaction for KOH in the laboratory.
Off season	F_4	Select for high brix value and other agronomic characters in the field. Evaluate grain hardness, milling quality, diastase activity, and optimum protein content with small samples of grain in the laboratory.
Crop season	F_5	Evaluate grain yield, biomass, and harvest index. Select for mold resistance and high brix value in the field. Conduct milling and other physicochemical tests for food quality in the laboratory (e.g., dough quality, gel consistency, flour particle size, protein content). Evaluate juice quality.
Off season	F_6	Carry out mini-product tests (for the desired food system) with the aid of taste panels. Conduct stalk and juice quality tests.
Crop season	F_7	Carry out multilocational yield tests. Evaluate selected entries through consumer tests.

Empirical selection for many desirable grain and stalk traits is possible in the F_2 generation. Experience indicates that in sorghum, segregation for several major genes continues until F_3. Therefore, selection within F_3 during the crop season should be profitable. Additional selection based on objective tests using small samples of grain could be carried out in the F_4 generation. In addition to grain yield tests, a battery of quality tests can be conducted using F_5 progeny harvests. It is desirable to conduct mini-product tests (e.g., micro-malting tests) in the F_6 generation, and advance selected lines to the F_7 generation for multilocational yield tests and consumer tests.

The breeding scheme presented here is only general and could be modified depending on the specific objectives of a breeding program within a region and the breeding system chosen. For example, in a population breeding scheme, after sufficiently random-mating the population, selection could be started in the S_1 generation in a similar method proposed for F_2 generation of a conventional breeding scheme and continued until the S_6 generation to obtain pure line varieties. In a breeding program where the objective is to improve a specific end use, the number of quality tests might be correspondingly reduced to speed up progress.

Collaboration

Some of the quality tests suggested in the last few sections need to be carried out by specialists (i.e., chemists and food technologists). Unless the screening technique is simple and rapid, breeders cannot carry it out routinely. For example, micromalting tests may have to be carried out in cooperation with breweries. Similarly, enzyme assays, specification of starch properties, and other sophisticated tests must be carried out in collaboration with chemists. It should be emphasized that improvement for multiple quality factors requires close collaboration between scientists of the various disciplines involved (i.e., breeding, biochemistry, physiology, pathology, food technology, etc.).

The principal job of a breeder is to assess the range of variation available for the desired trait and to determine its heritability. This can be followed up with appropriate selection and breeding procedures to improve the trait. Our knowledge of the physicochemical basis of the traditional foods is very limited and further research is required to suggest efficient, simple, and rapid physicochemical tests to predict specific food quality. Development of such techniques requires a close cooperation between breeders, chemists, food technologists, and engineers. Frequently, a novel technique or product is evaluated from grains of an arbitrarily chosen variety (e.g., a high-tannin variety) and its quality is rated good or poor. It might be possible to make better progress by choosing an appropriate range of varieties for such experiments in consultation with crop scientists. Breeders must respond to the needs of both consumer and industry. When a potential food product has been identified, breeders should focus their attention on the assessment of genetic variation for the desired trait or a correlated trait of the food product. For example, Murty et al. (1982b, 1984) screened a large number of germplasm and breeding lines and found superior genotypes for popped and boiled sorghum products.

Grain utilization is affected by supply, demand, industrial infrastructure, socioeconomic factors, and governmental policies relating to grain prices. Quality requirements are not static and may change over time. It is certain that alternate uses of sorghum will increase in the near future. Sorghum breeders can look forward to a more active and successful role in the improvement of sorghum and its utilization.

References

Axtell, J.D., Gebisa, E., and Munck, L. 1982. Sorghum nutritional quality—progress and prospects. Pages 589-603 *in* Sorghum in the eighties: proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International crops Research Institute for the Semi-Arid Tropics.

Creelman, R.A., Rooney, L.W., and Miller, F.R. 1982. Sorghum. Pages 395-426 *in* Cereals: a renewable resource, theory and practice (Pomeranz, Y., and Munck, L. eds.). St Paul, Minnesota, USA: American Association of Cereal Chemistry.

Doherty, C., Rooney, L.W., and Faubion, J.M. 1982. Phytin content of sorghum and sorghum products. Pages 328-333 *in* proceedings of the International Symposium on Sorghum Grain Quality, 28-31 Oct 1981, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Freeman, K.C., and Broadhead, D.M. 1986. Sweet sorghum culture and syrup production. Agricultural

Hand Book no. 611. United States Department of Agriculture - Agricultural Research Service. 54 pp.

Hallgren, L., and **Murty, D.S.** 1983. A screening test for grain hardness in sorghum employing density grading in sodium nitrate solution. Journal of Cereal Science 1:265-274.

Hoseney, R.C., **Varriano Marston, E.**, and **Dendy, D.A.V.** 1981. Sorghum and millets. Pages 71-144 *in* Advances in cereal science and technology, Vol. IV (Pomeranz, Y., ed.), St Paul, Minnesota, USA: American Association of Cereal Chemistry.

Hulse, J.H., **Laing, E.M.**, and **Pearson, O.E.** 1980. Sorghum and the millets: their composition and nutritive value. London, UK: Academic Press, 997 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Annual Report 1984. Patancheru, A.P. 502 324, India, ICRISAT. 376 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Annual Report 1985. Patancheru, A.P. 502 324, India, ICRISAT. 379 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Annual Report 1986. Patancheru, A.P. 502 324, India, ICRISAT. 367 pp.

ICRISAT West African Programs. 1987. Annual Report 1986. ICRISAT Sahelian Center, B.P. 12404, Niamey, Niger: ICRISAT. 160 pp.

Kirleis, A.W., and **Crosby, K.D.** 1982. Sorghum hardness: comparison of methods for its evaluation. Pages 231-241 *in* International Symposium on Sorghum Grain Quality, 28-31 Oct 1981, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Loomis, R.S., and **Williams, W.A.** 1983. Maximum crop productivity: an estimate. Crop Science 3:67-71.

Miller, F.R. 1986. Sorghum today and into the future. Keynote address presented during First Australian Sorghum Conference, 2-4 Feb 1986. Gatton, Queensland, Australia: Agricultural College.

Murty D.S., **Rooney, L.W.**, **Patil, H.D.**, and **House, L.R.** 1982a. A report on the International Sorghum Food Quality Trials (ISFQT), Sorghum improvement program progress report. ICRISAT Center, India. Patancheru, A.P. 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 42 pp.

Murty, D.S., **Patil, H.D.**, and **House, L.R.** 1984. Processing and cooking quality characters in sorghum. Pages 156-170 *in* Nutritional and processing quality of sorghum (Salunkne, D.K., Chavan, J.K., and Jadhav, S.J., eds.) New Delhi, India: Oxford and IBH Co.

Murty D.S., **Patil, H.D.**, **Rao, K.E.P.**, and **House, L.R.** 1982b. A note on screening the Indian sorghum collection for popping quality. Journal of Food Science and Technology (India): 19(2)79-80.

Novelle, L. 1985. Sorghum quality for malting and brewing. Pages 59-63 *in* The processing of sorghum and millets: criteria for quality of grains and products for human foods (Dendy, D.A.V., ed.), Vienna, Austria.

Prasada Rao, K.E., and **Murty, D.S.** 1982. Sorghum for special uses. Pages 129-134 *in* Proceedings of International Symposium on Sorghum Grain Quality, 28-31 Oct 1981, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Reichert, R.D. 1982. Sorghum dry milling. Pages 547-563 *in* Sorghum in the eighties: Proceedings of International Symposium of Sorghum, 2-7 Nov 1981, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International crops Research Institute for the Semi-Arid Tropics.

Rooney, L.W., **Kirleis, A.W.**, and **Murty, D.S.** 1986. Traditional foods from sorghum: their production, evaluation and nutritional value. Pages 317-353 *in* Advances in cereal science and technology, Vol. VIII (Pomeranz, Y., ed.), St Paul, Minnesota, USA.

Rooney, L.W., and **Miller, F.R.** 1982. Variation in the structure and kernel characteristics of sorghum. Pages 143-162 *in* Proceedings of the International Symposium on Sorghum Grain Quality, 28-31 Oct 1981, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Rooney, L.W., and **Murty, D.S., eds.** 1982a. Proceedings of International Symposium on Sorghum Grain Quality, 28-31 Oct 1981, Patancheru, A.P.

502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 406 pp.

Rooney, L.W., and **Murty, D.S.** 1982b. Evaluation of sorghum food quality. Pages 571-588 *in* Sorghum in the eighties: Proceedings of International Symposium of Sorghum, 2-7 Nov 1981, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Schaffert, R.E., and **Gourley, L.M.** 1982. Sorghum as an energy source. Pages 605-623 *in* Sorghum in the eighties: proceedings of International Symposium of Sorghum, 2-7 Nov 1981, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Schertz, K.F., and **Stephens, J.C.** 1966. Compilation of gene symbols, recommended revisions and summary of linkages for inherited characters of *Sorghum vulgare* Pers., Technical Monograph 3, Texas A&M University, USA.

Seetharama, N., Prasada Rao, K.E., Subramanian, V., and **Murty, D.S.** 1987. Screening for sweet stalk sorghums, and environmental effect on stalk sugar concentration. Pages 170-179 *in* Proceedings of the National Seminar on Technology and application for alternate uses of sorghum, 2-3 Feb 1987. (Ingle, U.M., Kulkarni, D.N., and Thorat, S.S., eds.). Parbhani, Maharashtra, India: Marathwada Agricultural University.

Discussion

J.E. Cecil: Where is phytate P located?

D.S. Murty: It is located in the aleurone embryo and pericarp. Doherty et al. (1982) observed that dehulling did not reduce percentage of phytate P in the product.

J. Chitsika: There is a wide variation in maximum sorghum diastatic units (SDUs) reported for sorghum malt. Can I propose to this workshop the need to carry out an international collaborative study on methods of SDU determinations? In such a study, it would no doubt be imperative to use the same sorghum malt.

D.S. Murty: I welcome this idea. There is a need to standardize diastase activity determination procedures so that scientists can understand each other better.

M.I. Gomez: As an addendum to Dr Chitsika's suggestion, there should be a systematic standardization of terminologies and methodologies for evaluation of other quality parameters as well.

A. Carney: The free air flow appears to be critical to development of SDU. Enzyme stability seems to extend to 70°C or 80°C in dry grain.

V. Subramanian: Standard laboratory conditions like relative humidity, temperature, grain weight/volume, and size of bag for malting quality need to be standardized.

A. Carney: The micro-malting system is critical to SDU.

R.L. Rooney: The proceedings of the Sorghum Quality Symposium are available from ICRISAT. They contain significant information on sorghum characteristics, standard tests, and traditional and industrial sorghum processes and products of interest to sorghum users.