Evaluation of Sorghum Food Quality

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Sorghum *(S. bicolor* L. Moench) is a staple commodity in several parts of the world and ranks fifth as a cereal crop in terms of production and utilization. However, the food quality of sorghum has not yet been clearly defined, probably because it is not used in commercial foods to the extent that wheat, rice, and maize are utilized. In sorghum consuming areas, only limited quantities of the product appears in metropolitan markets, and there are few if any standards available to distinguish grain quality, which is evaluated primarily by subjective criteria such as kernel color, appearance, size, and shape.

Crop improvement programs have become increasingly conscious of these factors that affect sorghum production and utilization (Murty and House 1980)", and are attempting to exploit the vast genetic resources available to improve sorghum quality. The objectives of quality breeding programs in the past were frequently vague because selection criteria for quality were ill defined or poorly established. Recently, however, considerable progress has been made to devise standard laboratory methods to evaluate the quality of the finished sorghum products. This paper discusses the major sorghum food products consumed, reviews information on the extent of genetic variation for the preferred food quality traits, and describes potential methods that could be applied in sorghum breeding programs. Only a brief discussion of sorghum structure, milling, and food properties as related to future food uses of sorghum will be made as it relates to sorghum breeding programs. More detailed presentations on these aspects were made in the International Symposium on Sorghum Grain Quality.

Structure of the Sorghum Grain

Structure of the grain has an important bearing on various processing and food quality traits. The structure of sorghum kernels varies significantly because of environmental and genetic factors. The shape, size, proportion, and nature of the endosperm, germ, and pericarp, the presence and absence of subcoat, and the color of the pericarp are all genetically determined. Rooney and Miller (1982} gave a complete description of the detailed structure of sorghum grain. The caryopsis, or kernel is composed of three main parts, the outer covering (pericarp), the storage tissue (endosperm), and the embryo (germ). An understanding of kernel structure and kernel properties is essential in order to comprehend sorghum quality characteristics. We will review briefly the essential parts of structure.

Pericarp

The pericarp can be subdivided into the epicarp, mesocarp and the endocarp. The epicarp is outermost and usually consists of two to three cell layers. These cells are long and rectangular in shape and contain wax and, occasionally, pigments. The mesocarp which underlies the epicarp may vary in thickness. When the mesocarp is thick and contains small starch granules, the kernel has a chalky appearance. Pearly sorghums have a very thin mesocarp that does not contain starch granules. The innermost layer of the pericarp is the endocarp, which consists of cross and tube cells. The cross cells are long and narrow with the long axis at right angles to the long axis of the kernel. One of the main functions of cross and tube cells is the transportation of moisture. These cells are also the breakage points when the pericarp (bran in milling terminology) is removed during milling of the grain. The pericarp varies in

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thickness within a kernel and between kernels within a sample of sorghum. Genetically, the presence of starch in the mesocarp is controlled by the Z gene (Rooney and Miller 1982). Actual thickness of the starchy mesocarp may be controlled by modifiers since thickness of the starchy mesocarp does vary among cultivars.

Testa

Just beneath the pericarp, some sorghum kernels have a highly pigmented layer called the testa or subcoat. Some sorghum lines contain a partial testa that is found at certain places around the kernel. The testa also varies in thickness from one line to another and from one area of the kernel to another. The color of the testa varies among sorghum lines. Pigmentation is associated with a high concentration of polyphenols which apparently differs considerably among sorghum lines with a subcoat (Bullard et al. 1980). Presence of a pigmented testa is conditioned by the complementary genes B_1 and B_2 (Rooney and Miller 1982).

Endosperm

The endosperm of sorghum consists of the aleurone layer, and the peripheral, corneous, and floury portions (Fig. 1). The aleurone cell layer located beneath the pericarp (or testa, if present} is a single layer of block-like rectangular cells. The aleurone cells have spherical bodies that vary in size which contain protein, phytin, minerals, water soluble vitamins, autolytic enzymes, and high levels of oil. They do not contain any starch granules.

The peripheral endosperm is beneath the aleurone layer and is an illdefined area consisting of the first 2-6 endosperm cells. These cells are small and blocky and contain small starch granules embedded in a dense proteinaceous matrix. The matrix protein is comprised mainly of glutelins (alkali soluble proteins) and prolamins (alcohol soluble proteins).

The corneous endosperm (hard, flinty, horny, vitreous) located beneath the peripheral endosperm has a continuous interface between the starch and protein. The starch granules are very angular or polyhedral in shape with depressions where protein bodies were trapped between expanding starch granules.

The floury endosperm areas have loosely packed endosperm cells. The starch granules are spherical and they are not held together by the protein matrix. In addition, small voids occur between starch granules and there is relatively little continuous protein matrix. The air spaces alternating with cell constituents diffuse light as it passes through the endosperm which explains the chalky or opaque appearance of the floury endosperm.

The relative proportions of the corneous to floury endosperm is termed kernel texture or endosperm texture. Kernels vary from corneous to floury depending upon genotype and environmental conditions. Endosperm texture plays a major role in determining sorghum quality.

Grain Processing Properties: Variation Among Genotypes of Sorghum

The milling properties of the grain, and consequently flour quality are affected by the structure and moisture content of the grain as well as the milling equipment, and grinding technique. Traditionally sorghum was often dehulled before grinding into flour and grits. Grain was moistened in the mortar and pounded by hand with a pestle. High endosperm recovery with minimum breakage of the endosperm and complete removal of the pericarp are desired by consumers. Striking differences between genotypes for dehulling quality evaluated by traditional methods have been reported (Murty and House 1980: Scheuring et al. 1982). Those grains possessing a thick pericarp and highly corneous endosperm produced the maximum quantity of decorticated grain without breakage, and with minimum effort and time required for pounding. Floury endosperm types and corneous endosperm types with a thin pericarp were relatively less desirable for hand processing. Conversely, grains combining a thin pericarp and corneous endosperm have proved acceptable for machine dehulling (Maxson et al. 1971; Shepherd 1982; Reichert et al. 1982) and endosperm recovery was positively correlated to grain with a more corneous endosperm. Shepherd (1979) and Oomah et al. (1981) developed two different prototype laboratory decorticating mills which require only 5 to 30 g of grain for dehulling. These prototype laboratory dehullers could be useful to evaluate the milling characteristics and food products made from dehulled grains.

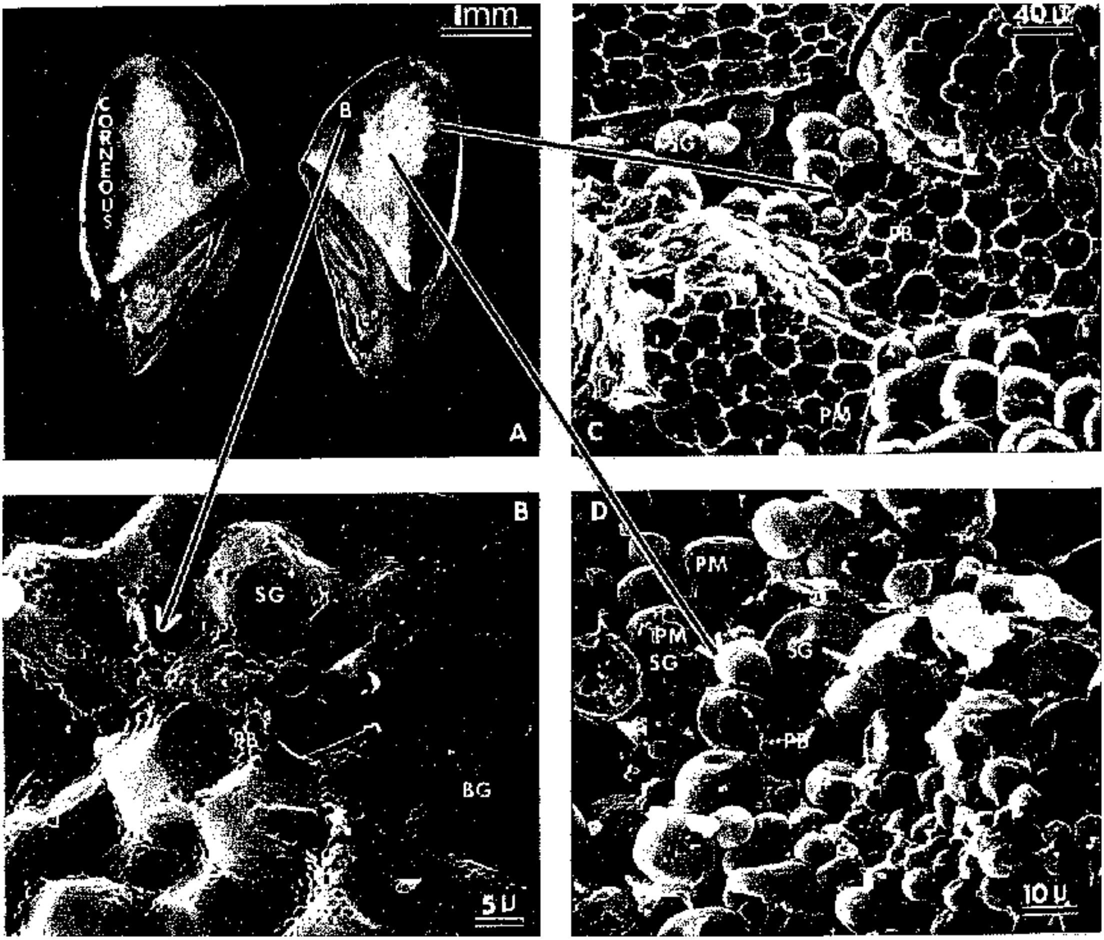

Figure 1. Scanning electron photomicrographs illustrating starchy endosperm structure: (A) longitudinal half kernel, (B) corneous endosperm area, (C) transition zone between corneous and floury endosperms, (D) floury endosperm area. SG-starch granule, PM -protein matrix, PB-protein body, BG-broken granules.

Shepherd's technique has been used by Da et al. (1982) to determine the milling properties and *to* quality of grain from individual F_2 heads. The milling technique clearly showed that sorghums with thick and thin pericarps differed in ease of milling.

Sorghum Food

Considerable progress to define grain quality has been made since the early 1970s. A great deal of interest has been shown and real progress made during the past 5 years and the ground work for continued progress is in place.

Vogel and Graham (1979) have given a detailed description of the various methods of sorghum consumption in the world. Questionnaires, correspondence, and field evaluation visits in Africa, Asia, and Latin America with various scientists have revealed that most sorghum produced for food is consumed in the following eight basic methods:

1. Unleavened bread —*roti, tortilla*
2. Leavened bread —*injera, kisra, dosai*

3. Thick porridge — *to, tuwo, ugali, bogobe, sankati*
4. Thin porridge — *ogi, ugi, ambali, edi*
5. Steam cooked products — *couscous, wowoto,* noodles
6. Boiled sorghum — *soru*
7. Snack foods — popped sorghum
8. Alcoholic and non-alcoholic beverages — *burkutu, busa, ting, obushera, abrey*

The products are referred to by many different names. Considerable variation exists in the exact techniques used to prepare products within each basic category. Usually, the differences observed in the actual preparation from one area to another and among households do not affect the quality of the grain. However, thick porridges are an exception.

Porridges are processed using acid, neutral, and alkali conditions (Rooney and Kirleis 1979). A sorghum variety with good porridge-making properties under acid or neutral conditions may not have acceptable quality when processed with alkali (Scheuring et al. 1982; Da et al. 1982). Thus, a variety like E35-1 that makes excellent acid *to* in Upper Volta has poor alkali *to* quality in Mali.

Variation for the Preferred Food Quality Parameters

Several workers have evaluated the grain processing and food quality traits of sorghum cultivars, particularly those of recent origin, in comparison with traditionally grown cultivars (Rao et al. 1964; Viraktamath et al. 1972; Pattanayak 1977, 1978; Scheuring et al. 1982; Obilana 1982; Juarez 1979; Khan et al. 1980). Large differences were reported among genotypes for various food quality traits.

Recently, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) carried out International Sorghum Food Quality Trials (ISFQT) in collaboration with various scientists in Africa and the Americas using grain samples from 25 cultivars grown in each of two years. It was found that the genotypes exhibited significant variation for quality traits over a range of food products (Murty and House 1980). Important findings of various sorghum food quality studies carried out in the past by various workers are summarized below for the major food products consumed in the world.

Unleavened Bread

Roti

In India, sorghum is ground into flour which is made into unleavened bread called *roti* or *chapati.* Maldandi-35 sorghum grown in the postrainy season is the most preferred cultivar for *roti* quality. The kernels of Maldandi are large, with a thin white pericarp and an intermediate endosperm texture. The characteristic size, shape, and luster of Maldandi grain sets the standard for sorghum quality in India. Maldandi types of sorghum cost the most in the grain markets. Grain from the new improved hybrids has, in general, a relatively poor *roti* quality and demands a lower price.

Consumer cooking trials, laboratory taste panels, and standardized *roti* making procedures have consistently shown that sorghum cultivars produce *rotis* with vastly different acceptabilities (Rao et al. 1964; Rao 1965; Anantharaman 1968; Viraktamath et al. 1972; Waniska 1976; Murty and House 1980; Murty et al. 1982a).

Murty and Subramanian (1982) used a standardized procedure to produce *roti* from different sorghum cultivars. Taste panel tests using sorghum consumers as panelists clearly documented that variation among sorghums that had acceptable evident quality existed. Murty et al (1982a) observed that the kneading and rolling quality of the dough and the taste, aroma, texture, and keeping quality of the *roti* varied among the several hundred cultivars studied. Typical variation among some pearly white cultivars is presented in Table 1. In general, *roti* made from grains with a pale yellow-white color, with an intermediate endosperm texture, without a subcoat and with a thin pericarp had acceptable organoleptic quality. 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 only partially understood (Murty et al. 1982a; Subramanian and Jambunathan 1982).

Tortilla

Tortilla, a form of unleavened bread usually prepared from alkali cooked maize, is consumed in Mexico and Central America. However, in some

Table 1. *Roti* quality characters of sorghum cultivars with pearly white grains with 40-60% corneous endosperm.

Genotype	Rolling[a] quality	Roti[b] Color[c]	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 taste 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 (1975).

countries sorghum or blends of sorghum with maize are made into *tortillas.* Bazua et al. (1978) and Khan et al. (1980) found that color was a major factor limiting the acceptance of sorghum *tortillas.* Khan et al. (1980) described laboratory methods for *tortilla* evaluation and noted that color of sorghum *tortillas* made from 38 cultivars varied from a light yellow to dark greenish brown. The cooking time and the wet milling properties of the *nixtamal* were affected by grain size, texture and structure. Sorghum grains without a subcoat, with intermediate texture, colorless pericarp, and low -polyphenol content produced the best *tortillas.* Sorghum kernels with visually similar characteristics have significantly different *tortilla* making potential (Iruegas et al. 1982; Khan et al. 1980).

Leavened Breads

Injera

Sorghum is consumed in Ethiopia in the form of a thin leavened bread called *injera.* The grain is milled into flour which is mixed with water and a starter culture and the mixture is then stored for 2 to 3 days. Cooked sorghum flour is added to the batter just prior to pouring it onto a hot griddle for cooking. The thin pancake is flexible, has a large number of evenly spaced "eyes" on the surface and remains flexible after overnight storage.

Poor texture is the major factor that limits the acceptability of many sorghum cultivars for *injera* (Gebrekidan and Gebre Hiwot 1982). Soft endosperm types with white or red pericarp, regardless of subcoat presence, produced the best *injera.* However, brown sorghums with high levels of tannin produced unacceptable *injera.* Among the soft sorghum varieties that appeared the same visually, significant differences in keeping properties of *injera* were observed (Table 2). A high yielding sorghum cultivar (Gato-994} from the Ethiopian Sorghum Program was not grown by farmers primarily because it produced poor quality *injera* (Gebrekidan and Gebre Hiwot 1982).

Kisra

Kisra is a leavened sorghum bread made from

Table 2. *Injera* quality parameters of selected sorghums from the International Sorghum Food Quality Trials in 1980.

Genotype	Grain	*Injera* Softness	*Injera* Color	*Injera* Taste	General desirability and remarks
M-50009	Pearly white, hard	soft	white	very good	Trace of bitter taste
M-50013	"	dry	bright white	good	Tastes and looks like maize *injera*
M-35052	"	dry	white	poor	Has maize taste
M-50297	"	dry	yellowish	poor	Dries too fast
CS-3541	"	dry	white	poor	Overall poor
Market-1	White, hard	dry	white	bad	Bad aroma and taste but good eyes
CO-4	Red	very soft	reddish	very good	Very good
WS-1297 (check)	Chalky white subcoat present	very soft	brownish	excellent	Similar to *teff,* excellent
IS-7035	"	dry	reddish	very good	Eyes are as good as *teff*
IS-7055	Brown subcoat present	dry	reddish	bad	Very bad eyes
IS-2317	White subcoat present	dry	reddish	bad	Bad aroma and taste but good eyes

Source: Gebrekidan and Gebre Hiwot (1982).

whole sorghum flour that is popular in the Sudan. In South India, a similar product called *dosai* is prepared. Information on variability for *kisra* quality characters among sorghum cultivars is limited. The *kisra* quality parameters of the 25 sorghum cultivars from the International Sorghum Food Quality Trials was determined (Murty and House 1980). In general, *kisra* made from grains with cream color and less than 40% of the endosperm corneous had the best texture and keeping properties. Genotypes with high tannin and phenol content were rejected in the consumer tests.

Thick Porridges

The use of sorghum to prepare thick porridges which are consumed with various sauces, stews, and soups is of major importance in Africa and India. In general, the porridges can be classified into porridge with acid, neutral, and alkaline pH. The pH used to prepare the porridge significantly affects texture, taste, color, and keeping quality of the product (Scheuring et al. 1982; Da et al. 1982). Alkali pH affects the color and texture of the porridge most significantly. Thus, the porridges, for purposes of grain quality evaluation, must be divided into three groups. A fourth group would be fermented porridges which we will cover separately. Our current information suggests that acid, fermented, and neutral porridge quality are similar but alkaline porridges are different. For example, E35-1 makes good acid and neutral *to,* but alkali *to* of E35-1 has poor keeping properties.

Acid Porridge

Sorghum is consumed in Upper Volta in the form of a thick porridge called *to* and is prepared using tamarind water, i.e., an acidic pH. Pattanayak (1977, 1978) reported that the best quality *to is* produced by the West African local varieties with a white pericarp and highly corneous endosperm. *To* made from introduced cultivars was frequently soft and sticky with poor keeping quality. In addition, the introduced cultivars had a softer endosperm texture, which greatly reduced yields of decorticated grain. The combination of poor milling properties with poor *to* texture severely limits potential production of the introduced varieties. We now have sufficient information and laboratory techniques to select varieties with

Table 3. Cultivar differences for acidic *to* quality among visually similar, white and corneous endosperm types.[a]

Genotype	Color	Taste	Texture	Keeping quality
M-50013	1.8	2.5	2.7	1.7
S-29 (Check)	1.8	1.9	1.7	1.8
SPV-8	1.4	2.0	1.6	1.3
IS-5758	1.2	2.0	1.8	3.1
IS-5452	2.2	1.7	1.9	3.0
CSH-6	1.5	1.7	2.0	2.4
SPV-352	1.7	3.0	2.9	2.6

a. Average of taste panel scores given by six Voltaic trainees on a scale of 1 to 5, where 1 is good. (Murty and House 1980).

Table 4. Variation for *ugali* quality characteristics among cultivars with white pericarp and corneous endosperm.[a]

Monotvpe	Color appeal	Taste	Texture	Keeping quality
E35-1	1.5	1.8	1.5	2.0
IS-5341	1.5	1.8	1.6	2.4
$UChV_2$	2.4	2.4	2.2	1.8
IS-6928	1.5	2.0	1.6	1.9
E-6954	2.0	2.1	1.9	1.9
IS-2550	2.0	2.2	2.3	3.4

a. Average of independent scores of taste panel tests conducted in 1979 and 1980 on a sclae of 1 to 5 (1 = good) (Murty and House 1980).

good *to* quality in the breeding programs. *T6* properties varied considerably among grains that had similar visual characteristics (Table 3).

Neutral pH Porridge

The use of sorghum flour from dehulled or whole grain to produce a porridge without acid or alkali addition is quite common. Information on *to* made with water at nearly neutral pH is available (Obilana 1982; Boling and Eisener 1982; Murty and House 1980; Akingbala et al. 1981 a,b; Murty et al. 1982 b).

Taste panels were conducted on *ugali* samples from 108 sorghum cultivars (Murty and House 1980), which were prepared using a standard procedure. The results indicated that the color, keeping quality, and texture varied greatly with the sample population. A pale yellow or white *ugali with* little tackiness was preferred, although a light red *ugali* was acceptable provided that its taste, texture, and keeping properties were good. Highly corneous grains were found to yield the best *ugali* product. Grains with a waxy endosperm produced a thin product. Desired *ugali* qualities were associated with thick and viscous gel properties. Sorghums with similar visual properties differed in *ugali* properties (Table 4).

Sankati, a porridge made in South India was made from the ISFQT samples (Table 5). The desired quality characteristics were similar to *ugali.* Desikachar and Chandrasekhar (1982) found that sorghums with good quality for making porridges produced *rotis* with poor quality, which was similar to the observations in the ISFQT data.

In Tanzania and Nigeria, some new improved varieties have not been accepted for production because of either poor endosperm recovery or poor porridge making quality (Eggum et al. 1982; Obilana 1982). Some of the varieties, which matured early, were severely damaged by molds, and were too soft to mill. These observations

Table 5. *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). (Murty et al 1982b).

emphasize the importance of routine selection for food quality in breeding programs.

Alkaline Porridge

Alkali from ashes is used to cook sorghum flour into to in Mali and parts of Nigeria and Upper Volta. The quality of the local Malian sorghum cultivars for making to is excellent; but nearly all exotic sorghums produce poor quality to (Scheuring et al. 1982). In addition, local Malian varieties produce to with good keeping characteristics over a broad pH range while some improved varieties are extremely sensitive to changes in pH. The observations in Mali have been confirmed by laboratory studies with Upper Voltaic sorghums (Da et al. 1982). Environmental factors significantly affect the quality of sorghums for use in alkali to (Scheuring et al. 1982).

Laboratory methods using grain from a single head of sorghum have been developed for thick porridges (Da et al. 1982). They will permit milling quality evaluation as well as evaluation of to texture. Scheuring et al. (1982) used a simple method based on cooking ground whole grain in alkali to produce to and evaluating to firmness subjectively after overnight storage.

Thin Porridges

Ugi is a thin porridge consumed in several countries of East Africa. Generally, a cream colored, smooth flowing product with a characteristic sorghum aroma is liked (Murty and House 1980). *Ugi* made from sorghums with a subcoat or brown pericarp tasted bitter. Another significant variation among cultivars for *ugi* quality was the gelling property of cooled *ugi.* Good *ugi* produced a highly consistent thick gel after cooling overnight. In general, sorghums with acceptable thick porridge quality will make acceptable thin porridges.

Fermented Porridges

Many porridges, thin and thick are made by fermenting either whole grain or flour from sorghums. *Ogi* production has been discussed by Obilana (1982) and Akingbala et al. (1981a,b). The brown sorghums produced low yields of *ogi* with poor organoleptic properties. White or red sorghums produced the best *ogi,* with white preferred. Often, *ogi* is used as a thick porridge and stored where upon its quality parameters effectively resemble those of acidic porridges.

Boiled Sorghum Products

Pearled sorghum kernels are often cooked and used as a substitute or extender for rice. In Mali, coarse grits from a special kind of local sorghum called *kinde (margaritiferum)* is used for production of rice substitutes. *Annam* or *soru* (Table 6) properties of sorghum cultivars varied considerably among genotypes (Subramanian et al. 1982). In general, a sorghum that cooks, looks, and tastes like rice is preferred. Thus, kernels with a corneous endosperm and white pericarp are preferred. Cooking time ranged from 54 to 114 min while the volume after cooking increased from 100 to 273%. The increase in cooked grain volume was positively related to grain density. Keeping quality of the *soru* differed among sorghum samples with similar appearance (Table 6). Sorghums with light red pericarp produced acceptable products.

Table 6. 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	1.6
M-50009	1.5	1.5	1.8	1.7
M-50013	1.3	1.5	2.0	2.1
M-50297	1.6	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). (Subramanian et al. 1982).

Steam Cooked Products

Couscous is a granular product made by steam proking agglomerated sorghum flour. It is popular In several West African countries. Sidibe et al. (1982) reported that a good *couscous* should neither be sticky nor dry. They found that the local *dagafara* sorghums with vitreous grains yielded more *couscous* product per unit of flour than other sorghums, and that the cohesion and integrity of the granules from *dagafara* flour were generally more desirable. All sorghums that produce acceptable *to* produce acceptable *couscous.* Therefore, selection for *to* quality may preclude the need to select for *couscous* quality. More information is required to determine if our current information is correct.

Snack Foods—Special Sorghums

India, special sorghum cultivars have been puffed or popped (Ayyangar and Ayyar 1936; Desikachar 1980). Sorghum lines with excellent popping properties and other special uses were discussed by Prasada Rao and Murty (1982). Generally, the pop sorghums have a low germ to endosperm size ratio. The kernels are small with a medium thick white pericarp and corneous endosperm. Popping, although common in India, is seldom used to process sorghum in Africa. In India, the popped sorghum is often used to produce other snacks and in special foods prepared for children.

Sorghum Food Quality Classification

Data from the ISFQT has permitted an overall evaluation of whether it is possible to breed sorghums that have properties which would permit their use for almost all sorghum foods. The average acceptability scores of the various sorghum foods evaluated in the ICRISAT collaborative ISFQT are presented in Table 7. In general, varieties like CSH-5, M-50009, Mothi, and M35-1 which had pale yellow/white grains with 60-70% corneous endosperm produced products with acceptable quality for all the food systems. The effect of local conditions might change the acceptability drastically due to grain molds and other factors.

The specific food qualities of sorghum cultivars were related to kernel texture and pericarp thickness. Kernels with a thick pericarp and corneous endosperm texture had the best hand milling properties while the floury grains were in general rejected. The pearly grain types were not readily accepted by consumers using hand milling since they required more effort in decortication, but they can be mechanically milled to produce excellent products.

Grains with 60-100% corneous endosperm were preferred for the preparation of stiff porridges like *to, ugali, bogobe, sankati,* and for rice-like products. Grains with 20-40% corneous endosperm were suitable for preparation of *kisra* and *injera. Kisra* is mainly produced from ground whole grain fermented for about 24 hr. So the inability to decorticate floury sorghum is not important. A similar situation exists in Ethiopia

Table 7. Overall acceptability of traditional milling quality and a range of food products made from 25 sorghum cultivars.[a, b]

S. no.	Genotype	Endosperm[c] texture	Milling quality	*Roti* (1979 & 1980)	*Tortilla* (1979)	*Injera* (1980)	*Kisra* (1979)	*Ugali* (1979)	Alkali *tô* (1979)	Acid *tô* (1980)	*Bogobe* (1979)	Fermented *Bogobe* (1979)	*Sankati* (1980)	*Soru* (1980)
1	M35–1	3.0	3.0	1.0	1.5	1.5	2.2	1.5	1.0	2.2	—	—	2.0	1.4
2	CSH-5	2.0	1.5	1.0	1.2	2.0	2.3	2.0	1.0	1.9	1	1	1.0	1.4
3	M50009	2.0	1.7	1.5	1.5	1.5	3.4	2.5	5.0	1.7	—	—	1.5	1.6
4	M50013	2.0	2.5	1.5	1.5	3.0	2.7	2.5	1.0	2.2	—	—	1.0	1.7
5	M35052	2.0	2.5	2.5	1.5	4.0	2.8	1.5	1.0	1.4	1	1	2.2	1.6
6	M50297	2.0	2.0	1.5	3.0	4.0	2.2	2.3	1.0	2.5	—	—	1.0	1.7
7	P721	5.0	5.0	5.0	4.0	4.5	2.5	4.0	5.0	3.0	—	—	4.0	2.0
8	CO-4	3.0	2.0	3.0	4.0	1.0	2.0	2.7	1.0	2.7	1	1	2.5	1.5
9	P. Jonna	3.0	2.0	3.0	4.0	4.0	2.1	2.5	1.0	3.0	—	—	2.5	2.4
10	Mothi	2.0	1.3	1.5	2.0	4.0	2.5	1.2	4.0	2.2	—	—	2.0	1.5
11	E-35–1	1.0	2.5	1.5	2.0	3.0	2.1	1.5	2.0	1.1	1	1	2.0	1.6
12	IS158	(waxy)	3.0	4.0	3.0	5.0	4.3	5.0	5.0	4.0	—	—	5.0	2.4
13	WS1297	4.5	3.0	4.0	5.0	1.0	3.8	4.0	1.0	3.7	—	—	4.0	2.3
14	Swarna	2.0	3.0	1.0	4.0	1.5	2.7	2.0	1.0	3.5	1	1	2.5	1.8
15	S-29	1.5	1.0	2.5	2.5	4.0	2.0	1.5	1.0	1.2	3	1	2.0	1.1
16	S-13	1.0	1.5	2.5	2.5	3.5	3.2	1.5	1.5	1.5	1	1	1.7	1.3
17	IS2317	3.0	4.0	3.5	4.0	4.5	2.6	3.5	1.0	2.2	—	—	3.0	1.5
18	IS7035	3.0	4.0	3.5	4.0	3.5	3.1	3.5	1.0	4.0	1	3	3.0	2.5
19	IS7055	3.5	4.0	4.0	4.0	4.5	3.4	3.5	1.0	4.2	1	3	3.5	2.0
20	IS9985	3.5	2.5	1.5	2.5	1.5	2.7	2.5	1.5	1.5	1	1	3.0	1.9
21	IS8743	3.0	2.0	3.5	4.0	1.5	3.3	3.0	1.7	4.0	—	—	3.0	2.0
22	Dobbs	4.0	5.0	5.0	5.0	5.0	4.4	5.0	3.0	3.2	3	3	5.0	3.0
23	CS3541	2.0	1.7	2.5	2.0	4.0	3.0	2.5	2.0	2.7	—	—	2.0	1.6
24	Segaolane	2.5	2.0	1.5	1.5	2.0	3.3	2.3	1.7	1.6	1	1	2.0	1.6
25	Market-1	1.0	1.2	2.0	3.0	4.5	—	1.5	1.5	1.0	—	—	2.0	1.8

a. Data from International Sorghum Food Quality Trials. The original data sources are as follows: *Roti*—D. S. Murty; *Tortilla*—L. W. Rooney, A. Iruegas, and G. Vartan; *Injera*—B. Gebrekidan; *Kisra*—H. Perten and S. Badi; *Ugali*—D. S. Murty; Alkali *tô*—J. Scheuring; Acid *tô*—S. Da and C. Pattanayak; *Bogobe*—N. Eisener; *Sankati* and *Soru*—D. S. Murty; Fermented *Bogobe*—N. Eisener. (Murty and House 1980)

b. Original data obtained on various quality parameters of each food product were averaged to give an overall score.

c. Endosperm texture was scored on a scale of 1 to 5 where 1 = completely corneous and 5 = completely floury.

where the sorghum flour is fermented for more than 48 hr to prepare *injera.* Grains with an intermediate texture were the most suited for producing unleavened breads *{tortilla* and *roti).* Therefore, sorghums can be grouped into classes depending upon texture of the grain similar to the USDA wheat classes. The soft sorghums would be most desired for leavened breads while the hard sorghums would be the most useful for porridges and rice-like products. The intermediate class could be most useful for unleavened breads.

In general, the brown sorghums with testa and spreader genes were unacceptable for all products evaluated. The presence of red or yellow pericarp did not adversely affect acceptance of most of the products as long as taste, texture, and keeping quality were acceptable. For example, in leavened breads, sorghums with a subcoat made acceptable products. The preferred color of porridges is white or yellow, but porridges from red sorghums are consumed. Even brown sorghums are consumed as porridges in some areas. Thus, color is not of critical importance in many of the rural food systems. However, color is critical for the unleavened breads, especially *tortillas.* On the other hand, if sorghum products are going to compete with maize and wheat foods in urban areas, a white color is needed for acceptance.

Effect of Environment on Food Quality

Genotype x environment interactions affect the chemical composition, physical properties and food quality of sorghum (Hulse et al. 1980; Shepherd 1982; Reichert et al. 1982; Rooney et al. 1980). It is clear that these interactions must be considered in sorghum quality testing programs as they are for other cereals (Heyne and Barmore 1965; Juliano 1979).

Environment significantly affects the quality of *roti* (Murty et al. 1982a), *tortillas* (Khan et al. 1980), and alkali and acid *to* (Scheuring et al. 1982; Da et al. 1982). The variations in quality are affected by drought, molds, weathering, insects, leaching of pigments and other factors. In general, the local varieties produced the most uniform quality *to* over different environments while introduced varieties varied greatly. The effect is on milling properties as well as organoleptic properties such as taste, color and texture, (Scheuring et al. 1982; Rooney et al. 1980).

Tests to Predict the Quality of Sorghum

It would be useful to identify simple physicochemical tests that could predict the quality of sorghum varieties for use in foods. Such tests have been used effectively for evaluating wheat and rice quality (Heyne and Barmore 1965; Juliano 1979). A major problem limiting the development of quick tests to predict sorghum quality was the lack of clearly identified cultivars with good and poor quality.

Amylose

The amylose content of sorghum does not vary as much as that of rice and has not been clearly shown to be related to food quality (Akingbala et al. 1982; Waniska 1976; Subramanian and Jambunathan 1982). The amylose content of 495 nonwaxy sorghum genotypes varied from 20 to 30% of the starch in the endosperm. Additional information to determine the potential value of amylose content is needed; but, amylose content of sorghum does not appear to be as important as it is for rice quality evaluation.

Alkali Tests

A test to predict the color of *tortilla* and alkali *to* by soaking five kernels of sorghum overnight or by boiling for 2 hr has been used by Khan et al (1980). The color of the cooked kernels or steeped kernels was evaluated subjectively by comparing with known standards. A variation of this method has been used by Iruegas et al. (1982) in Mexico. Waniska (1976) modified the alkali spread test that has been used successfully with rice by applying the alkali to milled kernels of sorghum. The method clearly distinguished waxy from nonwaxy kernels, but could not make clear distinctions among the ISFQT samples. A major problem may be the variability in milling damage to the decorticated sorghum kernels which causes variation in the rate of alkali absorption.

Gel Spread Tests

A number of tests based on gelatinization of flour water dispersions followed by measuring the consistency of the gel, appear promising but must be evaluated more carefully (Murty et al. 1982c; Da et al. 1982). A significant association of swelling power and starch solubility with the cooking properties of boiled sorghum was reported (Subramanian et al. 1982). However, the correlations are low, and more information is required to evaluate the potential of these tests.

Amylograph Cooking Characteristics of Starch and Flour

The amylograph cooking characteristics of sorghum starches and flour have been tentatively related to food quality of sorghum (Waniska 1976; Akingbala 1980). The setback viscosity of the sorghum starch and flour was high for sorghums with acceptable thick porridge making quality and was low for sorghums with acceptable *roti* making properties. Similar observations were recorded by Desikachar and Chandrasekhar (1981).

Flour Particle Size

The particle size distribution and starch damage in a flour affect the quality of the flour significantly. Murty and House (1980) studied the flour particle size index (PSI) of several cultivars using the method of Waniska (1976) and found a range of 25-80 PSI among genotypes. PSI values were affected by grinding and sieving methods and were subject to considerable errors. However, the PSI was correlated consistently with the texture of the endosperm. Particle size measurements are important and should be given a high priority in future research in sorghum quality testing procedures.

Percent Water Absorption and Water Uptake

The amount of water absorbed by the grains after soaking them in water for 5 hr at room temperature has been expressed as percent water absorption (Murty and House 1980). This parameter showed a broad range of variation among various grain types and was negatively correlated with *roti* quality. Desikachar and Chandrasekhar (1982) found that water uptake of flour was related to dough and *roti* quality.

Texture Evaluation by Objective Tests

The single most critical property of sorghum foods that affects their acceptance is related to texture. Simple objective methods to measure texture are needed and are not readily available. Keeping quality is a critical factor that relates to texture measurements. The Instron universal testing machine has been used to measure texture of to, *tortillas,* and *roti,* and the hardness of individual sorghum kernels (Waniska 1976; Da et al. 1982; Johnson et al. 1979). However the Instron is an expensive sophisticated instrument that requires considerable expertise to operate. It is not practical in routine plant breeding programs. But, it is extremely useful to determine basic information on texture. Then the basic information can be used to develop "quick and dirty" tests that can provide screening techniques.

A few simple tests have been applied to sorghum *to* (Waniska 1976; Akingbala 1980; Da et al. 1982) such as the stickiness measured using double pan balance and softness using a penetrometer. Both techniques can be used to distinguish between *to* samples prepared from a single head of sorghum. The penetrometer provides a relatively low cost objective method which can improve upon the use of subjective methods.

Color Measurements

The Hunter Colorimeter, Agtron and other instruments can be used to measure color objectively in terms of reflectance, "a", and "b" values that measure the intensity of the primary colors. The instruments are expensive, require sophisticated maintenance, constant voltage, and are in general impractical in routine breeding programs. An effective inexpensive method is to compare the color of the product with that of standard color charts. Murty et al. (1979) have used the Munsell soil color charts to describe the colors of *roti.* A standard set of colors representing the range observed for the particular food product can be purchased inexpensively and easily. The correct Munsell plates can be selected by using an instrument to determine the range in color values for an array of the specific foods, or the soil color charts can be compared until the appropriate color match is obtained (Rooney and Murty 1982).

Endosperm Texture and Hardness of Grain

The proportion of floury versus corneous endosperm in the kernel is called endosperm texture. Endosperm texture is related to hardness, milling properties and cooking characteristics of the flour.

The most common method to evaluate endosperm texture is to cut 10 to 20 individual, sound representative kernels with a pocket knife. Then, the relative proportion of corneous to floury endosperm is rated subjectively on a scale of 1 to 5, where 1 - 81 to 100% corneous, 2 = 61 to 80%, 3 = 41 to 60%, 4 - 21 to 40%, and 5 = 0 to 20%. The texture of the endosperm is subject to environmental effects; variation among individual grains within a sample is common. In some samples, 20 or more kernels are sampled to secure an average value. Sophisticated laboratory facilities are not needed to do this and considerable progress can be made by using it in selection programs.

More accurate measurements of texture have been made by Munck et al. (1982) and Kirleis and Crosby (1982) who measured the relative proportion of corneous to floury endosperm in individual kernels. In Munck's procedure, highly sophisticated equipment is required which limits its application to basic research only. The Vicker's hardness tester can measure the hardness within individual endosperm cells (Munck et al. 1982).

Endosperm texture is related to various indices of grain hardness which have been developed using standard milling and sifting procedures (Maxson et al. 1971) or, alternatively, by recording the time required to dehull a standard quantity of grain to a specified level and recording the extent of breakage in the recovered endosperm (Oomah et al. 1981; Shepherd 1979). Although these measurements are subject to errors due to the interaction of grain shape with the abrasive mechanism, they seem to be quite reliable and are related to endosperm texture scores or breaking strength measurements taken with the Kiya rice hardness tester. Kernel shape affects the measurements taken with the kiya tester; flat and turtle beaked sorghum kernels frequently give Teroneously high values (Murty and House 1980).

Selection Criteria for Breeders

Crop improvement programs generate a range of segregating material by making crosses between lines possessing good agronomic characters, disease and pest resistance, drought resistance, etc. These programs are confronted with the problem of choosing and advancing families which combine several economic characters, including food quality. Currently, there are no clear-cut methods to assist sorghum breeders to select for good food quality, as there are in wheat and rice breeding programs. Breeders in national or regional programs may select cultivars suitable for a particular product, while those in international programs may find it necessary to identify cultivars that are suitable to make a range of foods. Obviously, from the review made earlier, for most sorghum foods there is no clear identification of the physico-chemical properties of the grain that can be used to predict preferred quality, although several tests of possible significance have been reported. Simple tests tailored for laboratory use are urgently required to permit rapid progress in breeding for food quality in the developing countries.

An outline of a general scheme for quality testing in a breeding program is presented in Figure 2. Our experience indicates that considerable progress in quality breeding is possible by an empirical selection of the precise endosperm texture, while the food technologists and chemists continue research into the development of objective physico-chemical quality tests.

Selection in the F_2 generation should be for those grain characters which are controlled by major genes (Rooney and Miller 1982) such as colorless (rryy or R-yy?) and thin pericarp (Z-), absence of testa (b_1 b_1 or b_2 b_2), endosperm texture, and tan plant color (pp-). These characters could be selected by subjective methods in the field. A laboratory is not required. Where the sorghum crop is expected to mature towards the end of the rainy season, grain mold resistance is an important selection criterion. Grain quality characters, associated with the preferred food quality traits and mold resistance, may not necessarily be the same and the best recombinants which combine these two characters should be chosen. Grain of individual F_3 selections from the off-season crop could be used for laboratory tests of KOH color reaction. Since grain quantities might be limiting, samples from selections in the F_4 and F_5 generations might be used either for the study of gel viscosity or milling and flour quality. The evaluation of the qualities of the product per se needs to be done only on those entries which are selected for improved yield, adaptation, etc.

It is important that assessments on the food product be conducted with grain harvested in the main crop season for which the variety is intended. Consumer tests at the farmer's level should use only the most promising cultivars from

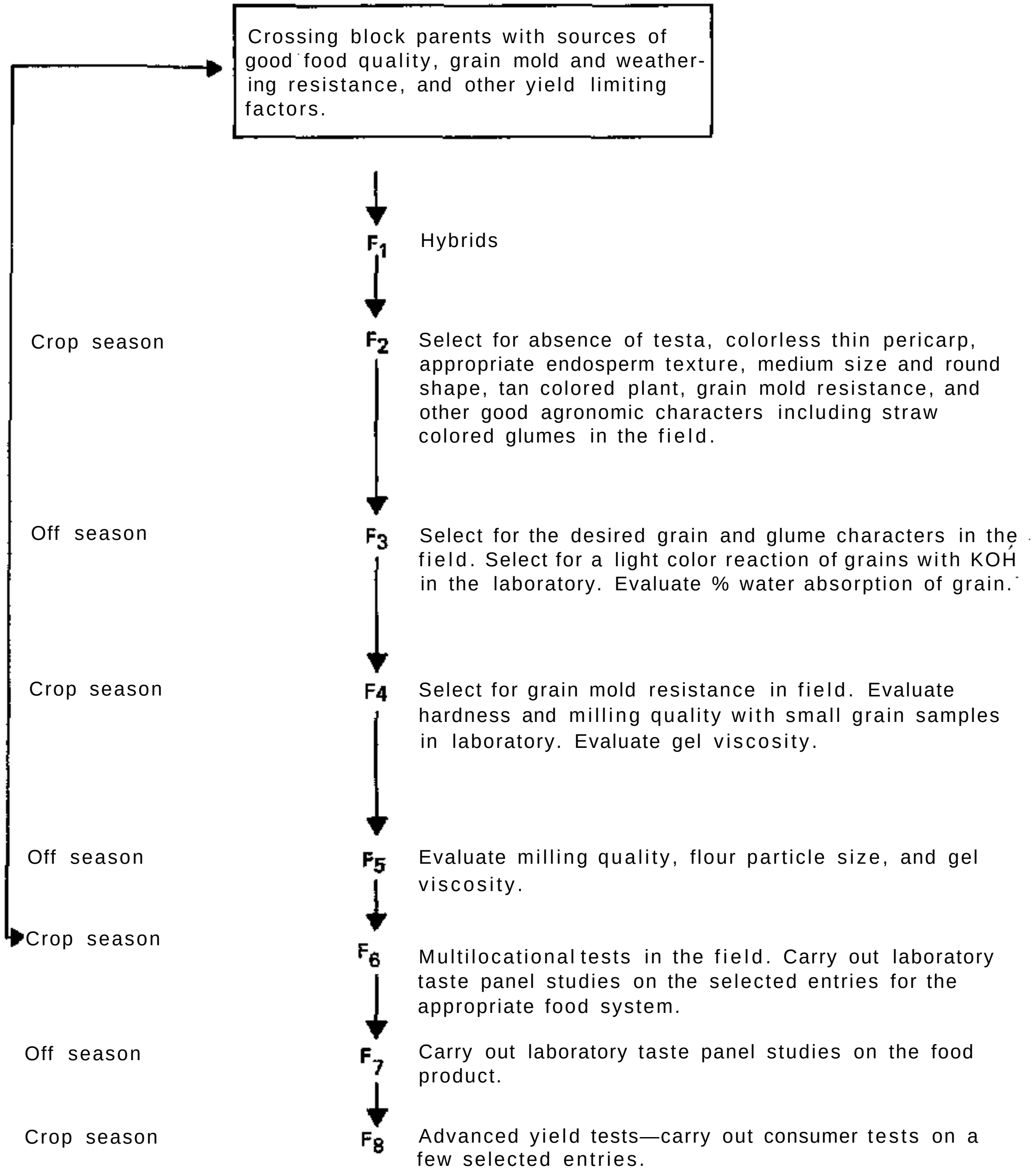

Figure 2. A proposed scheme for use in a breeding program to select for good food quality.

multilocation tests of yield and adaptation. The most preferred local varieties should always be included in these tests for comparison, This scheme could be modified to suit the major objectives of any breeding program involved in the improvement of yield-limiting factors like disease and pest resistance.

Food Technology and Sorghum Improvement

Future sorghum utilization can be increased most effectively through a combination of innovative new processing techniques along with the development of sorghum varieties with characteristics that will be utilized most effectively in the new processes. New milling techniques have been developed recently (Reichert 1982; Munck et al. 1982). The successful development of small mills that will supply stable sorghum products to urban consumers will increase the acceptability of sorghum for foods. The improved milling processes will circumvent some undesirable features of sorghum and will affect the kernel characteristics desired. For instance, the best sorghum for milling will probably have a softer endosperm texture than currently desired which will save in processing costs because the soft endosperm can be more easily broken down into flour or desired milled products.

Effect of Industrial Use on Quality Attributes

In the future sorghum will increasingly be used for industrial processing into flour, grits, and other products which will be used for production of various foods using blends of maize, wheat, and other commodities (Rooney et al. 1980; Miche et al. 1977). This trend is currently under way. For example, sorghum grits are used widely in Mexico as an adjunct in the brewing of European types of beer (Aldape 1981) and a number of food products from malted sorghum are sold commercially in South Africa. Recently, in Central America some efforts have been made to replace imported oats with sorghum flakes as a breakfast food. The development and initial testing of "pearl durra" in the Sudan looks promising (Badi et al. 1981). Thus, although the actual use of sorghum in processed products is small, the interest and ability to make commercial products is advancing steadily.

The widespread industrial processing and use of sorghum will produce increased demands for higher quality sorghums, and quality will change as consumers adjust and become familiar with processed products. Novellie and co-workers have successfully scaled up the sorghum beer process from a small village process to a large-scale modern industrial procedure with the production in S. Africa of 3 million liters annually, which is equivalent to the European beer produced in S. Africa (Joustra 1981, personal communication). The local beer contains a significant amount of solids which contribute to the nutritional well-being of the consumer.

Currently consumers prefer sorghum beer that is light pink with a foam on top of the beer. This beer is made by using 10% sorghum malt that has been soured through lactic acid fermentation, which is mixed with 65% maize grits, cooked, and then mixed with 25% sorghum malt for converting the starch into fermentable sugars. Then, the mash is strained and fermented with yeast for 2-3 days and drunk while active fermentation is occurring. Because 65% of the cereal ingredients are maize grits, the beer has a light pink color with a slight foam on top. The reason the maize grits were used early in the industrial process was because inexpensive maize grits were available. Now sorghum is much cheaper than maize, but it is not possible to switch back to a 100% sorghum beer because the color is too dark and there is no foam. The population has now accepted the industrialized sorghum beer and evidently traditional sorghum beer of yesterday is not as desirable. Ironically, projects underway in S. Africa currently seek to process sorghum into refined grits that will produce sorghum beer with light color and the foam. Sorghum must be low in fat to produce a beer with acceptable foam properties. Clearly, similar changes in consumer preference will occur in other areas of Africa as industrialization of sorghum occurs.

Future of Sorghum for Food

Production of sorghum will remain high and probably expand in the future. Breeding of sorghum with careful concern for its quality will provide a useful grain for the new or modified technological processes that will emerge. The new processing systems will provide refined sorghum and millet products to urban consumers which will eliminate much of the daily drudgery that is now associated with postharvest technology of sorghum. Progress made in the past, especially in the last 5 years, is encouraging and suggests that in the 1980s we will meet many of these objectives. A major reason for our optimism is that many young scientists have been trained. Hopefully, they will spearhead the efforts to improve sorghums for food. Failure to do so will be a disaster for the world.

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